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DELIVERY OF BROADBAND TO CANADIANS WITHOUT ACCESS VIA WIRELESS TECHNOLOGY AND GIS MODELLING

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in partial fulfilment of the requirements for the degree of
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Abstract

Millions of Canadians residing in northern, isolated, rural and remote communities do not have broadband internet and this has led to a national 'broadband divide' induced by geography. The rollout of wired broadband is limited in rural and remote areas because of the high deployment and maintenance costs that would be passed onto the consumer who would be unwilling to pay exorbitant subscription fees. Alternatively, wireless broadband access does not entail the kind of physical infrastructure and associated costs which dramatically changes how broadband internet can be provided beyond the urban zone. This research develops a geographic information systems (GIS) model to determine if emerging terrestrial wireless broadband technologies (WiMAX) can effectively service the rural and remote regions of Canada. In addition, the robustness of the GIS model is tested in Alberta using intervisibility analyses at multiple spatial scales. Results suggest that coarse-scale GIS modelling with minimal data requirements can reliably identify potential wireless broadband markets. This research clearly shows that GIS modelling can make a significant contribution to the analysis of wireless deployment planning, to the understanding of the relationships between wireless signal sources and consumers, and to the spatial configuration of terrestrial wireless broadband networks.

Dedication

Dedicated to the greatly missed
Alain Gaetan Cossette

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1

Thesis Purpose, Background and Study Area

1.1 Overview

An information society where individuals and groups exchange information was first proposed in the early 1960's (Machlup 1962; Wellar 1985), and extensive discussion today focuses on the considerable growth of an emerging knowledge society¹. In order for individuals to take-part in the knowledge society, effective and efficient information technologies are required (Rai and Lal 2000; Bertot 2003) to communicate information. A knowledge society simply cannot exist in a vacuum (Wellar 1989) and as such, without the necessary information technologies, the ability to participate in the information age becomes unattainable for those without access to broadband internet services.

¹ Knowledge Society – “A society that creates, shares and uses knowledge for the prosperity and well-being of its people.” (Government of New Zealand 2005)

A fundamental aspect of an information or knowledge-based society is the requirement of broadband communications to deliver and exchange information. Although one might argue that the *Information Age* matured in the 1990's with the large-scale deployment of broadband technologies, and the widespread adoption of the internet (Mansell 1999) around the turn of the millennium, participation in the information society remains out of reach for many. There are millions of Canadians and countless other individuals around the world who have yet to find the opportunity to participate in the information age simply because of the lack of broadband telecommunications where they are located.

Regions of sparsely distributed population where substantial amounts of land separate individual households are not economically appealing for wired or fixed broadband technologies like cable-modems or ISDN. As such, wireless broadband technologies come into play. The ability to provide access to terrestrial broadband wireless technology is a spatial question that involves the ability of wireless technologies to reach a sufficient profitable population base, in order to attract service providers (Prieger 2003). In planning for the rural and remote deployment of wireless broadband services, Geographic Information Systems (GIS) contain the functionality to study extremely large areas (i.e. Canada) and assess the market potential for existing, new, and emerging broadband wireless technologies. Thus, using GIS can help define and provide the impetus for bridging the urban/rural broadband divide.

Herein, a brief description of broadband is provided for those who are unfamiliar with this technology; the issues of Canada's urban / rural broadband divide are discussed to emphasize the contribution of this thesis. As well, the objective of this thesis and its research questions are made explicit along with a description and justification for the selected study area. The end of this chapter provides a breakdown of the thesis.

1.2 Broadband

In this thesis broadband telecommunications refers to high-speed internet access that connects an “end-user” to the internet backbone² (Industry Canada 2001). Individuals are typically connected to the internet through an internet Service Provider, (ISP) where transfer speeds are faster than dialling to an internet connection by telephone. This is because dialup connections are limited to a maximum of 56-64 kilobits per second (Kbps) (CRTC 2004), whereas, urban areas typically have access between 1 - 7 megabits per second (Mbps) using hard-wired infrastructures such as cable-modems or copper telephone lines.³ High speed broadband is roughly eighteen times faster than a dialup connection.⁴ Cable and DSL access can only be provided within a certain distance to a backbone connection which typically limits DSL to urban areas. A broadband alternative for rural and remote regions is satellite but unfortunately has drawbacks because of the time it takes for the signal to travel long bidirectional distances from the satellite to earth and back again. For more information please refer to the Broadband Section in Appendix A and Appendix B.

In 2002, Canada was above the North American average where 30% of dwellings used broadband (Alcatel 2004) and internationally, Canada was second to South Korea in terms of broadband penetration (Phillipson 2004). Drawing a parallel with earlier assessments of how changes in technology are affecting individuals and institutions (Wellar 1983), having broadband in a dwelling at the present time represents a major advance in promoting and achieving time-efficient interaction with the internet’s products, processes, and participants.

² The internet backbone is the wireline and wireless network infrastructure that links all the parts of the internet together.

³ Dialup and

⁴ Rogers High Speed internet <http://www.shoprogers.com/Store/Cable/internetContent/extreme.asp> (Date Accessed: 07 Feb 2006); Shaw High-Speed Xtreme-I: <http://www.shaw.ca/en-ca/ProductsServices/internet/ShawHighSpeedXtremeI/> (Date Accessed: 07 Feb 2006)

1.3 Canada's Urban / Rural Broadband Divide

Canada is one of the most highly urbanized countries in the world, with more than 80% of its 32 million residents living in urban areas. However, the urbanized population only occupies about four percent of the country's landmass. Further, almost two-thirds of the entire population is concentrated in 27 major urban centres (Statistics Canada 2002; Natural Resources Canada 2005). To re-phrase, less than 20% of the population is spread out over 96% of Canada's vast expanse, with many of these dwellings located in the northern, remote and isolated reaches of rural Canada (Wellar 1989; McNiven and Puderer 2000).

These numbers demonstrate that Canada's urban/rural divide is significant in terms of the numbers of dwellings involved and the geographic divide aspect, which depicts the dense concentration of urban areas and the dispersed rural regions. As for the relationship between the population divide and the broadband divide, it is also significant: approximately 5 million people (as of late 2004) of varying socioeconomic and demographic backgrounds live within northern, isolated, rural and remote regions where no broadband internet services currently exist other than satellite (Figure 1.1) (Industry Canada 2003). Whereas 85% of urban households, have access to broadband.

Access to broadband is particularly acute in Canada's northern and/or isolated communities, especially those located in the Arctic, and an urgent need exists to solve the problem of accessibility in these locales. As a result of broadband's superior ability to overcome physical or geographic distance with regard to communications, the argument can be made that broadband contributes to an increased quality of life. The basis of the argument, which is similar in structure to societal assessments of previous advances in information technology (Wellar 1977; Wellar 1983), is that individuals who can fully utilize bandwidth-intensive websites for data/information gathering and other communications-based services, are better

able to perform or function at both the individual and the community levels (Industry Canada 2001; Gómez-Barroso and Pérez-Martínez 2005).



Figure 1.1. Current availability of broadband internet access in Canada is shown by the shaded areas.

With the development of previous milestones in the field of computers and communications (Wellar 1977; Wellar 1983; Wellar 1983), broadband technologies are now generally perceived as an essential infrastructure that is necessary for the effective and efficient operation of enterprises and organizations in the Information Society. As such, access to broadband is deemed to be essential for the delivery of programs such as e-medicine, e-health, e-education, e-governance, and e-entertainment, all of which are available to urban

residents (Industry Canada 2004). For example, e-health service empowers individuals to manage their health better through the improved dissemination of information (Government of New Zealand 2005) while E-health (telemedicine (Darkins and Cary 2000)) also encompasses the use of broadband to provide medical care remotely so that neither the specialist nor patient requires lengthy travel.

1.4 Government of Canada

In 2001 the Canadian National Broadband Task Force (CNBTF) recommended that every Canadian should be provided with broadband internet service (BIS) access by the end of 2004 (Industry Canada 2001). The CNBTF also emphasized that aboriginal communities are to receive accelerated focus. Prior to the recommendations of the CNBTF, the Government stated in the 1997 Throne Speech that it wanted Canada to be at the forefront of the information revolution. The policy commitment to remove the rural and remote broadband divide was charged to Industry Canada. Consequently, Industry Canada developed an internet broadband portal to help distribute broadband internet to rural, northern and remote communities where market forces alone have insufficient financial incentives to deploy BIS (Industry Canada 2001; Hamilton 2002; Industry Canada 2002). Industry Canada has developed two programs to help provide the required infrastructure. Specifically, in the Broadband for Rural and Northern Development Pilot Program, \$79-million was invested in organizations representing 1380 communities (Industry Canada 2004). The second program, the National Satellite Initiative, was established for communities where satellite is the only possible means of delivering broadband. Various partners contributed \$155 million to help cover the high cost of satellite technologies and equipment. However, a 'community connection' is expected to be available for only 10 – 15 years, which is the lifespan of the satellite (Industry Canada 2004). Although the government has taken some steps to help bridge the digital divide, as of late 2004 approximately 5 million people still lacked BIS.

1.5 Thesis Purpose

The purpose of this thesis is to undertake a spatial analysis that will advance the Canadian government's commitment to deliver cost-efficient broadband telecommunications (wireless, satellite, wireline) to the almost five million Canadians living in rural, remote and isolated locations that are currently without broadband service. Geographic Information Systems is used to determine if emerging terrestrial technologies could effectively and economically provide service to households without service.

1.6 Central Research Question

Based on emerging terrestrial wireless technologies, can a Geographic Information Systems model be developed and applied over a large region in order to determine if broadband internet service could be provided where broadband is not available?

- If so, then what effects does the spatial scale of analysis have on the robustness of the model results?
- Should this model be used for a Canada scale analysis?

Due to the variety of definitions, this thesis adopts the standard definition of a model as a simplified representation of reality. By way of elaboration, the development of the GIS-based model involves both the generalization of a spatial process and the generalization of reality within the data used to represent the 'real world'. As such, the GIS-based model in this research encompasses both a modelling of data (Chapter 3 and 4) and a processing step (Chapter 2).

1.7 Study Area

The study area is the province of Alberta (Figure 1.2). Although broadband internet access issues are present throughout Canada, this research aims to create a model in order to determine if a Canada-scale analysis is warranted. Alberta was selected because it represents a portion of the Canadian landmass where service for broadband in rural / remote regions is lacking and service in urban areas is well represented (Figure 1.1). In addition, Alberta has a number of different physiographic regions, such as the Rocky Mountains and the Foothills in the west, the Alberta Plains in the south and a small portion of the Canadian Shield in the north. Although not delineated in Figure 1.2, the changes in elevation illustrate the physiographic variety found in Alberta. Poignantly, Alberta includes most of the topographic characteristics found elsewhere in Canada and, as such, this region is appropriate for testing a wireless broadband communications model and its relative performance under different physiographic characteristics.

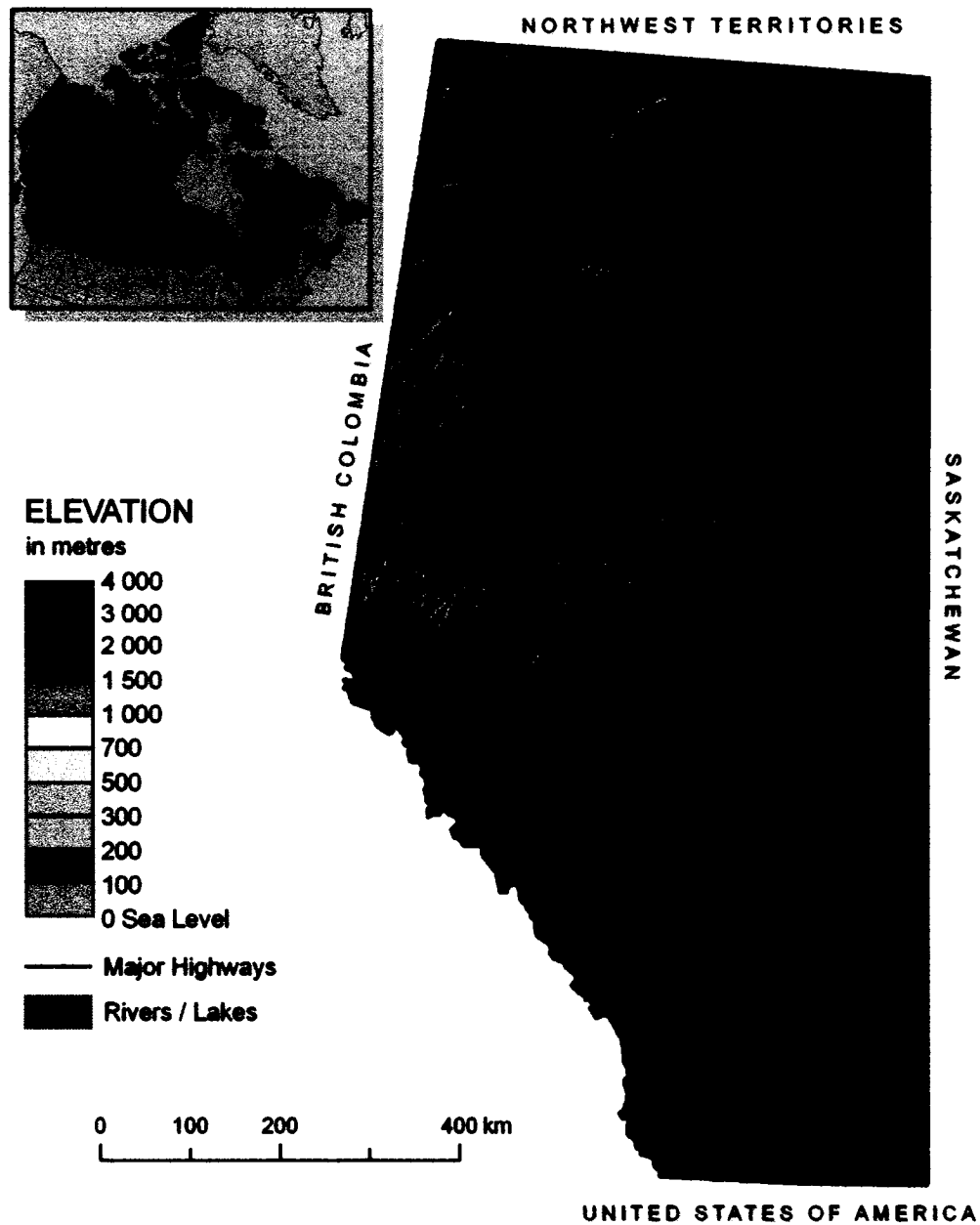


Figure 1.2. Map of the study area with the elevation, major cities, water / rivers of Alberta (Natural Resources Canada 2005).

1.8 Thesis Structure

The thesis is organized into six chapters and eight appendices. This first chapter provides a general introduction and rationale for this thesis and the selection of the study area. The second chapter describes the model approach and scenarios under which it was applied for wireless communications. Specifically, a simple GIS-based model is developed and used to estimate whether emerging terrestrial wireless technologies (WiMAX) could be profitably deployed in the rural and remote regions of Alberta. The model is run under two scenarios, which estimate the potential number of subscribers under ideal conditions and the potential number of subscribers as constrained by topography. Chapter 3 describes the methods undertaken to create the required for the wireless models, while Chapter 4 describes validation through application to high-resolution data within a subset of the study region of Alberta. Chapter 5 presents the results and discussion of the model application. Finally, Chapter 6 presents the recommendations and the conclusions of this research.

Appendix A and Appendix B contain in-press refereed papers arising from this thesis research. The two publications provide more discussion and background about the issues surrounding the Canadian broadband geographic divide. The remaining appendices describe the details of the computer code that underlies the model as referred to in Chapters 2 and 3.

The paper in Appendix A was co-authored by four individuals. I carried out the research into broadband, its technologies and Canada's urban / rural divide and provided much of the background for the paper. Additionally, I developed the methods for the upper and lower limit scenarios and carried out the procedures; my role in the paper in Appendix B was similar, however there was no lower limit scenario and therefore no program was developed.

The two publications in the Appendices provided results that indicate a need for further model refinement. For example, both papers used coarse (1 km) resolution data (Dissemination Areas) and suggested the need for comparison of model results to high-resolution datasets. This thesis provides that comparison.

1.9 Review

This chapter has outlined the importance of broadband and the Government of Canada's commitment to have broadband available to all Canadians. It also provides a brief introduction into broadband and the urban and rural broadband divide that presently exist in Canada. Most important, it has outlined the purpose of this thesis and its central research question along with a description of the study area.

2

Model Development

2.1 Overview

Accessibility to terrestrial broadband wireless technology for rural and remote dwellings without access is a spatial question which involves the capacity for different technological solutions to reach a profitable population base. While specialized software for the analysis and planning of wireless technologies (e.g., PlanetEV® by Marconi Corporation plc.) provide very accurate models of radio propagation they are designed for applications in small regions. These specialized software packages represents a second tier of analysis, such as when one is ready to determine placement of broadband towers at a local level to survey levels of precision. At the scale of a large landmass, such as Alberta, the software and procedures contained within a Geographic Information System (GIS) can be utilized as a first approximation, Using GIS provides the means to addressing the spatial question of

whether emerging terrestrial wireless technologies can effectively provide service to rural and remote dwellings without broadband access.

The advantage of using GIS is that it can provide generalized first approximations of where towers should be located. Therefore, using GIS we model the two types of wireless communications: Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) (Figure 2.1). LOS communications is when radio waves travel from the communication tower to the receiving antenna, unobstructed⁵. Whereas, with NLOS communication, obstacles can obstruct the path⁶ between the tower and receiving antennae but with a combination of software and multiple signal paths, communications services can still be delivered (Figure 2.1).

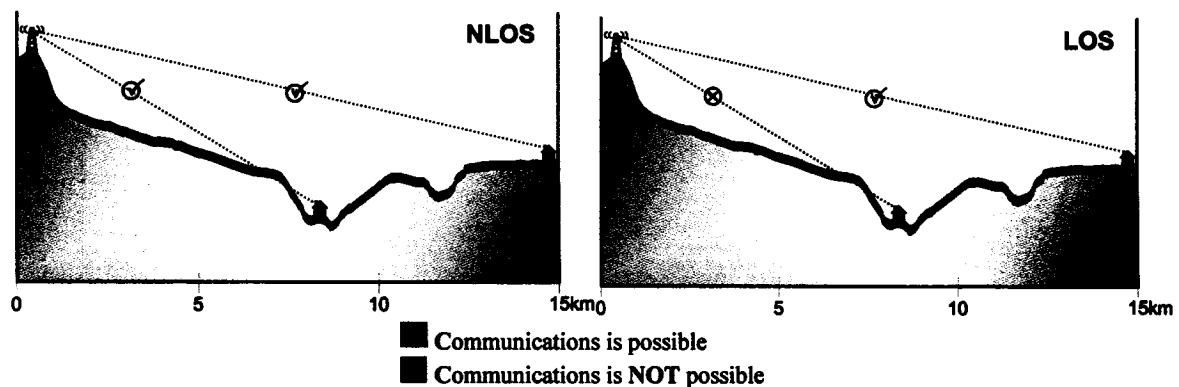


Figure 2.1. Illustration demonstrating the ability to provide broadband internet using LOS (right) and NLOS (left) wireless communications.

⁵ In radio propagation theory this is called 'free space' propagation because there is an unobstructed communication path between the antenna and transmitter.

⁶ Again, in radio propagation theory the NLOS is more complicated and can range from a "plane earth loss model" that presents interference via a single reflected ray to refraction, scattering and knife-edge diffraction. Here we assume the most extreme case of radio interference for the NLOS scenarios.

Therefore, based upon the two types of wireless communication, two models are developed that reflect the theory of wireless communications for use in GIS: unobstructed (NLOS) and obstructed (LOS). First, the unobstructed assumption specifies that radio waves can travel bi-directionally without interference. This unconstrained assumption is called the Upper Limit Scenario (ULS). This term is used because it represents the maximum number of dwellings that potentially could be provided with access. The ULS is an ideal wireless telecommunications model whereby all possible individual dwellings within a given distance or service radius of a telecommunications tower (transmitter/receiver) can access wireless protocols.

Second, the constrained assumption incorporates the most important factor in radio interference: topographic variations. Due to varying topography, radio telecommunications cannot always provide reliable signal quality for broadband to all possible locations within a given distance of a tower. Accounting for topography, only those areas that can be viewed from a communications tower, provides a more realistic estimate of populations that can be served. The topographic constraint represents the Lower Limit Scenario (LLS) because we use the term in order to illustrate the worst case scenario.

The model in this thesis is applied to two broadband wireless access scenarios at two spatial scales. Specifically:

1. **Upper Limit Scenario (ULS):** This approach is based on NLOS assumptions and calculates the number of dwellings that could potentially be reached within 5 km and 50 km of all potential broadband telecommunications towers. The resulting estimate represents the upper limit of the potential market for the existing design specifications of WiMAX technology at 5 km. The 50 km NLOS scenario is used here for comparative purposes, that is to say, to provide a simple

count of total potential dwellings within the maximum WiMAX service area. NLOS technology within 50 km from a communication tower does not currently exist within the WiMAX specification.

2. **Lower Limit Scenario (LLS):** This approach is based on LOS assumptions and is applied to the same radii as the ULS. This analysis yields an estimate of the lower limit of the potential market for broadband wireless access (BWA) for existing WiMAX specifications. In this case towers are assigned a height of 30 meters while the receiving antenna is 3 metres in height.

The telecommunication models developed in this Chapter are based on the use of raster datasets, but a key component to modelling is the cell size or raster resolution. If the cell sizes of the supplied rasters are too small (e.g., 1 metre) then a large study area may not be computationally feasible for even the most powerful computers. It has even been demonstrated that the spatial resolution of a Digital Elevation Model (DEM) can affect propagation results for radio-frequency analysis (Dodd 2001, Rose 2001). Therefore, in order to provide a sufficient broad-scale overview of where potential wireless broadband services could be deployed in Alberta, these two scenarios are applied at two spatial scales:

1. **Coarse Resolution Analysis (CA):** Processed at a $1,000 \times 1,000$ metre level of generalization.
2. **Fine Resolution Analysis (FA):** Processed at a 90×90 metre level of generalization.

In both cases the generalizations are represented by raster data for both the topography and dwellings. The modelling of the required datasets are detailed in Chapter 3 for the CA and Chapter 4 for the FA.

2.2 Modelling Non-Line-of-Site (NLOS)

This section describes the NLOS model. The model was entirely conducted using neighbourhood (focal) functions within a GIS. In this NLOS analysis the terrain is assumed to be completely flat. Under these circumstances, and with the exception of the earth's curvature, all dwellings are assumed to have a clear line-of-sight with a communication tower located within a distance of either 5 or 50 km. Locations that have been deemed acceptable as tower sites are examined to determine the total number of dwellings that could be provided with access (Figure 2.2). It is important to note that NLOS technology within 50 km from a communication tower does not currently exist with the WiMAX specification and this scenario represents the maximum achievable market. The software specific GIS procedure for this process is outlined in Appendix C.

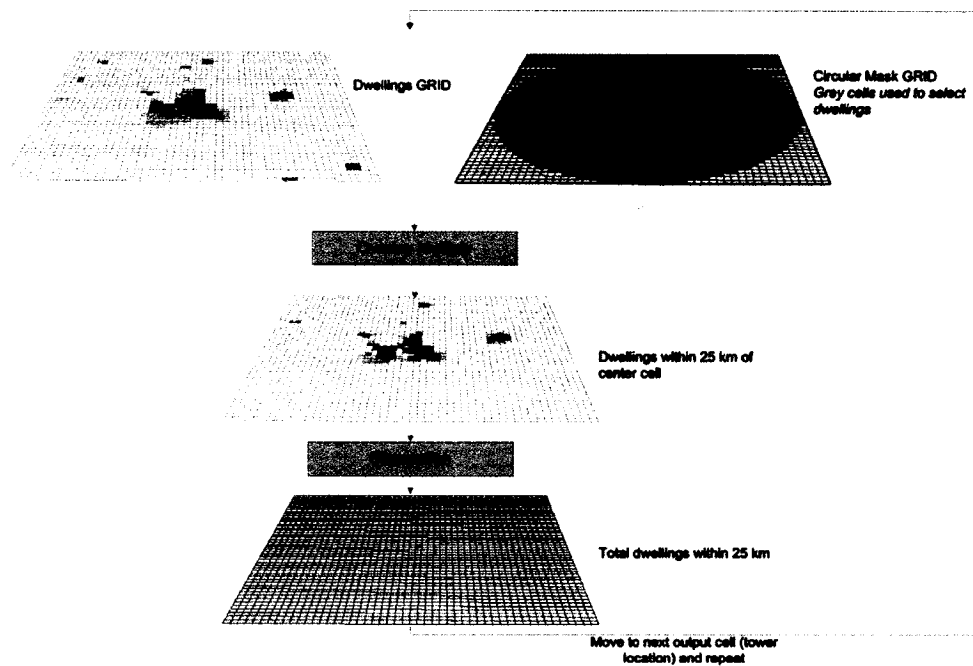


Figure 2.2. Process of deriving the NLOS model. This example is for a 25 km radius surrounding the potential tower location at the centre of the study region.

2.3 Modelling Line-of-Site (LOS)

The LOS model makes use of the topography to determine if towers could possibly have a direct and non-obstructed view of dwellings. Determining which dwellings have LOS is ascertained by examining if a 30m tower⁷ would have a direct sight to a 3m antenna located at the centre of each raster cell (Figure 2.3). Surrounding each tower site, all cells with LOS have their dwelling values summed together. It is assumed that dwellings that do have LOS can be provided with broadband internet service (BIS). The entire process is outlined in Figure 2.4 and the process model described above is repeated for each location where a tower could possibly be located.

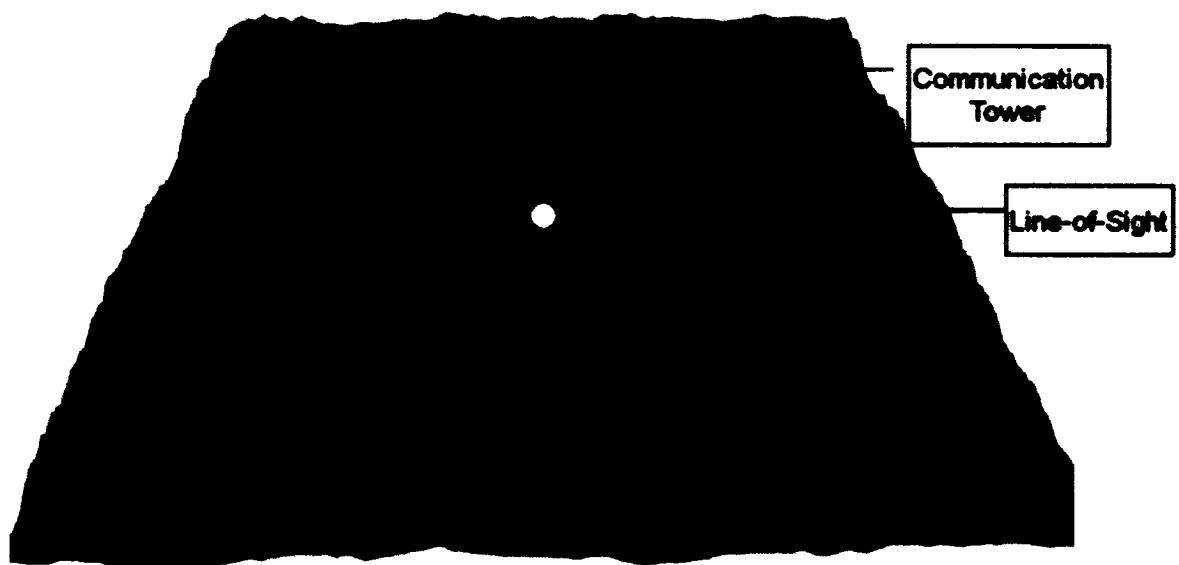


Figure 2.3. 3D Visualization of the LOS Examination for a sample area. Dark greyish patches represent area's visible from a communication tower of 30m.

⁷ Typically a tower of this type is twice this height (~60m) to compensate for vegetation above the terrain. However, in our case we are using only the topography and choose a 30 m height which will provide more conservative estimates of the serviced region around each potential tower.

There are numerous tower sites to be examined, as a result, a custom application was developed to repeatedly carry out the LOS, viewshed and summation analysis. The code was written using the Visual Basic and ArcObjects within ESRI's ArcGIS. The code is described in Appendix D while the required dataset is listed in Table 2.1.

Table 2.1. Required data for examining the lower limit scenario (high resolution).

Spatial Data Name	Data Type
Derived Elevation	Raster
Derived Locations of Possible Towers	Point
Derive Dwellings Locations	Raster

A GIS program was developed to carry out the LLS (Appendix D). A problem that was soon discovered after first executing the program for the CA was that it was very time consuming. It was taking an average of 9.6 seconds to process each tower site.⁸ This would have represented waiting a month before any results would be yielded.⁹ Therefore, the workload was distributed on a network of computers in order to reduce the wait-time. For this to function and minimize the amount of user input required to run the scenario, a network program consisting of text files and various folders, was employed. This technique permitted the processing to operate smoothly on an average of sixty computers which significantly reduced the waiting period to less than three or four days (Appendix E).

⁸ Dell Precision 650. Dual Intel Xeon™ 3.2GHz CPU with 4GB RAM.

⁹ Note: for the refined resolution it would have taken 6 months of processing on a single machine.

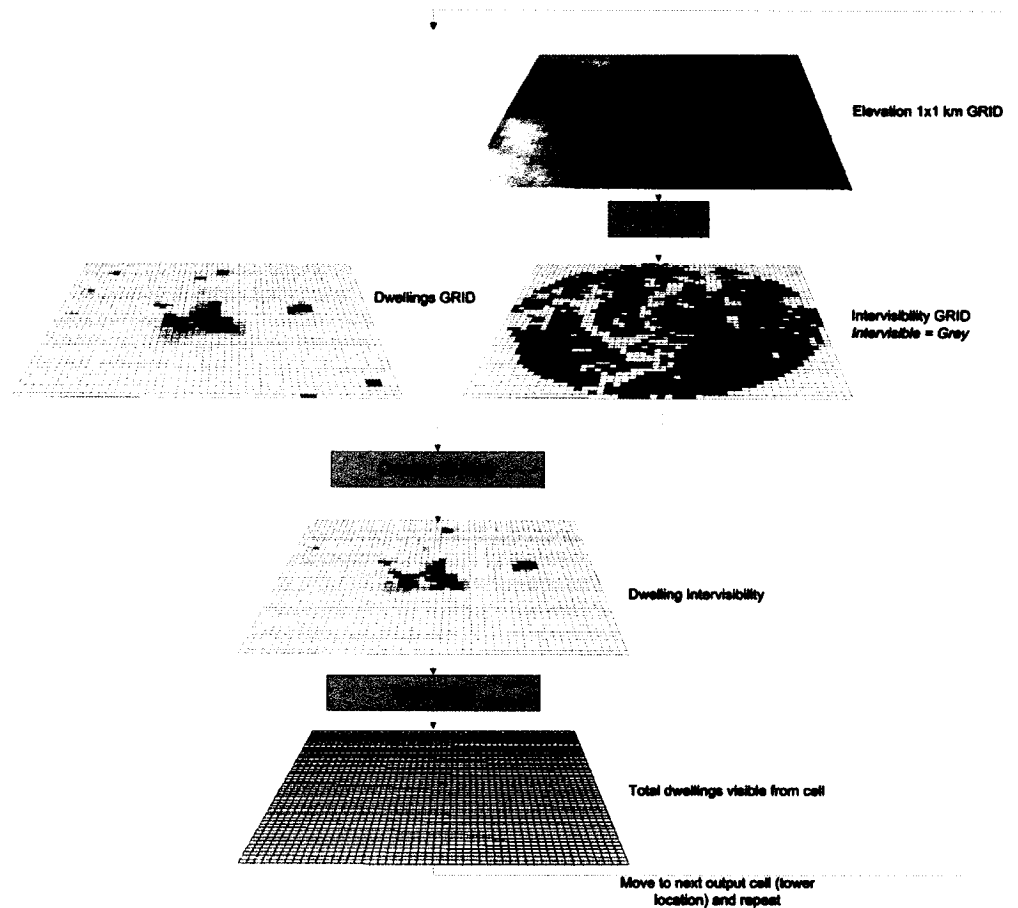


Figure 2.4. Process of deriving the number of dwellings potentially served by WiMAX using LOS and viewshed analyses. This example is for a 25 km intervisibility analysis with the potential tower location at the centre of the study region.

2.4 Review

This chapter has described the general theory of wireless communication, unconstrained and constrained. The unconstrained, NLOS, is represented by ULS, while the contained, LOS, is represented by the LLS. Both scenarios evaluate the potential for broadband wireless service to be provided to dwellings without broadband access. The results of the scenarios are outlined in Chapter 5.

3

Data Modelling: Coarse Resolution

3.1 Overview

In chapter 2 the general theories of wireless communication (line-of-site and non-line-of-site) were described. For those scenarios to function, three datasets are required (Table 3.1). Unfortunately the location of possible tower sites and the location of dwellings were not available ‘off-the-shelf’, instead, they had to be developed in this thesis. Therefore, this chapter describes the methods used to develop the required data for the Coarse Resolution Analysis (CA) undertaken for the Lower Limit Scenario (LLS) & Upper Limit Scenario (ULS) analyses.

The reason for having to develop the data is because as is often the case, data does not exist and typically if they do, they are not in the format required (raster, vector or the correct resolution). In this present study, the exact location of dwellings was not publicly available because it would invade the privacy of individuals. While it is also unlikely that every

household in Alberta has been electronically mapped, those that have are locked away in local land registries and cadastral datasets.

Table 3.1. A breakdown of the spatial data required for the upper and lower limit scenarios.

Spatial Data Required	Data Model Required	Scenario
Location of a Possible Towers	Points	ULS & LLS
Location of Dwellings	Raster/ Vector Footprint	ULS & LLS
Elevation	Raster	LLS

With regard to locating where communication towers can be placed, the issue is even more complex; zoning regulations for communication towers are set and controlled locally and it would have been time-prohibitive to research and determine each municipality's regulations, especially when conducting provincial and national analyses. In light of the complexity of the data acquisition requirements it becomes necessary to develop appropriate solutions by modelling the required dwelling data.

In order for the required dwelling data to be representative, various other data sources are utilized and combined. This chapter is divided into a number of sections for ease of understanding, however, before the methods are detailed, an overview describing the required data for the ULS & LLS models is provided.

3.1.1 Overview for the Identification of Tower Sites

To identify tower sites every location of the study area (e.g., each 1×1 km raster cell) is first considered as a potential location. Then areas that are not suitable to the construction of a tower are removed. For example, water bodies (because towers cannot be constructed on

water) and environmentally protected areas (i.e. National Parks, Conservation Areas) are considered unacceptable locations. This line of reasoning could be followed further to incorporate lawful locations (municipal, provincial and federal) and unoccupied properties (e.g., roof tops), but to research all of the authorized and restricted locations, would be unrealistic due to time and resource restrictions. Therefore using available data such as water, significant areas, roads and provincial boundaries, the location of potential sites are identified. A diagram of the data involved is illustrated in Figure 3.1 while section 3.6 describes the methods undertaken.

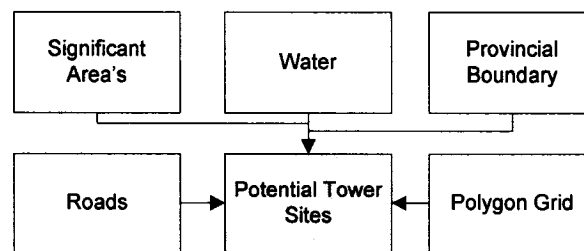


Figure 3.1. Diagram illustrating the use of the dataset to model the location of potential tower sites.

3.1.2 Overview for the Identification of Dwelling Locations

Identifying the location of dwellings is done by removing areas where dwellings cannot be situated and then distributing the known number of dwellings into a grid. However, “in reality households will tend to be clustered in particular parts of a census unit, the necessary assumption made here is that the values measured within a census unit are distributed equally across the census unit” (Sawada et al. 2006). Therefore, to ensure that dwellings are spatially located where they are likely¹⁰ to exist, the smallest available census units (blocks) and data tuning methods (sharpening) are employed. Furthermore, we assume that dwellings cannot be located in water and that most dwellings will be located within one kilometre of a

¹⁰ The term ‘likely’ is utilized because the exactly location of dwellings cannot be confirmed.

road. The process of identifying dwelling locations is conducted by using the data illustrated in Figure 3.2 while section 3.4 (page 36) describes the methods. This procedure is generally referred to as a dasymetric mapping approach (Mennis 2003).

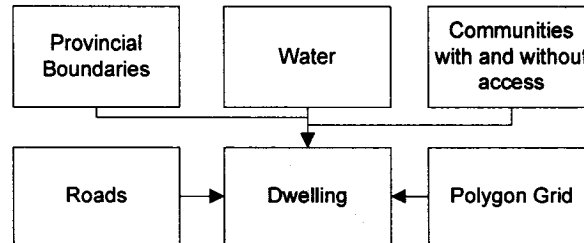


Figure 3.2. Diagram illustrating the use of the dataset to model the dwelling values.

3.1.3 Overview to Organizing the Elevation Rasters

The modelling of elevation was not required because the data were publicly available, but the datasets needed to be merged and aggregated into an appropriate spatial resolution for analysis. A detailed explanation of how the data were merged and aggregated is explained later in section 3.2 (page 25).

3.1.4 Employed Datasets

The datasets used for the ULS & LLS are listed in Table 3.2. This table also provides a brief description of the data, the distributor, the data format, the coordinate system and the modelling stage un which it was used.

Table 3.2. General overview of the data utilized for examining the possibility of providing broadband wireless access under two scenarios.

Data Description /Product Name	Distributor	Data Format	Projection	Scale of Data	Stage of Usage
Elevation Data (Digital Elevation Data)	GeoBase Natural Resources Canada	USGS DEM	North American Datum 1983	90 m	Elevation, Tower Distribution & Dwelling Distribution
Boundaries for Canadian Provinces. (ArcCanada 2.0)	ESRI	Polygon	GCS North American 1983	1:50,000	Tower & Dwelling Distribution Analysis
Major Water Bodies (CanMap® Water)	DMTI Spatial Inc	Polygon	GCS North American 1983	1:50,000	Tower & Dwelling Distribution Analysis
Minor Water Bodies (CanMap® Water)	DMTI Spatial Inc	Polygon	GCS North American 1983	1:50,000	Tower & Dwelling Distribution Analysis
Canada Road Network (2005 Road Network)	Statistics Canada	Line	GCS North American 1983	1:10,000	Tower & Dwelling Distribution Analysis
National Road Network	GeoBase Natural Resources Canada	Line	GCS North American 1983 CSRS98	1:10,000	Tower & Dwelling Distribution Analysis
Dissemination to Community Identification Number	Gerry Briggs	Table	NA	NA	Dwelling Distribution
Communities with and without broadband access	Gerry Briggs	Table	NA	NA	Dwelling Distribution
Significant Areas of Alberta	Alberta Government	Polygon	NAD 1983 Transverse Mercator	1:250,000	Significant Areas
Alberta Crown Reservations	Alberta Government	Polygon	NAD 1983 Transverse Mercator	1:250,000	Significant Areas
Alberta Parks and Protected Areas	Alberta Government	Polygon	NAD 1983 Transverse Mercator	1:250,000	Significant Areas
Blocks Points	Statistics Canada	Point	GCS North American 1983	NA11	Dwelling Distribution

¹¹ The Block Points are the centroids of the Block Polygons (page 39).

3.1.5 Scale

All datasets used in this coarse analysis (CA) were represented at spatial scales smaller (i.e. 10 metres) than the scale of analysis, 1 km (1×1 km). Thus, the datasets, and in particular the Census Blocks and DEM data, are appropriate for up-scaling¹² using summations and averages.

The remainder of this chapter explains how the required datasets were developed including the elevation raster, the dwelling value raster and the location of communication towers raster. This chapter also details how the supporting data, the location of significant areas and the polygon grid were derived.

3.1.6 Development of Spatial Data

Prior to manipulating or using any spatial data, they were converted to the Canada Albers Equal Area Conic projection (with the exception of the elevation raster) as this projection's properties preserves area proportionally. This is important because areas are calculated by creating a 1×1 km grid that is then used to determine the distribution of dwellings. Throughout this study ESRI © ArcGIS 9.2 was utilized with noted exceptions. In such instances ESRI © ArcView 3.2a was employed because a downloaded script called Split Shapefile¹³ was only available in 3.2a.

3.2 Organization of Elevation Rasters

This section describes the creation of a 1×1 km (1 km resolution) elevation raster using digital elevation data (also referred to as a DEM (Digital Elevation Model)) (GeoBase 2005). Preparing the elevation raster was conducted by merging numerous raster datasets

¹² Up-scaling refers to changing the data to a more coarse resolution. For example from a 90 m resolution to 1 km resolution.

¹³ Split Shapefile <http://arcsripts.esri.com/details.asp?dbid=12777> Jeff Jenness (Date Accessed: 12 Jan 2006)

(approximately 300) into a single raster file. Then the raster was generalized (via aggregation) into a 1 km resolution. For this process the required data were provided by Natural Resources Canada. An outline of the required procedures is illustrated in Figure 3.3.

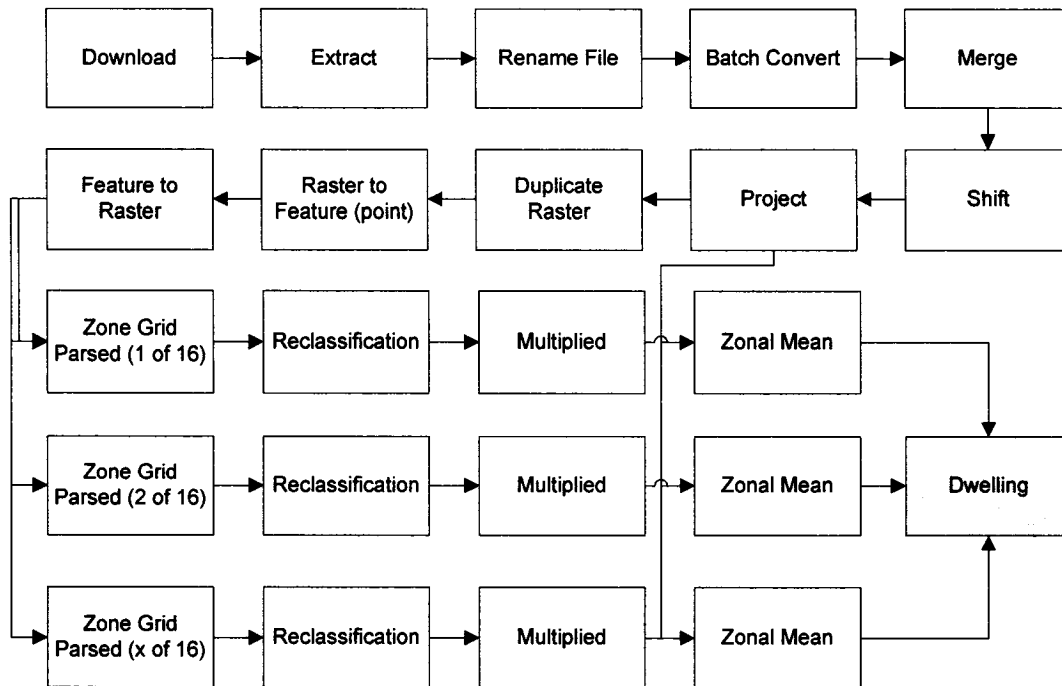


Figure 3.3. Procedures for creating a 1 km elevation raster of the study area and beyond.

Assembly of the Elevation Raster (90 metre resolution)

The first step to compiling the elevation raster data was to download the 1:250,000 scale data from the GeoBase web portal and uncompressing the files into a single folder. In order to use the data in ESRI ArcGIS© they had to be converted from DEMs into ArcInfo GRID rasters. Although ArcGIS cannot directly use DEM files, it does have the tools to convert them into rasters. Rather than manually converting hundreds of DEM files, a program was

developed to do this automatically (Appendix F). Once the files were converted to raster they were merged into a single mosaiced layer. The merging process is illustrated in Figure 3.4 while the software specific expression for ArcGIS is provided in Figure 3.5.

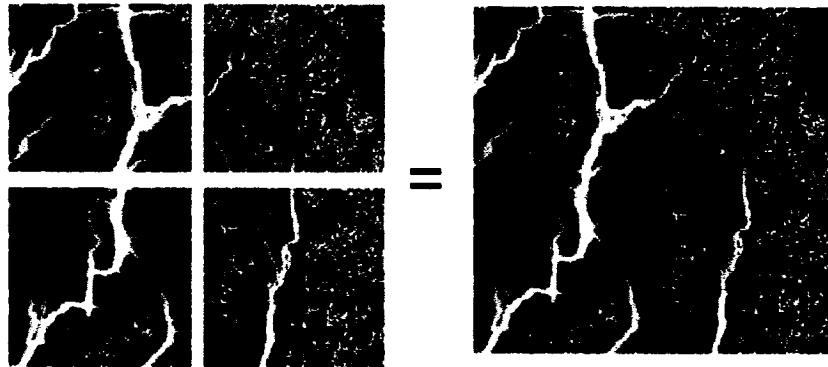


Figure 3.4. An illustration of how the raster merge function in the raster calculator combines adjacent raster layers into a single raster file.

```
Merge([1], [2], [3], [4])
```

Figure 3.5. Sample expression used in the raster calculator of Spatial Analyst in ArcGIS 9.1 to merge the numerous rasters together.

Data provided by GeoBase were disseminated using the coordinate system ‘decimal seconds’ unfortunately ArcGIS requires references as ‘decimal degrees’. Therefore, the elevation raster required coordinate conversion. Coordinate conversion was aided by the metadata provided within the rasters’ ‘readme’ files. Figure 3.6 highlights the bounding coordinates that were collected from rasters located along the outer boundaries of the mosaiced dataset. The software-specific expression is illustrated in Figure 3.7. After the correction of the data, using the cubic resampling method, the raster was projected to Albers Equal Area Conic (Canada).

East Bounding Coordinate: -104
North Bounding Coordinate: 68
West Bounding Coordinate: -132
South Bounding Coordinate: 49

Figure 3.6. The boundary coordinates collected from the metadata of the raster files that are located along the boundaries.

```
ShiftOut = shift([Final], -123, 49, 8.333333333333333333333333333e-4)
```

Figure 3.7. The shift command used in the raster calculator to spatial adjust the elevation data provided by GeoBase.

Creation of the Zone Grid

Although the data from GeoBase had been aggregated, projected and could be used for other analyses, they needed to be scaled-up to a resolution of 1 km for the coarse resolution analysis of the ULS and LLS scenarios. The method used to aggregate the 90 m elevation raster to 1 km resolution was done by calculating the mean of the cells that intersect a 1 km raster cell (Figure 3.8). A zone function, *zonalmean*¹⁴, was used to aggregate the cells. The *zonalmean* function “records in each output cell the mean of the values of all cells in the <value grid> that belongs to the same zone as the outcell” (ESRI 2002).

In order to use the *zonalmean* function two different raster layers are required: a raster with unique zones and a value grid (elevation). The unique zones represent the cells that will be assigned the average value of the overlapping cells from the value grid. Unfortunately, only the value grid (elevation) exists. As a result, a 1 km zone grid with unique raster values was created before the zonal function was carried out.

¹⁴ The term *zonal mean* function is software-specific with ArcGIS however many spatial and remote sensing type software can carry this process out.

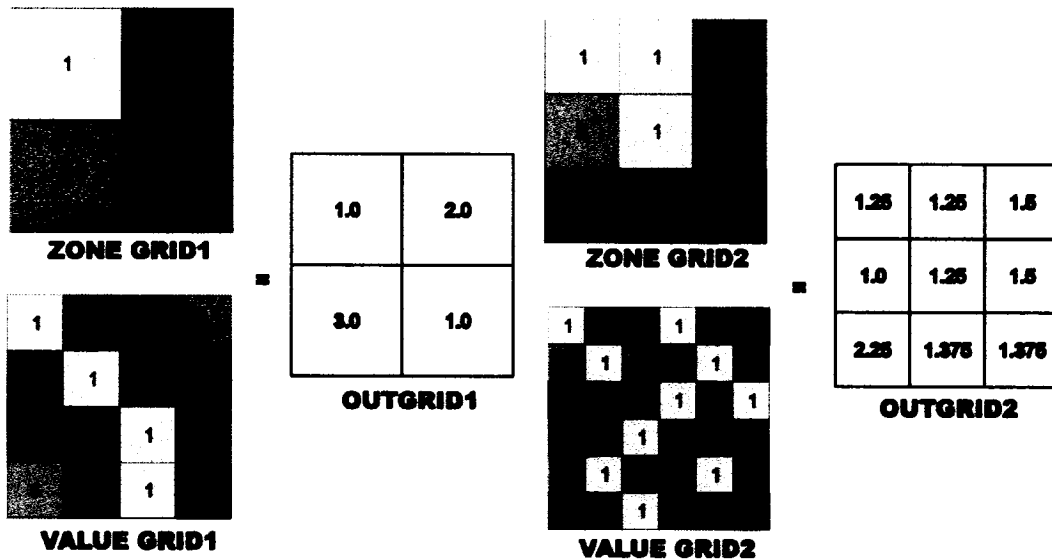


Figure 3.8. Diagram of the zonalmean function where (a) has unique zone grids and (b) has cells in the zone grid that have the same value. Note that raster cells with the same value in the *zone grid* averages all of the intersecting values from the grid cells.

Creating a zone grid requires a number of steps. The first step is to create a grid of 1 km raster cells. To accomplish this, the output cell size in the options of Spatial Analyst (an ArcGIS extension) was changed to 1,000 metres. Next, using the Raster Calculator the value grid (elevation) was entered as the only input. The raster calculator then converted the cells to 1 km. Although the 1 km raster contains some elevation values it is not sufficient for use as a zone grid because each cell is not likely to have a unique value (or zone identification number) assigned to it. If the *zonalmean* function is carried without each cell in the zone grid having a unique value, then the final elevation will not correctly represent the average elevation of a specific discrete location. This concept is illustrated in Figure 3.8. Therefore, to avoid this problem each cell of the newly created raster was assigned a unique value. This assignment was done by converting the 1 km raster to a point layer where the conversion assigns each point a unique identification number. This layer is then converted back to raster

using the *Feature to Raster* function, which preserves the unique identification number assigned to each cell (Figure 3.9).

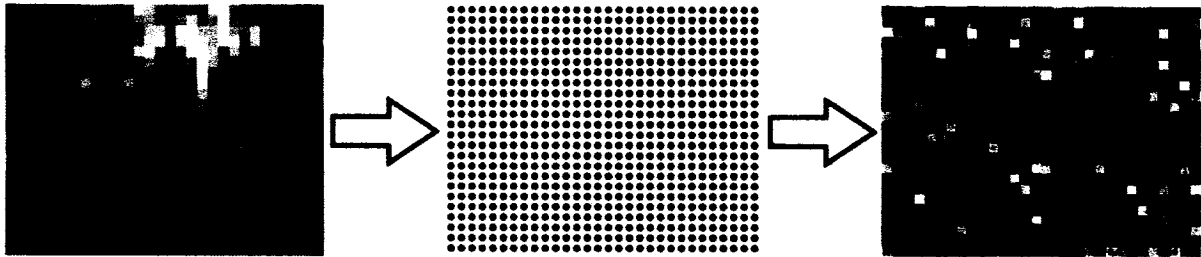


Figure 3.9. An illustration of how to assign unique values to a raster. The 1st step is to connect the raster to a point feature and then (2nd) to convert the point back to raster based on the unique identification number each point was assigned.

Value Attribute Table

At this point both the required zone grid and the value grid have been created. However, there was one last obstacle to overcome before the elevation raster was created using the *zonalmean* function. To use the *zonalmean* function, the zone grid requires a Value Attribute Table (VAT). A VAT is (typically) automatically created with integer grids; however, ArcGIS does not create the table if there are more than 100,000 cells. To bypass ArcGIS's limitation, the conversions were done in batches of less than one hundred thousand cells. This does not affect the resultant elevation raster or the study's results. The zone grid raster could then be parsed into more manageable rasters using ArcGIS's Raster Calculator. The software specific procedures are listed in Table 3.3.

Once the files are parsed, a grid of 1 and 0's (True and False values) was created. The resultant rasters were then reclassified so that only those cells with values of 1 remained,

while the 0 values were changed to NoData (removed). In order to reassign the cells unique values, the resultant rasters were multiplied by the 1 km ZONEGRID raster (created Creation of the Zone Grid on pages 28-30).

Table 3.3. Commands used in the Raster Calculator of ArcGIS to parse a raster into smaller raster files.

```
part1 = [ZONEGRID] > 100000
part2 = [ZONEGRID] >= 100000 & [ZONEGRID] < 199000
part3 = [ZONEGRID] >= 199000 & [ZONEGRID] < 298000
part4 = [ZONEGRID] >= 298000 & [ZONEGRID] < 397000
part5 = [ZONEGRID] >= 397000 & [ZONEGRID] < 496000
part6 = [ZONEGRID] >= 496000 & [ZONEGRID] < 595000
part7 = [ZONEGRID] >= 595000 & [ZONEGRID] < 688000
part8 = [ZONEGRID] >= 688000 & [ZONEGRID] < 793000
part9 = [ZONEGRID] >= 793000 & [ZONEGRID] < 892000
part10 = [ZONEGRID] >= 892000 & [ZONEGRID] < 991000
part11 = [ZONEGRID] >= 991000 & [ZONEGRID] < 1090000
part12 = [ZONEGRID] >= 1090000 & [ZONEGRID] < 1189000
part13 = [ZONEGRID] >= 1189000 & [ZONEGRID] < 1288000
part14 = [ZONEGRID] >= 1288000 & [ZONEGRID] < 1387000
part15 = [ZONEGRID] >= 1387000 & [ZONEGRID] < 1486000
part16 = [ZONEGRID] >= 1486000 & [ZONEGRID] < 1585000
```

Elevation Aggregation

The zone function was then used to scale-up the 90 m elevation raster to a resolution of 1 km. The *zonalmean* function was then repeated for each of the parsed value grids using the software specific expression in Figure 3.10. Finally, all of the resultant rasters for the *zonalmean* function were merged into a single raster (Figure 3.4). The resultant 1 km elevation raster is illustrated in Figure 3.11.

```
Zonalmean([Zonegrid], [ValueGrid])
```

Figure 3.10. Sample 'zonalmean' expression used in the raster calculator of Spatial Analyst in ArcGIS 9.1.

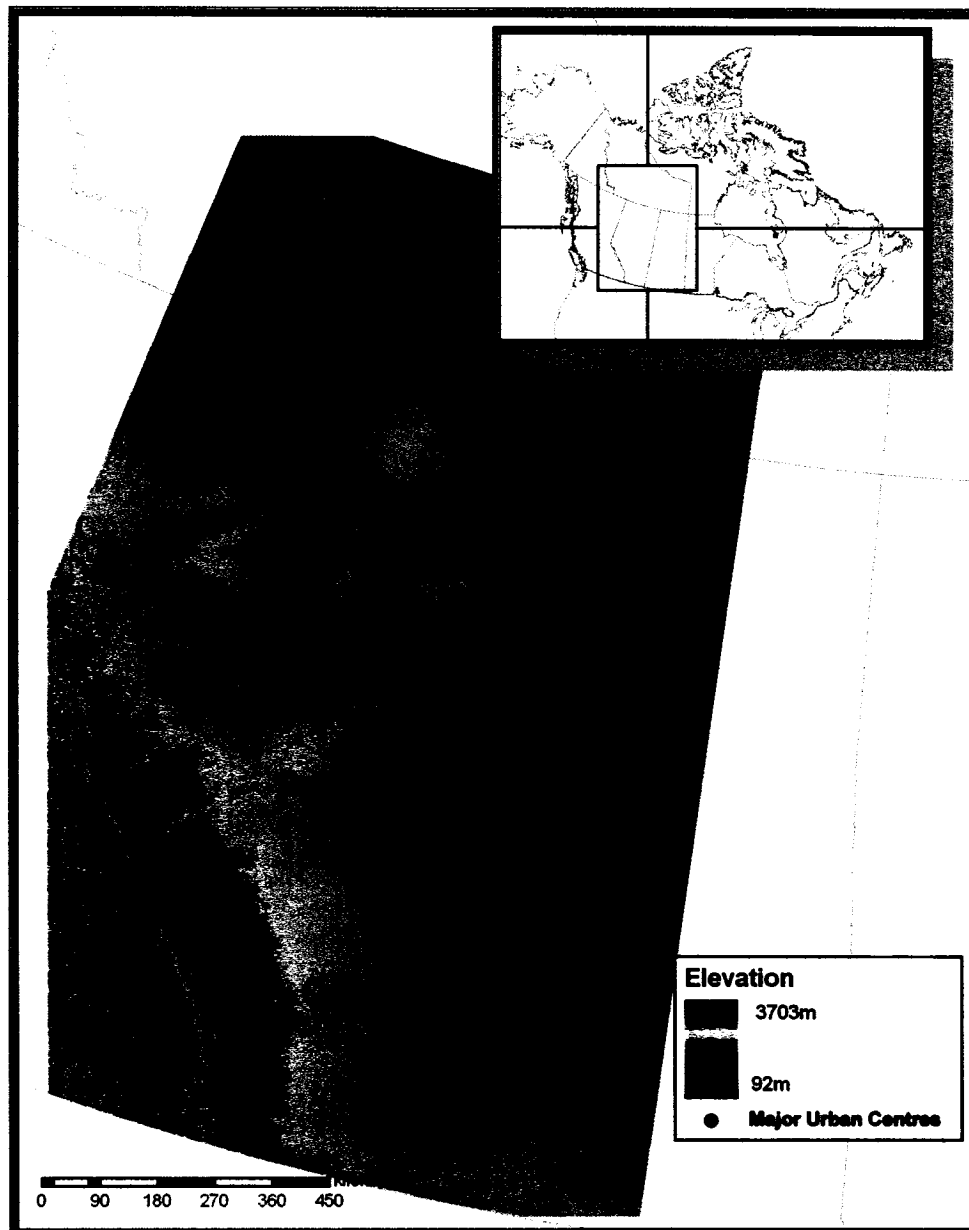


Figure 3.11. Elevation raster at a 1 km resolution using GeoBase data.¹⁵

¹⁵ Note: that the resultant map does not represent the bounding coordinates provided in Figure 3.6 because it was clipped in order to remove excess raster cells that were well beyond the study area.

3.3 Creation of the Grid Network for Alberta

This section describes the methods used to create a polygon grid (a vector set of rectangular cells) covering the study region. A polygon grid is required so that when the dwelling locations are identified, they can be converted to raster. The grid is also used in the final stages when identifying potential tower sites which permit all of the rasters to align. When rasters do not align properly errors can propagate throughout an analysis. The only necessary data required to develop the polygon grid is the previously constructed digital elevation raster.

In 2003, Robert Nicholas released an ArcScript¹⁶, which creates a polygon grid (also known as a fishnet). However, the limitation of this program is that it cannot retrieve the boundaries of a layer, to be used as the fishnet extent. Therefore, values must be manually retrieved from another dataset. The ArcScript requires three sets of information: the lower left corner (the extent of the grid), the number of rows and columns (the size of the grid) and the cell size (the resolution of the grid). During this process a spatial index is created. A spatial index provides each cell with a unique identification number. This spatial index is used when identifying potential tower sites (page 45). The linkage between the layer properties and the completed fishnet form are illustrated in Figure 3.12 while the resultant polygon grid is illustrated in Figure 3.13.

¹⁶ Fishnet <http://arcscripts.esri.com/details.asp?dbid=12807> Robert Nicholas (Date Accessed: 12 Jan 2006)

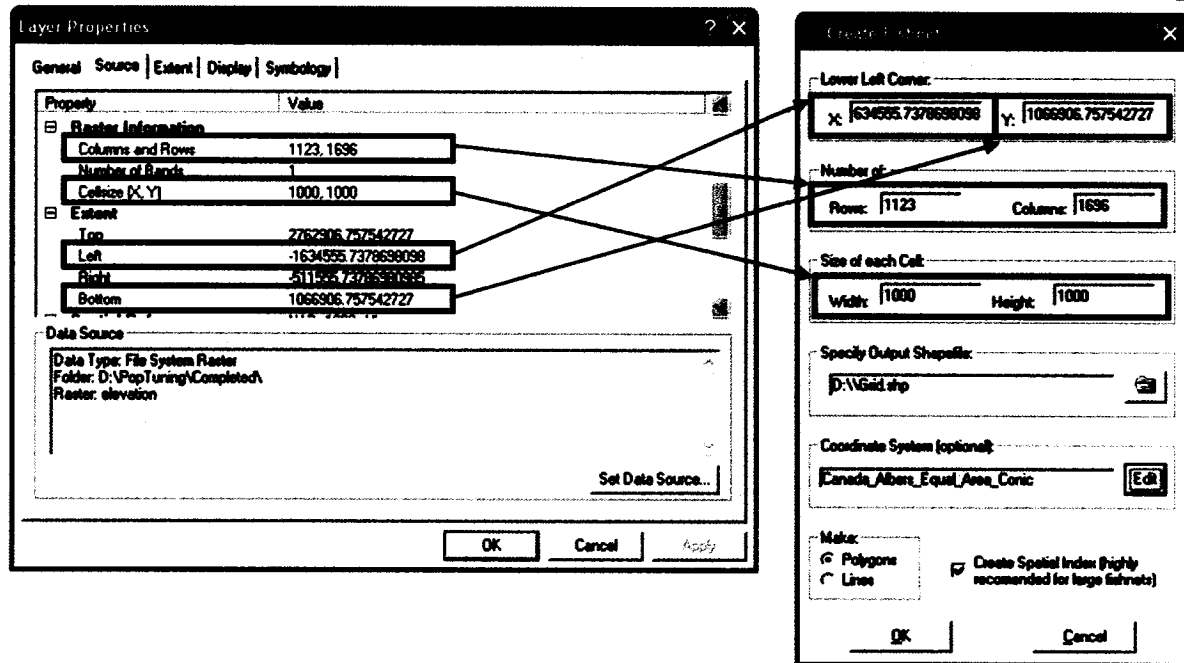


Figure 3.12. Linking the properties of the elevation raster with the input variables required for Robert Nicholas's Fishnet program.

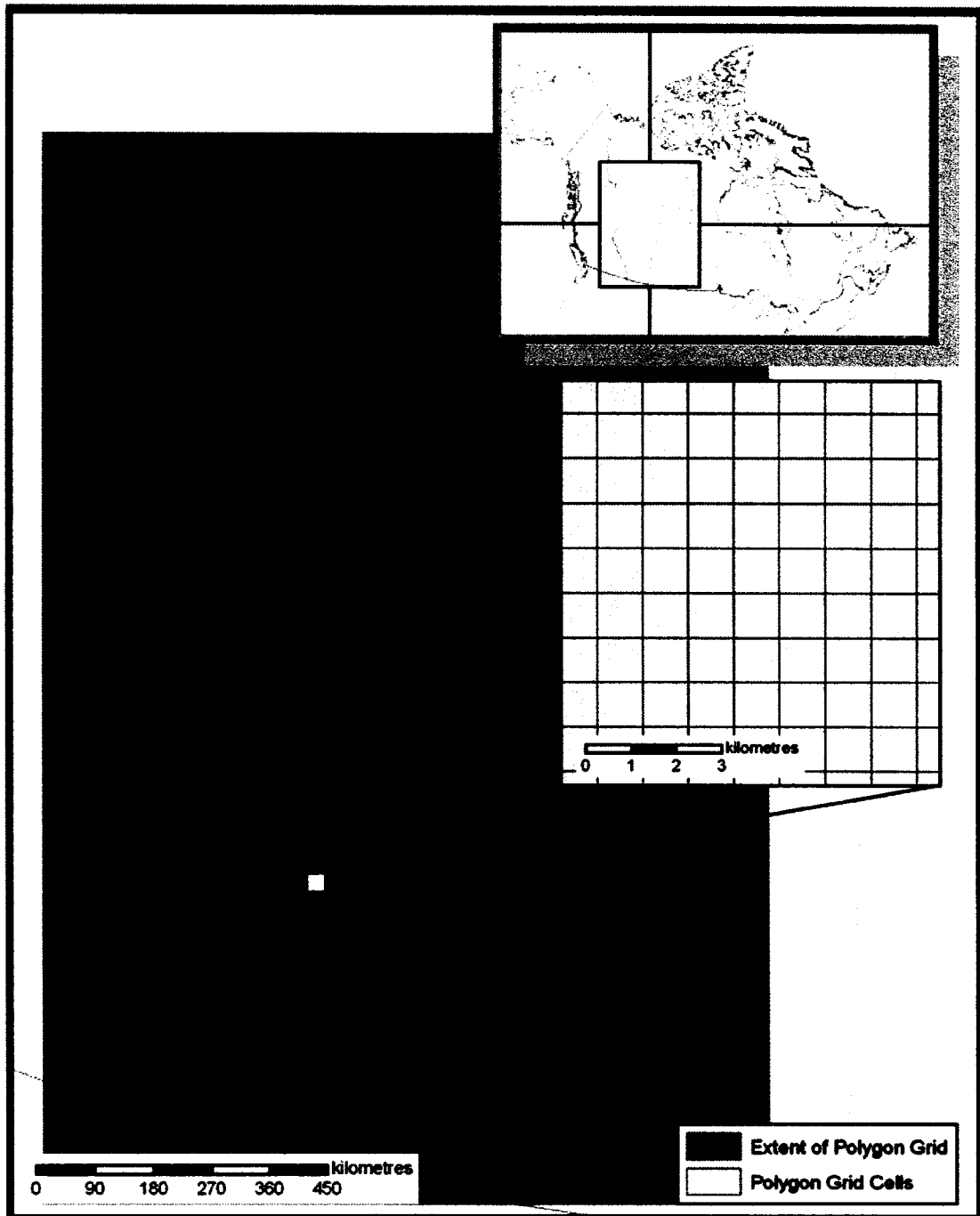


Figure 3.13. Resultant 1×1 km polygon grid.

3.4 Identification of Dwelling Locations

This stage describes the process used to identify the location of dwellings. The primary input into the analysis of the LOS and NOS models are dwelling values. It is assumed that each dwelling currently without access, including urban areas, is a potential subscriber to a wireless broadband service. Information regarding the location of areas without broadband services was provided by Gerry Briggs of Industry Canada.

Census blocks are “the smallest geographic area for which population and dwelling counts are disseminated” (Statistics Canada 2002). Polygons representing census blocks unfortunately do not specifically identify the location of dwellings. Therefore, removing locations where dwellings cannot exist, such as water bodies, and assuming dwellings are located along roads (Figure 3.14) helps increase the accuracy of the dwelling layer. Moreover, dwellings tend to be clustered in particular areas of a given census unit (e.g census tract, subdivision) and it is assumed that the dwelling values are distributed evenly within one kilometre of a road across the census block. As such, the dwellings are distributed into a more organized and systematic grid.

As well, the irregular shapes of the block data are converted to discrete non-overlapping 1×1 km grid cells (Figure 3.14). A schematic of the methods used to distribute dwellings from irregular block polygons into regular grid cells is outlined in Figure 3.15 while the required data are listed in Table 3.4.

Towers located within Alberta may also provide internet access to dwellings located outside the provincial boundary (excluding USA). As a result, dwellings surrounding Alberta are also identified and therefore are also included in the distribution of dwelling values. The resultant raster is illustrated in Figure 3.26.

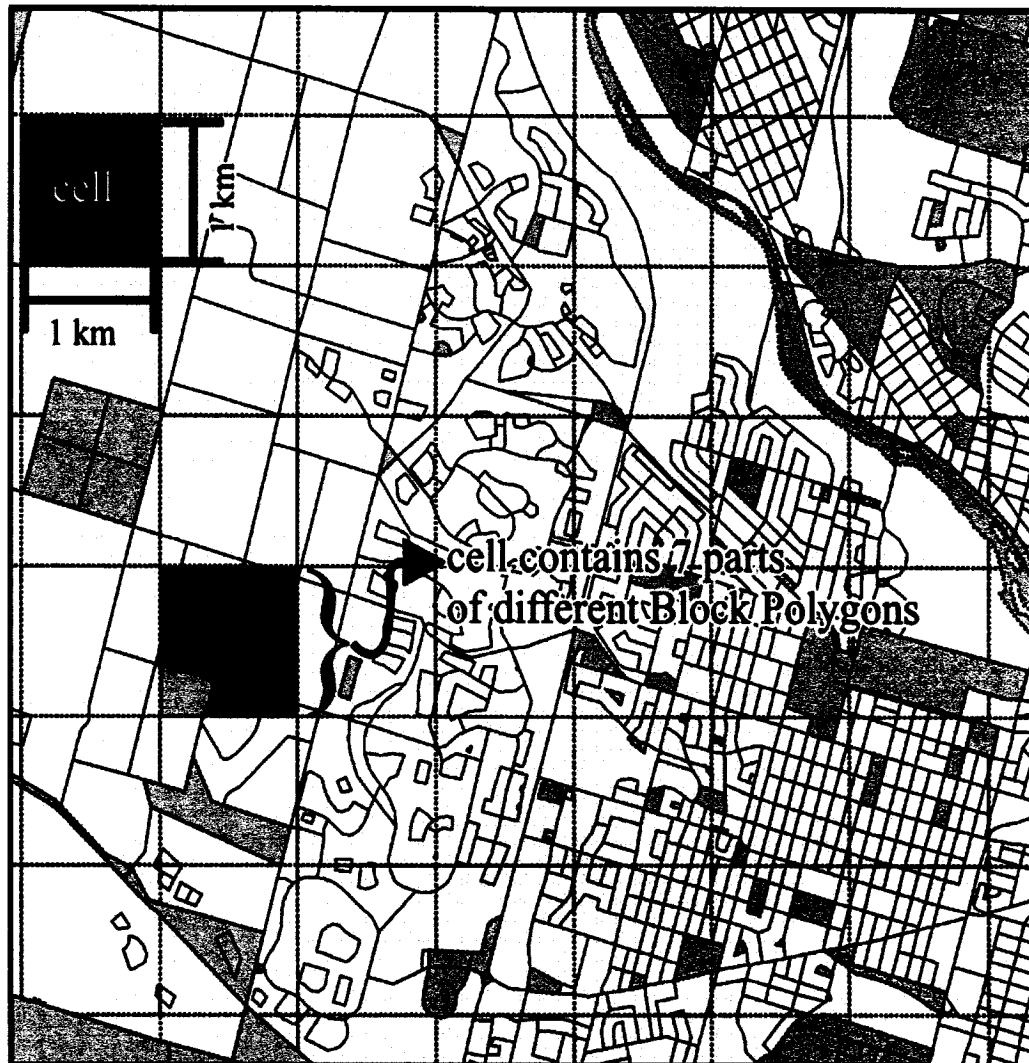


Figure 3.14. Example of regular grid overlaid on census block; light grey areas are the blocks, darker grey areas are water bodies or blocks without populations that were removed from analysis; dotted lines represent the 1 km cells (one is highlighted in black with dimensions); one example is given of how one cell intersects seven different blocks and as such, the number of households assigned to the cell is equal to the sum of households taken from the proportional population assigned to each piece of the 7 blocks intersected by the cell (Sawada, Cossette et al. 2005).

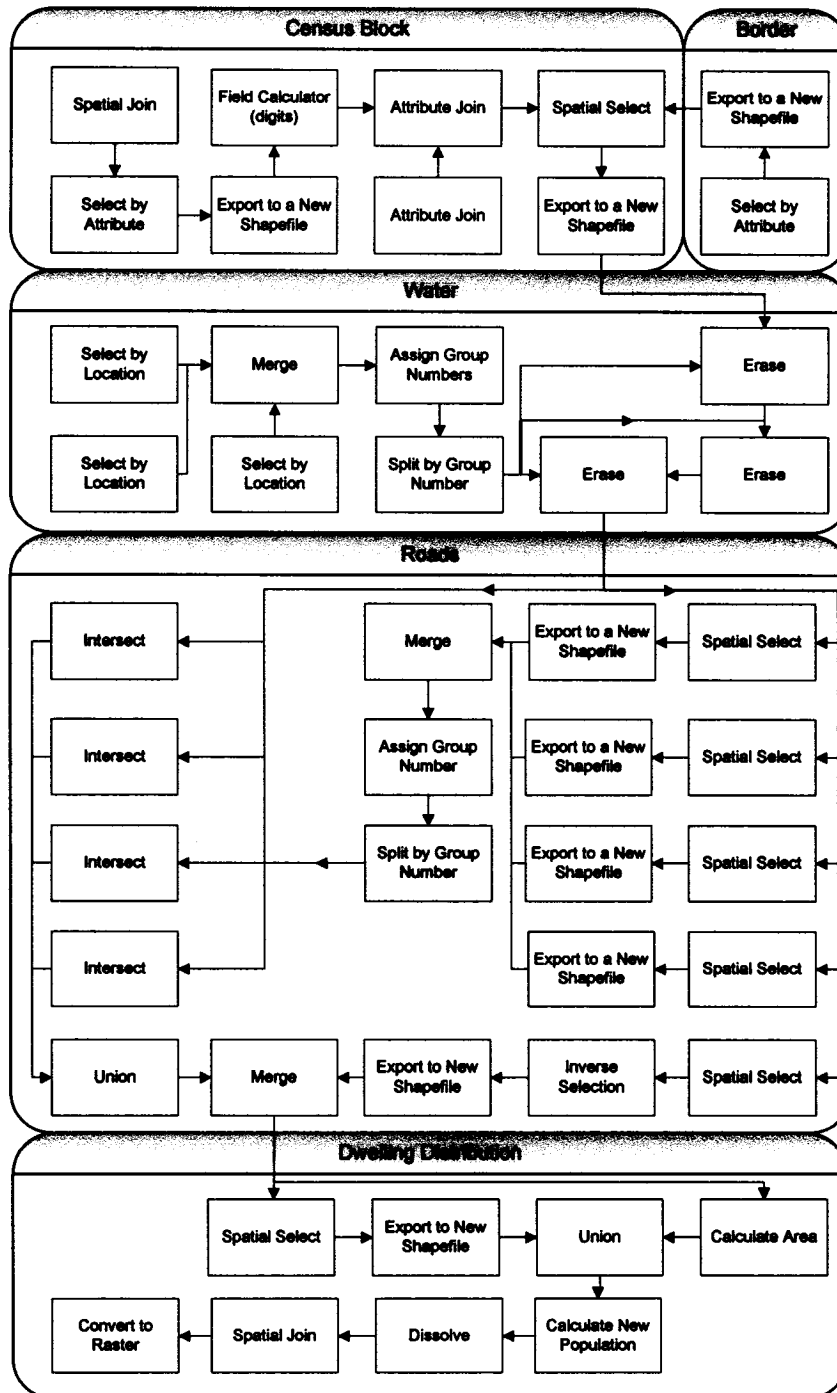


Figure 3.15. Methods used to identify the location of dwellings.

Table 3.4. Data utilized for spatial distributing dwellings across the study area.

Spatial Data Name	Provider
Canadian Boundaries	DMTI Spatial
Polygon Blocks	Statistics Canada
Point Blocks	Statistics Canada
Major Water Bodies	DMTI Spatial Inc
Minor Water Bodies	DMTI Spatial Inc
National Road Network	Natural Resources Canada
Statistics Road Network	Statistics Canada
Dissemination to Community Identification Number	Gerry Briggs
Communities with and without broadband access	Gerry Briggs
Derived Digital Elevation Data	Natural Resources Canada

There are many steps to identifying the location of dwellings. Therefore, for ease of understanding, the process is organized into steps which are outlined in Figure 3.15 and described as:

1. Alberta Boundary

The first step is to acquire a polygon representing the political division of Alberta. The Canadian boundaries layer is used and Alberta exported into a new layer.

2. Census Blocks

In the next step, the census blocks are prepared. Census blocks, provided by Statistics Canada, are the smallest available spatial unit for distributing dwelling values. For unknown reasons, Statistics Canada provides information about census blocks in two formats: A point layer with the dwellings values and a polygon layer with only a block identification number. Therefore, the polygon layer is assigned the dwellings values by spatially joining the point layer to the polygon layer. When linking the two together it was found that some of the blocks had dwelling value of zero, these non-zero polygons were selected and exported into a new layer that is hereto referred to as the block polygon layer.

3. Removal of Blocks that have Access to Broadband

In this step, the polygon blocks that have access to broadband internet are removed. The data are provided by Industry Canada (Gerry Briggs) in the form of two database tables. One table indicates communities with access to broadband, while the second table links the communities' identification values to Statistics Canada's census units called 'Dissemination Areas' (DA). The tables from Industry Canada can be joined based on the community identification number; however, joining the new table to the block polygon is more complex.

The identification number assigned to each census block is a ten-digit number based on Statistics Canada's numbering system (Table 3.5). In order to match the tables provided by Industry Canada to the blocks, the two right digits of the block identification number must be removed. An expression entered into the field calculator of ArcGIS is used to remove these extra digits (Figure 3.16). The shortened identification number is placed in a new field so as to preserve the identification numbers for use in Roads step (page 45). Removing these two extra digits makes it possible to join the tables from Industry Canada to the census blocks.

Table 3.5. Breakdown of how block id numbers are assigned.

Block Code	Description
12 080411 01	12: Province
	09: Census Division
	0411: Dissemination Area
	01: Block

After linking the tables to the blocks, the blocks that did not have access to broadband were 'selected by attribute'. Then, polygons that were either contained in, or were within 60 kilometres of Alberta were sub-selected from the previous selection and exported into a new

layer. The second selection was conducted because the block polygons were provided for all of Canada and only the blocks within 60 kilometres of the study area were required.

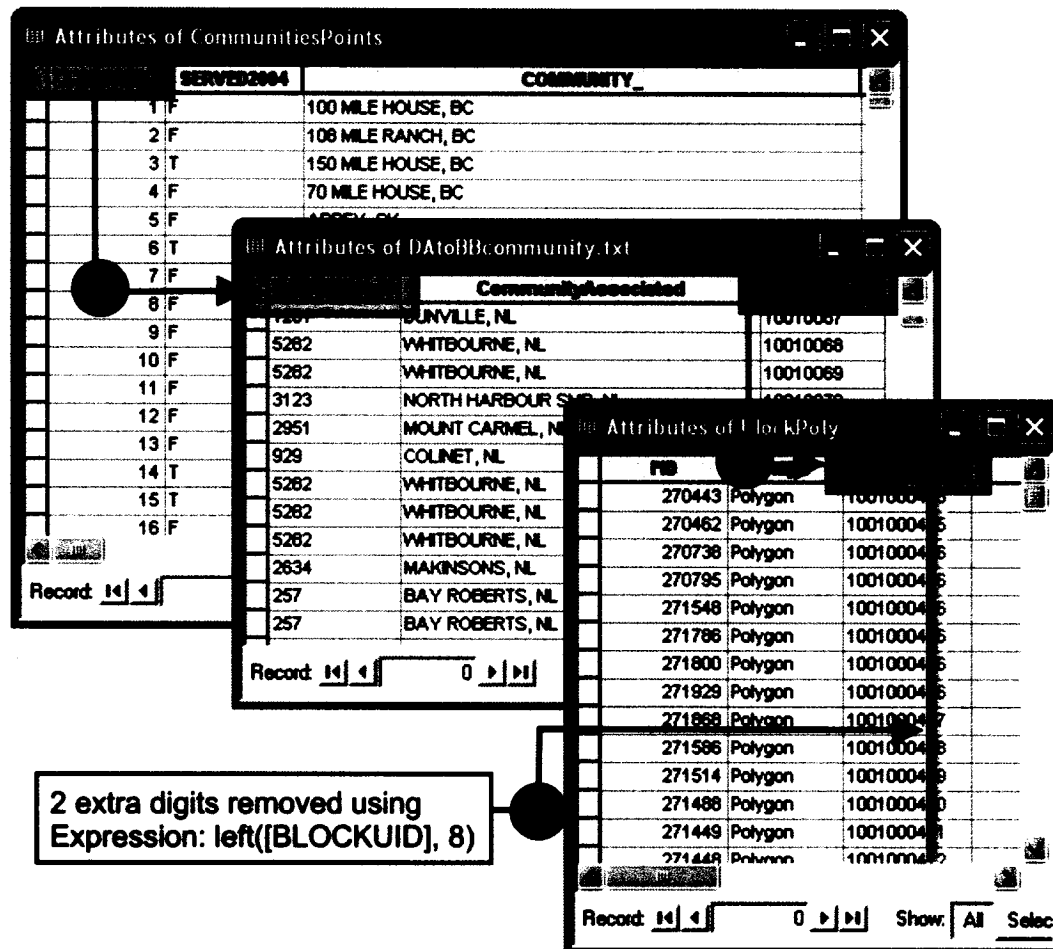


Figure 3.16. Diagram for joining the two tables provided by Gerry Briggs (Industry Canada) to the census blocks in order to represent the blocks that have access to broadband and those that do not. The first step (1) is to join the two Industry Canada tables based on the community identification number. (2) Then the two extra digits of the block identification number are then removed and the (3) dissemination areas and the block identification numbers are joined.

4. Water Bodies

Here water bodies are removed and erased from the new sub-selected block polygon layer. This step is conducted for two reasons. First, the study area contains countless lakes, many of which do not intersect the block polygon and so these lakes are removed. Second, based upon the premise that dwellings cannot be located in or on water, water bodies like rivers intersecting the block polygon are also erased (Figure 3.17). Data for this step are provided by DMTI Spatial Inc in two separate layers, major and minor water bodies and by province (a total of eight layers).

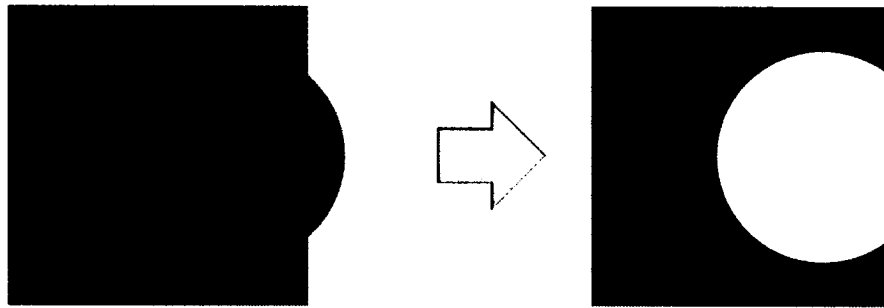


Figure 3.17. Example of a 'erase' in ArcGIS (modified version of ESRI ArcGIS 9.2 Help File).

A "select by location" is conducted where water bodies that intersect the block polygon are selected and then exported into new layers before the eight layers (provincial, major and minor) are merged into a single water layer.

Next, water bodies are erased from the block polygon. However, due to the large number of remaining water bodies within the block polygons (approximately 230,000) it becomes difficult to remove the remaining water bodies all at once without causing the system to

“crash”. Spatial software can process the large number of polygons however it is more convenient to remove them in smaller batches. As a result, the water bodies are separated into sixteen smaller layers using the program developed in Appendix G. Once separated, water bodies are then erased from the block polygons without fear of a system failure.

5. Roads

In this step, the method used to limit dwellings along roads is explained. Once the water bodies have been removed it is possible to isolate the location of dwellings based on the assumption that they are typically located near roads. As previously mentioned, this step assumes that dwellings are located within 1 kilometre of a mapped road. Therefore, this step removes areas beyond 1 kilometre from a road from the block polygon layer. This removal is done by converting the roads into polygons and then creating a union (Figure 3.18) with the remaining block polygons.

In order to minimize the number of polygons that have to be dealt with, roads are spatially selected from the National Road Network dataset (GeoBase). Roads that are within one kilometre or intersect with the block polygon from the *previous* step (Water Bodies) are selected and exported into a new layer. Next, because GeoBase distributes its road data by province, the four provincial and territorial datasets are merged into a single layer.

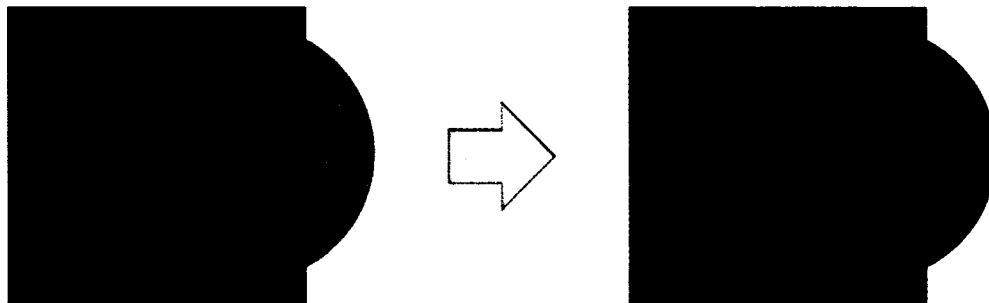


Figure 3.18. Example of a 'union' in ArcGIS (modified version of ESRI ArcGIS 9.2 Help File).

Then, to convert the remaining road segments to polygon, a 1 km buffer is created using the buffer tool; this process converts the polylines of the road into polygons (Figure 3.19). Similar to the water step (page 42), the number of road segments is numerous (approximately 320,000 segments) which results in many polygons being created. Therefore, prior to buffering the lines from the roads segments, they are separated into sixteen layers with fewer lines. This is conducted using the program developed in Appendix G. After the roads segments have been separated, they then are converted to polygons using the buffering tool.

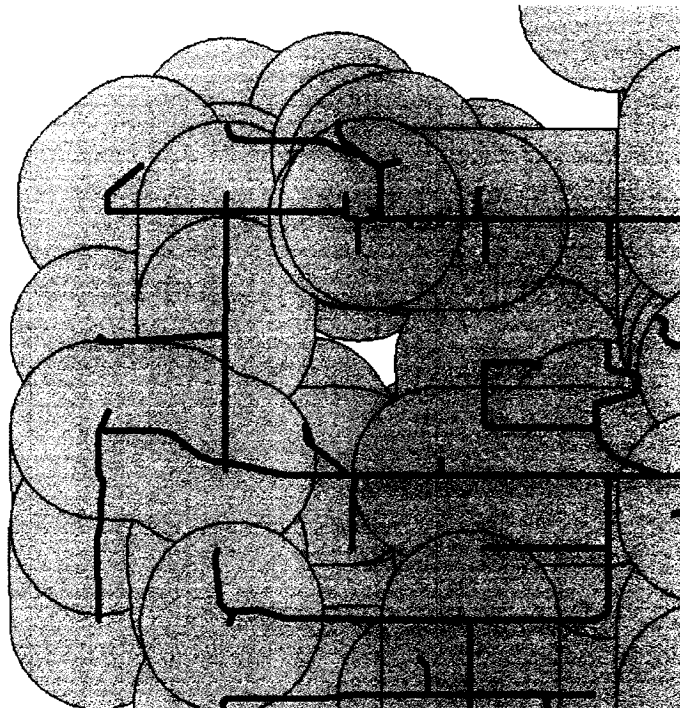


Figure 3.19. An illustration demonstrating buffering the road segments. Thus, converting them from a line to polygon.

The reason that there are so many lines in the roads data distributed by GeoBase is that they provide road data in short segments. A road segment can be as short as a street corner (e.g 10 m) or a long stretch of highway (87 km not illustrated) (Figure 3.20). Therefore to prevent the system from “crashing”, the roads segments are separated into 16 layers with fewer lines prior to buffering.



Figure 3.20. An illustration demonstrating the varying lengths of roads segments for data provided by GeoBase. The varying colour illustrates different road segments.

The buffered roads layer and the polygon block layer are then unioned. Since the roads layer has been split into 16 smaller layers they are each individually unioned with the polygon

block layer. Next the blocks are dissolved (Figure 3.21), based on their Block ID. By intersecting the buffered roads with the block polygon, only those areas along the roads are identified. Since there were 16 resultant layers, a union of the results was created before being dissolved again based on the blocks' unique identification numbers.

It became apparent during the analysis that both the GeoBase and the Statistics Canada roads data were incomplete. Although both were missing road segments, they were not missing the same segments. To ensure that the zones along the roads from both datasets were included, the process was also repeated using the Statistics Canada road data. At the end of this process both resultant maps were unioned together and dissolved based on the blocks' unique identification number (Figure 3.21). As a result, a polygon layer representing blocks with dwelling values near roadways and not in water was created.

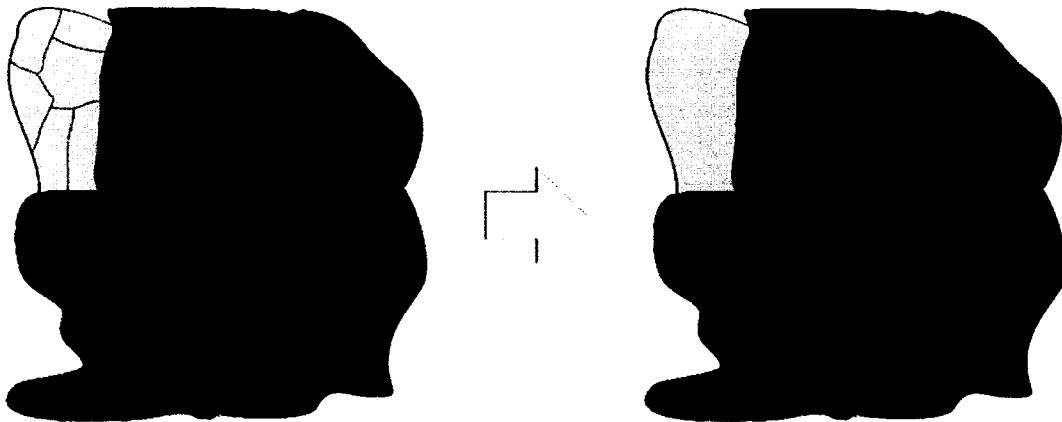


Figure 3.21. Illustration of Dissolving Polygons together based on similar values.

blocks were missing because they did not have any nearby roads. After reviewing the data these areas were identified as being remote and isolated and as a result they were selected and appended to the resultant layer. The 10 identified blocks that were not near roads were identified by conducting a “select by location” of blocks within one kilometre of roads (using both Geobase and Statistics Canada road layers) and then inverting the results. It was found that these selected polygons (census blocks) were on average 10 kilometres away from any road while two of them were approximately 40 kilometres from the nearest road. These census blocks may have had roads that were not mapped or potentially could be fly-in communities. Nevertheless, these 10 blocks were appended to the resultant block polygon layer.

6. Distributing Dwelling Values

This step explains the process of converting the irregular shapes of the block dwelling data into discrete non-overlapping 1 x 1 kilometre (km) grid cells (Figure 3.14). A schematic for distributing the dwelling values onto a regular grid is illustrated in Figure 3.22.

First, the area of each block polygon is calculated. Area is calculated in ArcGIS by creating a new field (type double) called *preArea*. Then, the area for each polygon is calculated by using the code listed in Table 3.6 the original block polygon area is needed later when calculating the number of potential dwellings in each grid cell.

Table 3.6. Formula used in the Field Calculator to populated cells with their areas.

Dim pArea as iArea
Set pArea = [Polygon]
pArea.Area

After calculating the initial area for the polygon blocks, the next part was to distribute dwelling values evenly within the 1 km polygon grid cells using a *union* overlay (Figure

3.14). However, there were many excess polygon grid cells (nearly two-million) that were not required because they did not intersect any block polygons. Therefore, to remove excess polygon grid cells, a “select by location” of the cells that intersect the block dwelling polygons was carried out. These selected grid cells were then exported into a new layer.

Then the new *grid* layer and the *block* polygon layer were unioned. Each new polygon contained the cell’s identification number, the block dwelling values and the initial area of the blocks, if applicable. Not all polygons in the union held block information because some parts of the grid extended beyond the edges of the block polygon.

After unioning the two layers together, the block polygon was broken into smaller parts (Figure 3.23) and their areas were calculated. The percentage of area that each smaller part contained from its original block polygon was multiplied with the number of dwellings within the block. These values represent the number of likely dwellings within each smaller part – again assuming that dwelling counts are distributed uniformly over the block polygon. Then each new polygon is calculated based on the formula in Figure 3.24 using a new field (type double) called *NewPop*.

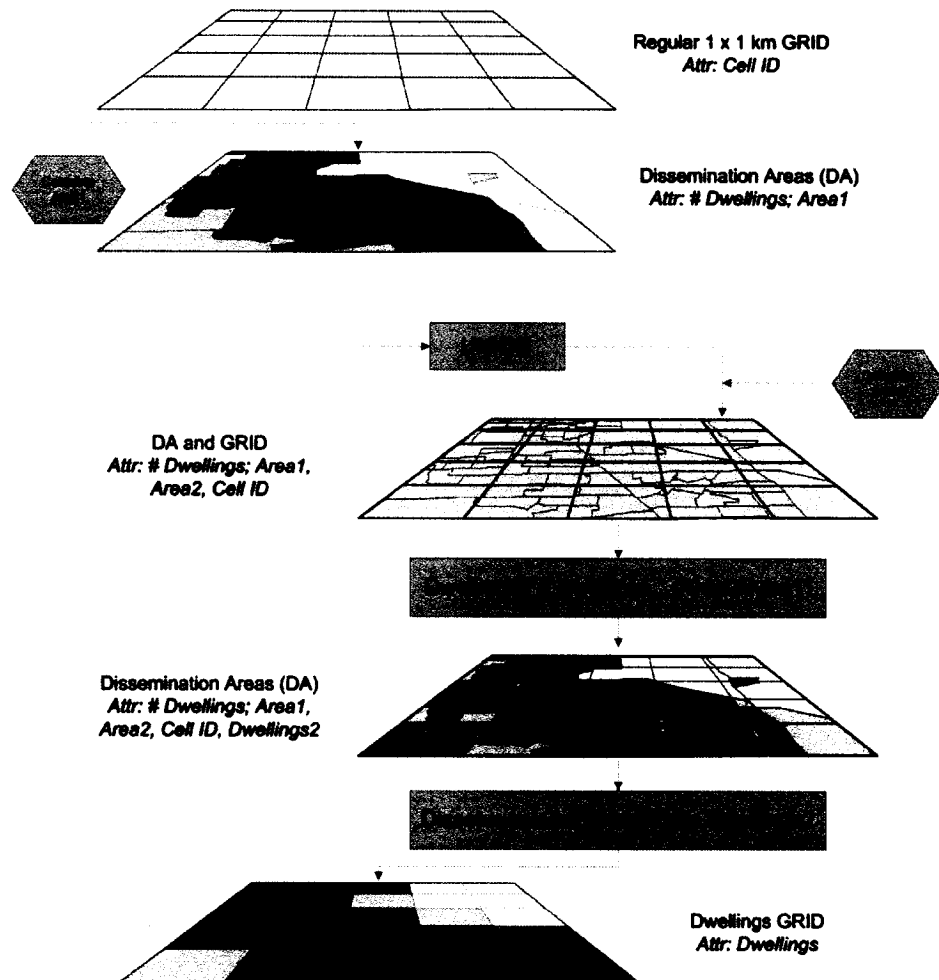


Figure 3.22. Process for deriving a regular 1 x 1 km grid of dwelling values counts from irregularly shaped blocks. This process begins once all waterbodies and rivers have been cut-out of the block layer. If the number of dwellings input equals the number in the output then the process is validated (Sawada, Cossette et al. 2005).



I

$$New_Population = \left(\frac{Area_of_the_Split_Polygon}{Area_of_the_block} \right) \times Block_Population$$

Figure 3.24. Formula for calculating the likely population based on area.

The population of each polygon grid cell is calculated by summing the *New Population* from each block polygon part contained within its area (Figure 3.25). This is conducted by dissolving each block polygon into a 1×1 grid based on the unique identifier from the polygon grid cells.

To ensure that the total number of dwelling in the derived dwelling layer is consistent with the number of dwellings that was initially input into the system a comparison was conducted. Using the statistics function from ArcGIS. Both the layers had an identical number of dwelling values.

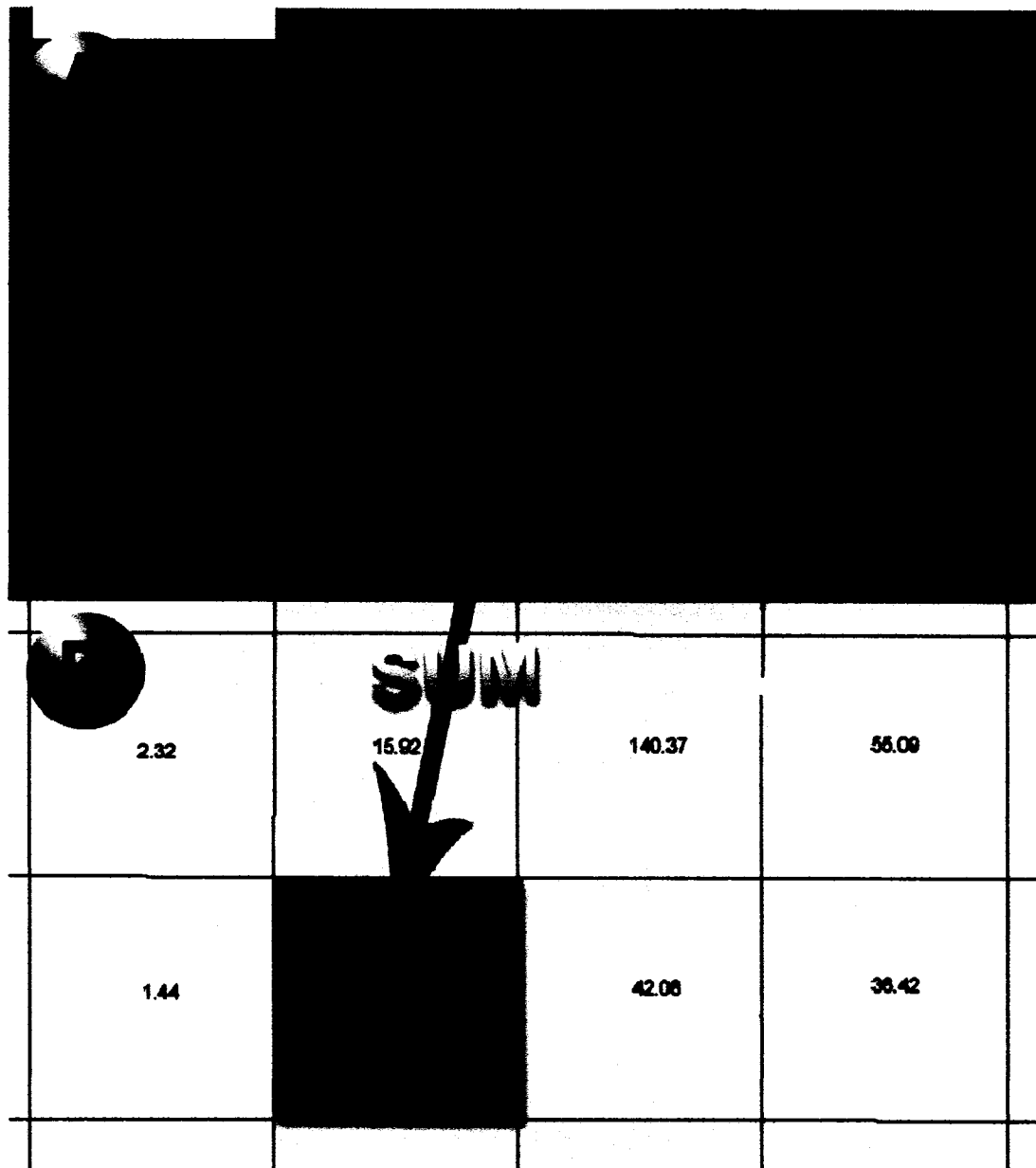


Figure 3.25. Illustration of dissolving and summing the values together for a polygon grid where the numbers represent the potential number of dwelling located within (A) that shows the block polygon broken in smaller parts and (B) that illustrates the dissolved block polygons into a regular grid with the summation of the values.

6. Distributing Dwelling Values

The final step for distributing the dwellings values was to convert the polygon into a raster grid. The Spatial Analyst option's were set to have the same extent as the derived elevation raster, and a cell size of 1 km. The resultant raster is illustrated in Figure 3.26.

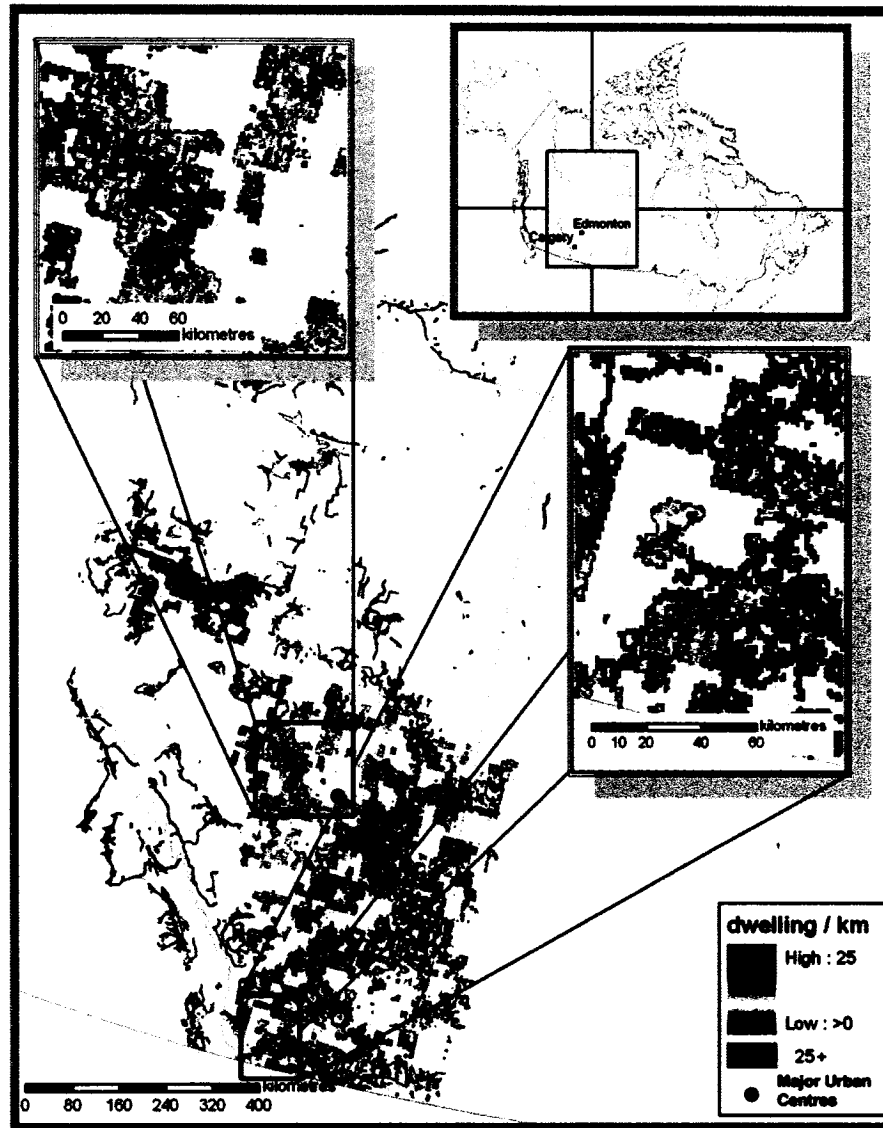


Figure 3.26. Raster representing dwellings without broadband access in and around Alberta.

3.5 Identification of Significant Areas

Although, the spatial data that are created in this section are not directly utilized in the study, they are used in the development of data for identifying locations of possible communication towers. This stage aggregates the data from various data providers in order to identify environmentally significant and protected areas in Alberta. A schematic of the procedure is shown in Figure 3.27, and the data providers are listed in Table 3.7.

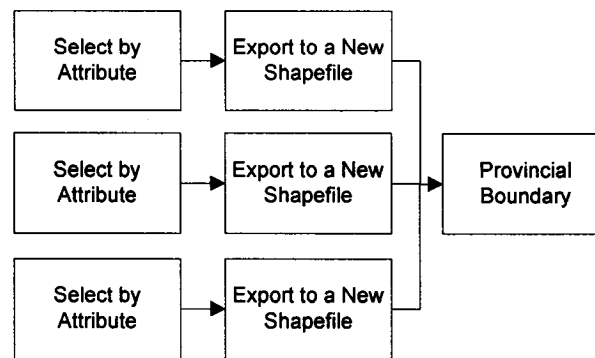


Figure 3.27. Schematic for creating spatial data of significant areas in Alberta.

The method for creating a single layer of significant areas in Alberta is straightforward; select the significant areas and then union them into a single layer. Table 3.7 lists the dataset as well as a record of the significant areas that were utilized. Note that not all of the significant areas were retained because some would have created duplicates when combined with other layers. A map of the resultant layer is illustration in Figure 3.28.

Table 3.7. Data utilized for creating a single layer of all significant areas in Alberta as well as the areas that were retained from each of the parks.

Environmental Significant Areas of Alberta provided by the Alberta Government			
Area's Retained	Whooping Crane Nesting Habitat	Egg Island Ecological Reserve	Peace Athabasca River Delta
	Coyote Lake Natural Area	Bow Valley Provincial Park	Writing-on-Stone
	Bow River – Calgary to Siksika Reserve	Lessard Creek Peat Plateau Bog	Genessee Natural Area
	Bistcho Lake Peat Plateau Bog	Milk River Ridge	Beauvais Lake Provincial Park
Alberta Crown Reservations (conservation areas) provided by the Alberta Government			
Area's Retained	Alberta Beach	Frog Lake Heronry	Mt. Tecumseh
	Anton Lake	Gooseberry Lake	North Ram-Nice...
	Armstrong Lake	Hawk Hills	Oxville
	Battle River	Hindville	Pembina Bigoray
	Bear River	Hollow Lake	Perryvale
	Big Sagebrush	Hot Pot	Pinhorn
	Brazeau Tufa	Irish Creek	Ponton River
	Burning Sulphur	Jackpines	Poplar Creek
	Campsie	Kimiwan Lake	Primula
	Cardinal Divide	Kleskun Creek	Primula
	Caribou River	La Saline	Pringle Mountain
	Carseland	Lac Tremble	Schrader Creek ...
	Clearwater River	Lake of the Falls	Sounding Lake
	Clyde Fen	Lasthill Creek	Tawatinaw River
	Coyote Lake	Willow Creek	Torlea
	Dunvegan	Little Smoky Iosegu	Vermilion Lake
	Eagle Creek	Lomond	Viking
	Eagle Nest	Lorraine	Wabamun Lake
	East Porcupine	Macintosh Lake	Watt Mountain
	Edgerton	Majeau Lake	West Stony Creek
	Fairydell Creek	Monitor	White Earth Valley
	Fort Sask. island.	Mount Butte	
Parks and Protected Areas provided by the Alberta Government			
Area's Retained	All of the parks and protected areas were kept because the data includes Ecological Reserves, National Parks, Natural Conservation Area's, Provincial Parks, Provincial Recreation Area's, Wilderness Park and Wildland Provincial Park.		

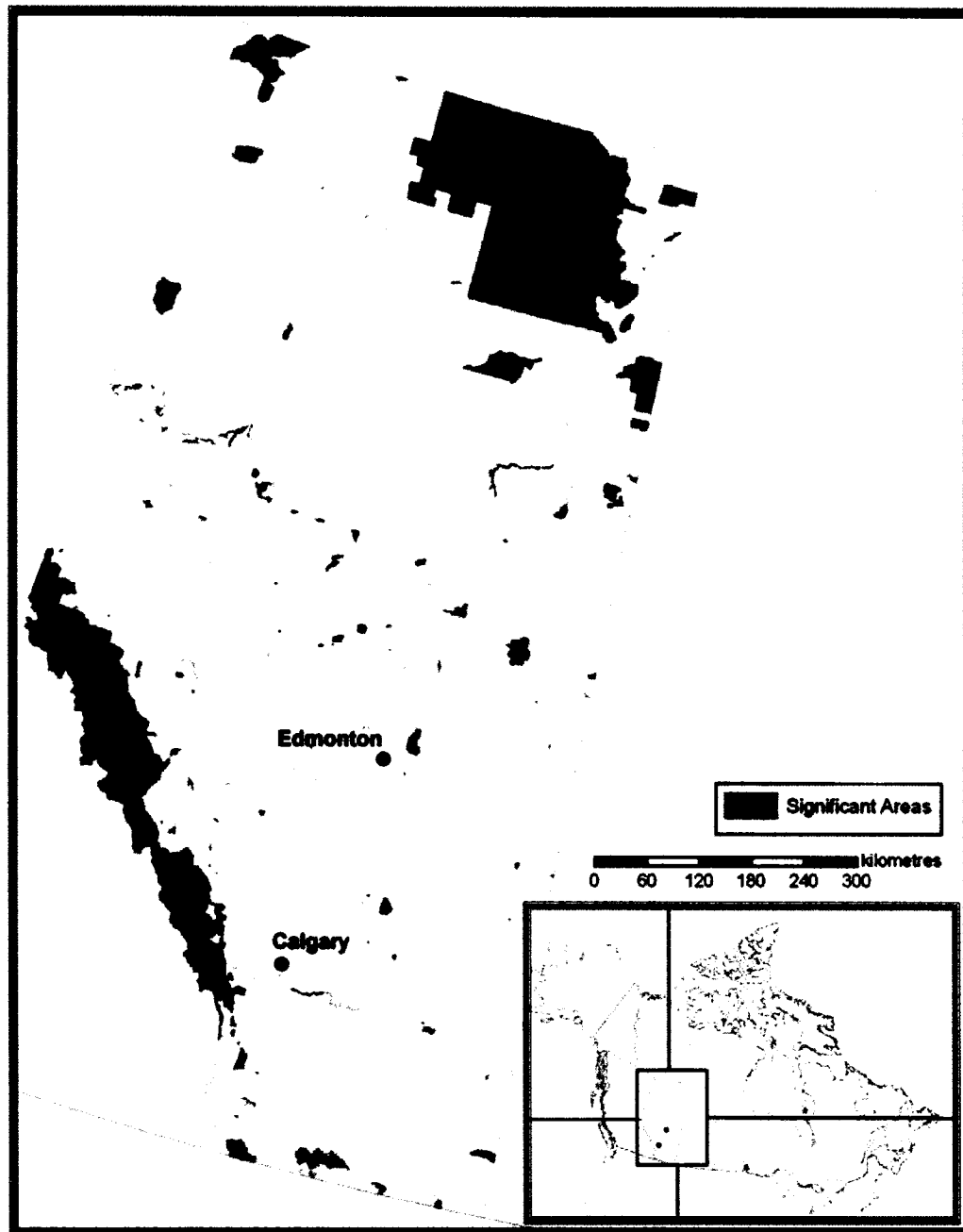


Figure 3.28. Map of areas considered significant for Alberta.

3.6 Identifying Potential Tower Sites

This section describes the process of identifying potential tower sites. Potential towers are located at the centre of the polygon grid cells created in the previous section. To model the data, we spatially select grid cells within Alberta and then areas where towers cannot be constructed are removed (erased). In the section “identification of dwelling locations” (page 36), the location of possible dwellings extended beyond the Alberta limits (excluding the USA) however, in this section, we only identify tower locations within Alberta. The procedure is outlined in Figure 3.29, while the required spatial data are listed in Table 3.8.

The premise upon which potential tower sites are modelled is that they cannot be built in parks, conservation areas and other environmentally or protected areas. Additionally, towers cannot be located within water bodies. These inappropriate areas are removed as potential tower sites.

Table 3.8. Required data for creating a point file of possible locations for tower in the study area.

Spatial Data Name	Provider
Boundaries for Canadian Provinces	ESRI
CanWater Major Water Bodies	DMTI Spatial Inc
CanWater Minor Water Bodies	DMTI Spatial Inc
Derived Polygon Grid	Not Applicable
Derived Significant Areas of Alberta	Not Applicable
2005 Road Network File	Statistics Canada
National Road Network	GeoBase (Natural Resources Canada)
Derived Elevation Raster	Not Applicable

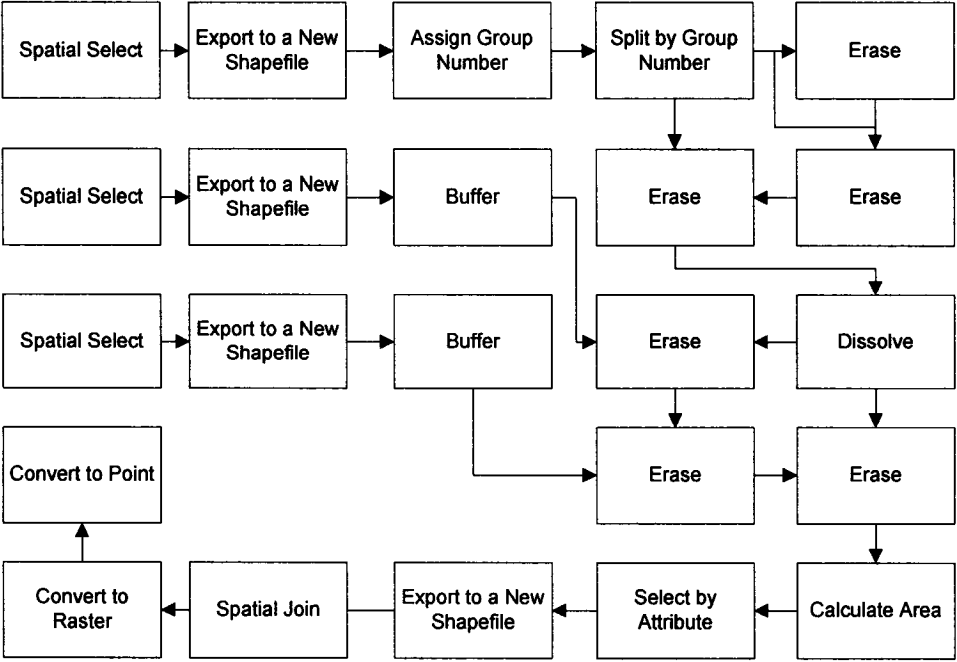


Figure 3.29. Procedures for creating a point layer for possible tower locations in Alberta.

The process begins by isolating the polygon grid cells within Alberta. These polygon grid cells that intersect the provincial boundary of Alberta are spatially selected and exported into a new layer. Next, the major and minor water bodies are erased (Figure 3.17) as potential sites. For efficiency, the polygons' major and minor water bodies were separated into layers with fewer polygons. The devised program in Appendix G is utilized to split the polygons. Once separated, the unlikely sites are erased from the polygon grid.

During the erasing process, some of the remaining polygon grid cells were broken and split apart, they were dissolved back together based on their unique identification numbers.¹⁷

¹⁷ Polygon grid cells were assigned a unique identifier using the spatial index in the Polygon Grid Creation stage.

After removing the water bodies as potential sites, the significant areas of Alberta had to be erased. Prior to eliminating these significant areas, the fact is that there are dwellings located within some parks, such as Banff and Jasper. To account for this reality, towers were permitted to be located with 1 km of the roads. Therefore, a 1 km buffer along the roads was erased from the significant area data. This was achieved by selecting roads that are either located within 1 km or contained within a significant area (Figure 3.30a). These selected roads were then exported into a new layer. A 1 km buffer along these roads was created (Figure 3.30b), which was then erased from the significant areas of Alberta (Figure 3.30c). The result is a dataset of the significant areas with the buffered roads erased.

With the roads within significant areas erased, the significant areas can be erased as potential tower locations. Once erased, the polygon grids were dissolved back together based on their unique identification number.

Potential tower sites must have enough area available for construction of a tower. Therefore, the next step removed polygon grid cells that lacked the necessary area in which to construct a communication tower. All polygons whose available area for a communication tower was less than 30% of the cell's total area were deemed inadequate and removed as possible tower locations. In order to remove inadequate cells, a new field (type double) was created and the areas were calculated (Table 3.6) Cells that had an area more than 0.7 km^2 were selected by attribute and exported as a new layer.¹⁸

Although key elements of the model have been executed the location of possible tower sites must be converted from polygon grid cells to a point type dataset for the LLS, and to a raster for the ULS.

¹⁸ Less than 10,000 cells of the total 576,451 remaining cells were removed. To reiterate, approximately 1.7% of the remaining cells had insufficient areas.

The process to convert a polygon layer to a raster requires two steps. First, the attribute table of the polygon grid is linked to the original polygon grid based on the unique identification numbers. Only the matching polygon cells are retained, exported into a new dataset, and then converted into raster.¹⁹

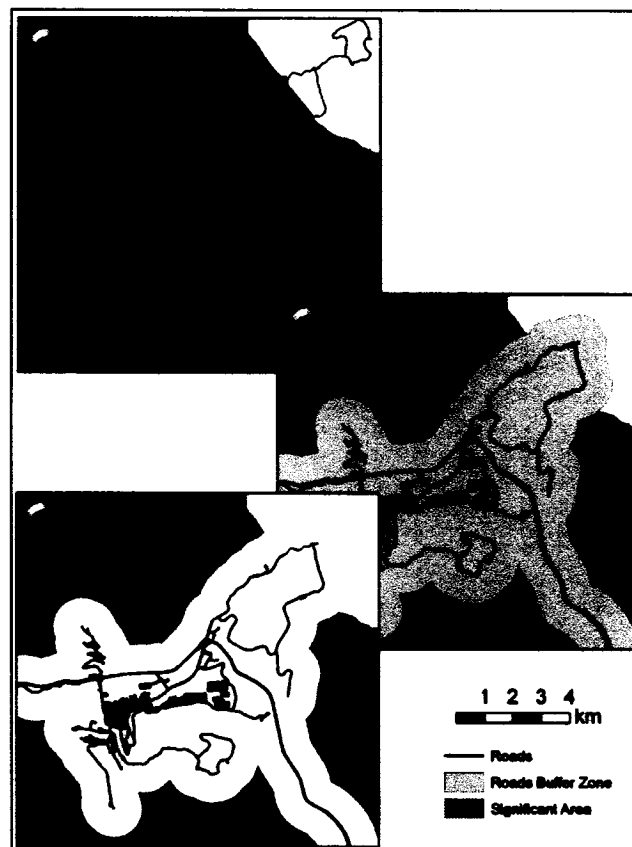


Figure 3.30. The process to identify potential tower sites within significant areas. (A) Roads located within a significant area; (B) A 1 km buffer applied to the roads; (C) The new boundaries of the significant areas with the 1 km buffer erased.

¹⁹ One could convert the polygon directly to raster but then there is the risk that not all of the potential tower sites might be converted to raster because they are no longer perfect squares.

To create the point dataset, the raster is converted to a point dataset where the raster cell size is 1 km and the extent is equal to the derived elevation raster. The resultant point map representing potential tower sites is illustrated in Figure 3.31.

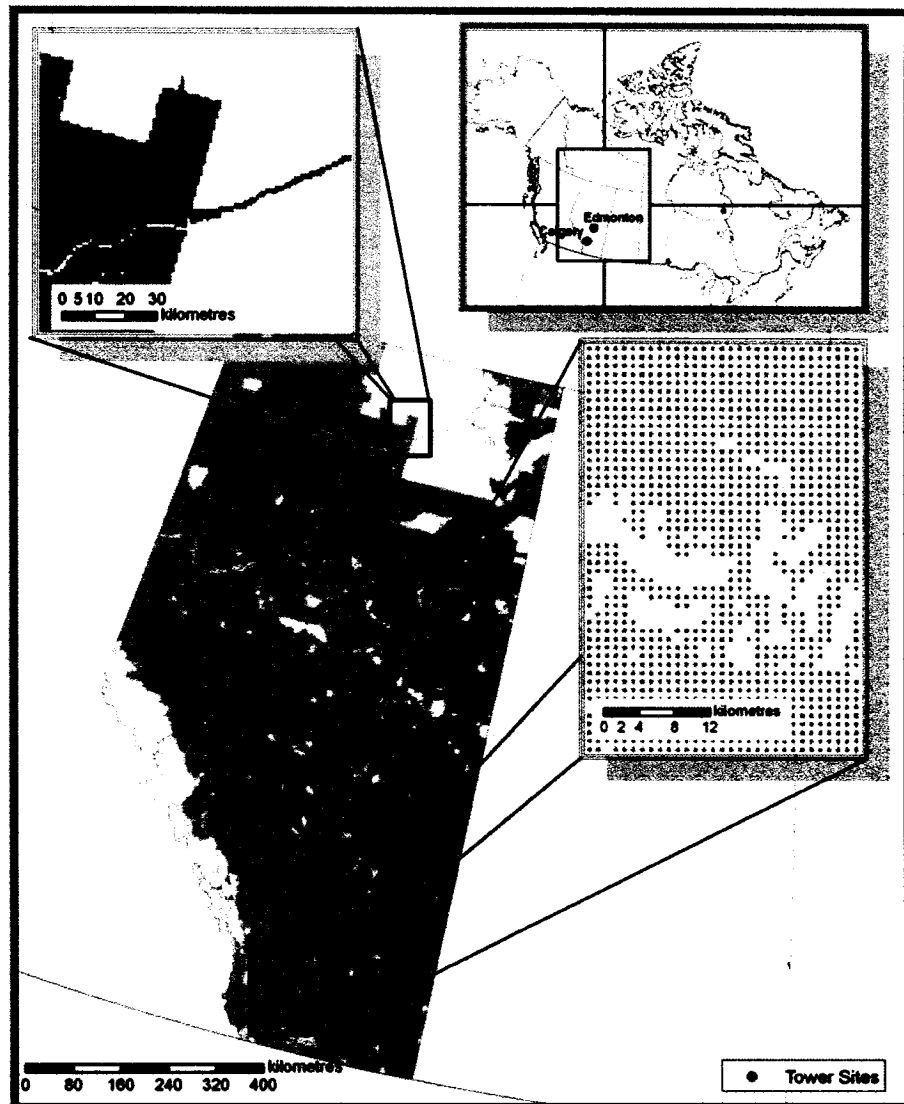


Figure 3.31. Resultant point map of possible tower locations.

3.8 Review

This chapter has described detailed procedures for the development of the three required datasets for the Coarse Resolution Analysis (1×1 km). The developed data for the analysis includes the location of potential towers sites, the location of dwellings and an elevation raster. However, other data such as a polygon grid and the identification of significant areas had to be developed in order to create the aforementioned data. The data developed in this chapter were used for both the upper and lower limit scenarios.

4

Data Modelling: Fine Resolution

4.1 Overview

The previous chapters detailed the procedures used for the Upper Limit Scenario (ULS) and Lower Limit Scenario (LLS) as well as the models and procedures for developing the data for the Coarse Analysis (CA) (1 km resolution). While the coarse analysis (CA) provides a sufficient broad-scale overview of where potential wireless broadband services could be deployed, the accuracy of the CA is limited. By using higher resolution data and comparing the results, we can demonstrate the degree of reliability for the CA study. In order to validate the CA, a regional subset of the study area (Alberta) is examined using higher resolution spatial data. This chapter outlines the methods undertaken to produce the 90×90 m resolution data to be used in the Upper Limit Scenario (ULS) and the Lower Limited Scenarios (LLS) described in Chapter 2 so that a comparison can be conducted between the

1 km and 90 m resolution analyses. This chapter outlines what is hereto referred to as the fine analysis (FA).

This chapter describes the two models employed to identify the location of dwellings within the study area. One model, called the general dwelling approach, follows the same methods as those found in Chapter 2 for isolating dwellings. The second model, the detailed approach, more accurately estimates where dwellings are physically located (Figure 4.1).

There are two major sections to this chapter. The first section describes the slight methodological modifications done to create the necessary datasets used in the scenarios at the 90m resolution, as well as the model of the general dwelling raster. The second section describes the model utilized to create the detailed dwelling raster. Both FA approaches involve the same potential tower sites for ease of comparison between the FA general and FA detailed approaches.

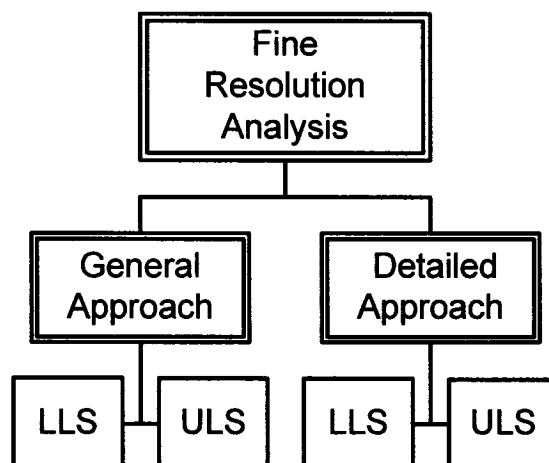


Figure 4.1. An organization chart of the two dwelling approaches general and detailed that are conducted with the fine resolution data.

4.1.1 FA Region Subset

When the resolution increases, the processing time for the lower limit scenario also increases. In fact, the processing time for the scenario increases substantially every time the resolution of analysis is increased. Therefore, the area for the FA subset was selected based on the same number of tower sites that were processed in the CA (304,806 tower sites). The area formula (Equation 4.1) is used to calculate the area of the bounding box.

$$\text{length} \times \text{width} = \text{Area} \quad (\text{Equation 4.1})$$

When the area is 575,944 cells (1×1 km cells), the length of the subset was then calculated to be 759 cells (68.3 km) wide. However, this area (68.3×68.3 km) was deemed to be slightly small and was instead increased to cover an area of 100×100 km. The area of the FA subset was adjusted because the number of computers that were available to process without interruption had increased from 35 computers to 90. Therefore using Equation 4.2 it was calculated that there would be a maximum of 1,234,321 sites to process if every location within the subset had to be examined.

$$\left(\frac{\text{Width}}{\text{Resolution}} \right)^2 = \text{Maximum number of tower sites} \quad (\text{Equation 4.2})$$

where the width was 100 km and the resolution was 90 m.

With the increased access to computers, it would take approximately 2 days on 90 computers to carry out a 50 km LLS based on the fact that the LLS for CA at 50 km took on average 3.5 seconds per point to process. However, these calculations are nothing more than estimates because of the increased resolution (90 m) and the increase number of cells to be examined.

Even with the increase in processing time, the FA analysis was not unmanageable. Therefore, a 100×100 km area was used for the FA subset. The region in which to place the 100×100 km box was selected based on topography and the varying dwelling distribution. The dwelling population in the FA region varied from concentrated to sparse dwelling distributions (Figure 4.2).

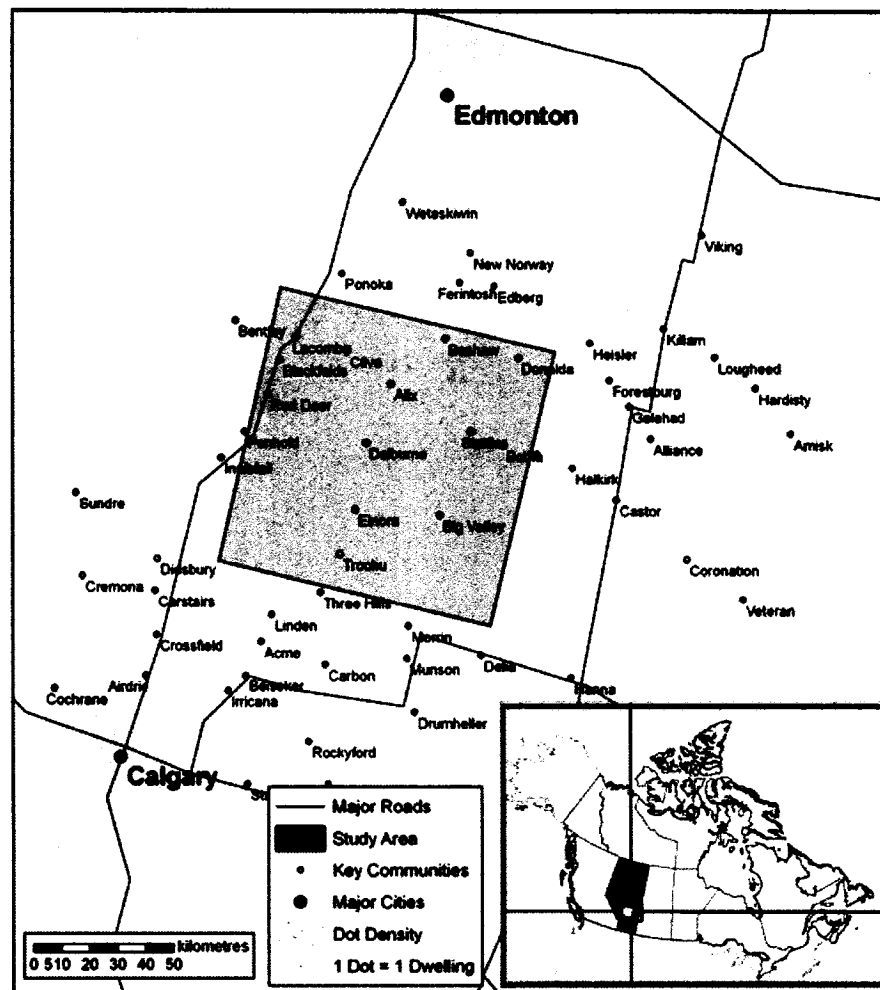


Figure 4.2. The location of the sampled study area with a 60 km buffer for examination at high resolution.

4.2 Modifications to the Datasets and the General Dwelling Approach

This section describes the slight changes that were carried out in order to create the necessary data for the FA analysis: elevation raster, polygon grid, general dwelling raster, significant areas and possible tower sites. The sections are ordered in the same manner as chapter 2.

4.2.1 Development of an Elevation Raster

The original Level 1 elevation data (CDED Level 1) acquired through the GeoBase portal has a resolution of 90 m.²⁰ Therefore, to make the DEMs consistent, they were reprojected to 90 m using bicubic resampling. Second, to display the sample study area as well as a 60 km buffer zone (Figure 4.3) and not the entire province of Alberta, the ArcGIS Spatial Analyst options were set with a SW bounding coordinate of -116°W 50°N (Figure 4.3).

²⁰ The CDED Level 1 dataset is disseminated with a raster resolution of 3 decimal seconds, and in this region represents approximately 90 m in the y component and 30-60 meters in the x component depending on latitude. As a result, there is some generalization that takes place in the 90 m DEM when it is projected, however, the amount of generalization is far less than in the CA.

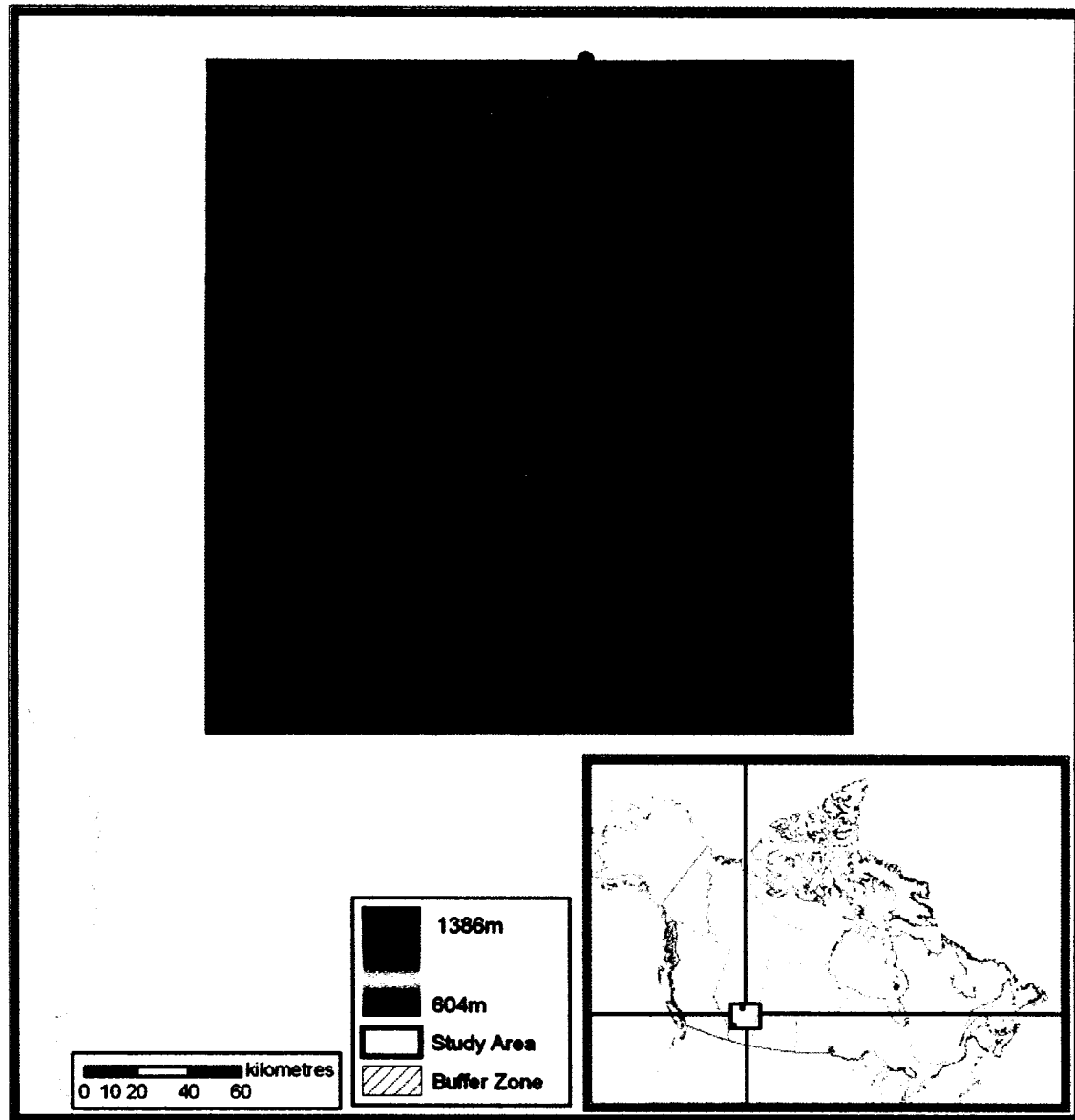


Figure 4.3. The resultant elevation raster used in the upper and lower limit FA scenarios.

4.2.2 Creation of the Grid Network for Alberta

For analytical convenience, during the creation of the 90 m vector polygon grid, the location and cell size were chosen to be identical to the newly generated elevation raster. Please refer to Chapter 2 (page 33) for more details as to the methods used in the creation of the polygon grid.

4.2.3 Dwelling Distribution

In order to distribute dwelling values in the study area, the only adjustment made was to the census blocks. In the CA process (page 36), dwellings located in provinces surrounding Alberta are also identified and located in the dwelling values. Therefore census blocks that are located within 60 km of the sample region are also included in the FA. Census blocks beyond the 60 km buffer are removed from the analysis in order to expedite processing. The resultant *general dwelling raster* is illustrated in Figure 4.4.

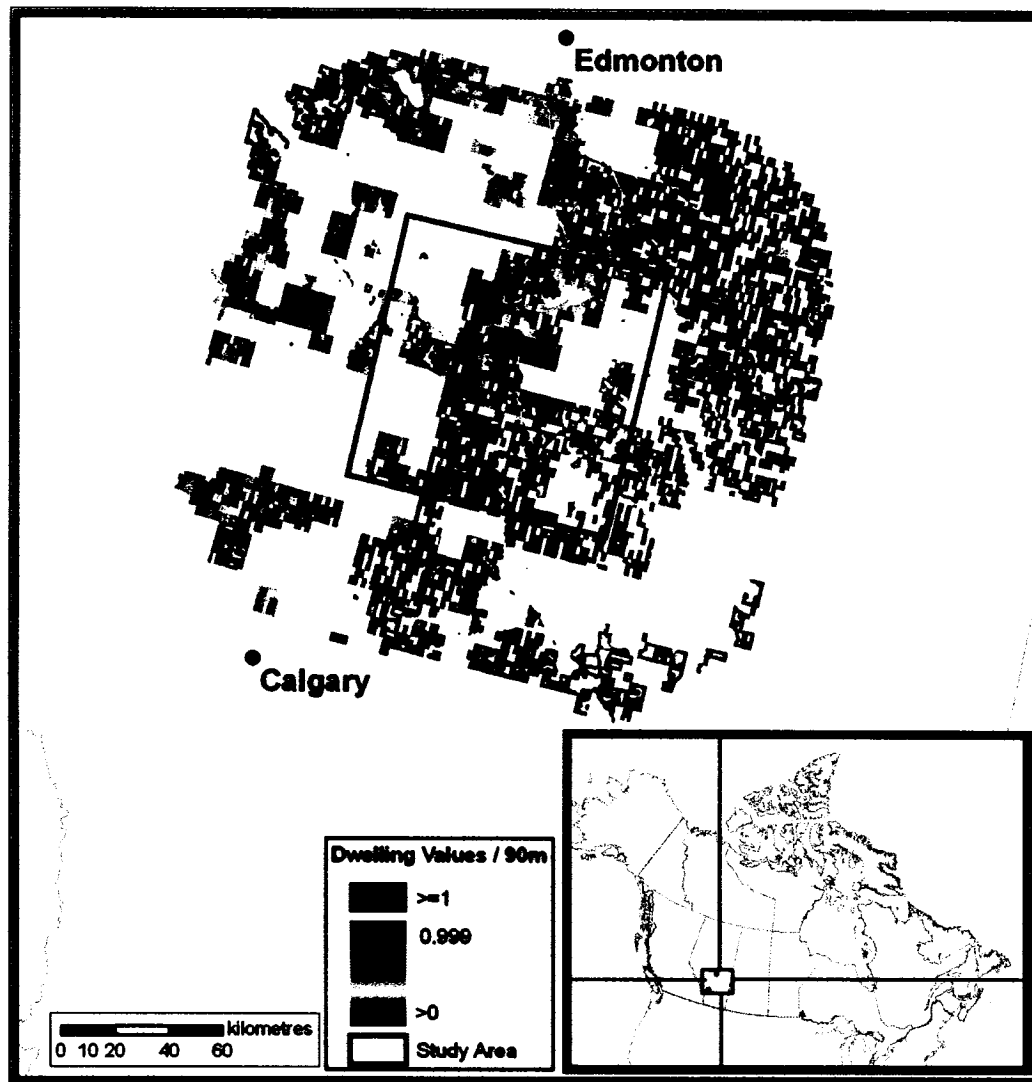


Figure 4.4. The resultant general dwelling raster at a 90 metre resolution.

4.2.4 Identification of Significant Areas in Alberta

To identify significant areas²¹, the same polygon utilized in Chapter 2 (page 54) was applied to the study region. Therefore no changes were applied to this data.

4.2.5 Possible Tower Locations

The method for identifying potential tower sites is slightly altered for the FA. As in the CA, identifying possible tower sites is accomplished by removing areas where towers cannot be located. Therefore, in the high resolution process more datasets were utilized to help eliminate more areas where towers could not be placed and thus reducing the total processing time.

Some of the datasets used to eliminate unlikely tower sites contained either points or lines such as railways and churches. For each data type, an exclusion zone was applied. These datasets and their exclusion zones are listed in Table 4.1 while Figure 4.5 illustrates the resultant point layer.

The minimum exclusion zone size in Table 4.1 is always 90 m, a full raster/vector cell. In some cases, the coordinate of a point or line feature's exclusion zone may intersect more than one cell and in such situations these cells are eliminated as possible tower locations. These cells are excluded because a tower cannot be placed at these particular locations.

²¹ For this thesis 'significant areas' include areas where development is highly controlled such as a National and Provincial Parks, Conversation Area's and other areas set aside for special reasons to protect wildlife and natural habitats.

Table 4.1. Data utilized for identifying where tower locations cannot be situated and the area surrounding these locations that are also excluded.

Description of Dataset	Distributor	Data Format / Exclusion Zone
Buildings	NR Can	Point (not excluded)
Industrial (Petro Well & Liquids Depot)	NR Can	Point (100m radius)
Grain Elevator	NR Can	Point 100m radius
Arena	NR Can	Polygon (10m radius)
Churches	NR Can	Point (20m radius)
Transmission Line	NR Can	Line (25 (50m wide)
Industrial (Tank: Vertical)	NR Can	Point (25m radius)
Grain Elevator	NR Can	Polygon (30m buffer)
Rail station	NR Can	Point (40m radius)
Airfield	NR Can	Polygon (50m buffer)
education	NR Can	Point (55m radius)
Watercourse	NR Can	Line 5m (10m wide)
Pipeline	NR Can	Line 5m (10m wide)
Railway	NR Can	Line 5m (10m wide)
Roads	NR Can	Line 7.5 (15m wide)
Highway	NR Can	Line (140m wide)
Embankment	NR Can	Polygon (Entire)
Recreation And Amusement (Cemetery, Exhibition ground, park/sports field)	NR Can	Polygon (Entire)
Industrial (auto wrecker, solids depot / dump, mining area)	NR Can	Polygon (Entire)
Water body	NR Can	Polygon (Entire)
Wetlands	NR Can	Polygon (Entire)
Expressways Casements	NR Can	Polygon (Entire)
Secondary Highways Casements	NR Can	Polygon (Entire)
Primary Highways Casements	NR Can	Polygon (Entire)
Major Roads Casements	NR Can	Polygon (Entire)
Education	NR Can	Polygon (Entire)
Crown Land	NR Can	Polygon (Entire)
Minor Water Bodies	DMTI Spatial Inc	Polygon (Entire)
Major Water Bodies	DMTI Spatial Inc	Polygon (Entire)

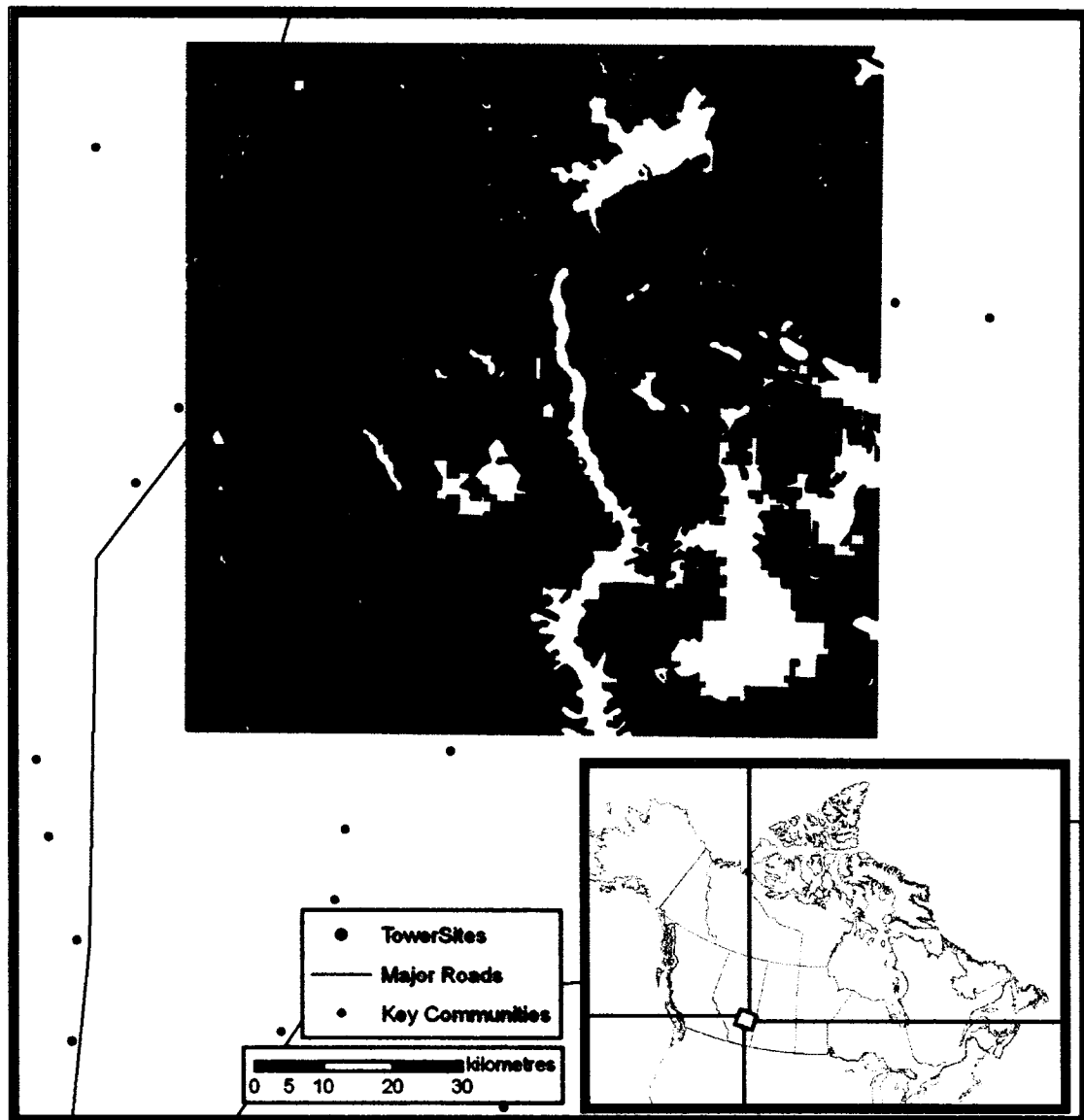


Figure 4.5. The resultant layer of possible tower sites at a 90 m resolution.

4.3 Development of the Detailed Dwelling Distribution Layer

Dwelling counts are a logical subscription unit for Broadband Wireless Access (BWA) providers. A dwelling represents the location of the client's wireless antenna. Ideally, for a more accurate analysis the location of each dwelling should be known. Unfortunately due to confidentiality, Statistics Canada does not reveal the precise locations of dwellings within a Census Block - only the total number of dwellings. In Chapter 2, the number of dwellings in each 1 km raster cell was determined by spatial intersection of the block data polygons with the grid polygons. This is sufficient for the CA because of the scale of interest. However, with the finer resolution analysis (FA) (90 m), blocks that are larger in area will not accurately represent the locations of dwellings to the spatial precision required. Therefore, National Topographic Database (NTDB) 1:50000 map sheets for the FA sample study area were used to identify the location of dwellings. However, the number of dwellings within Census Blocks from 2001 does not always correspond to the number of buildings within the NTDB data for the following reasons:

1. Dwelling counts are from 2001, whereas the NTDB building data range in date from the 1970's to the 1990's; and
2. There can be more dwellings than there are buildings simply because some buildings (e.g., apartments, condominiums etc.) contain more dwellings in one structure.

Therefore, the detailed dwelling distribution layer was derived via automated and manual methods, including the use of building points and other datasets in addition to the close inspection of approximately 4000 census blocks. Using data provided by Natural Resources Canada and Statistics Canada, a more spatially accurate dwelling distribution raster was devised for use in the upper and lower limit scenarios.

The process for identifying dwelling locations within each 90 m cell for the FA involves a comparative analysis between the dwelling counts and the number of buildings. Census blocks with dwelling counts equal to the number of buildings were assumed to be correct. In these situations the building locations (points) are substituted for the census block dwelling counts and then the number of buildings (dwellings) within each 90 m cell is determined. Those census blocks whose dwelling counts are not equal to the number of buildings are manually inspected. Due to the physical location of the sample study area, in rural and remote areas of Alberta, it is likely that extra building points are actually barns, silos and other farm buildings. This incites the need for inspecting and adjusting the data. In most cases removing two or three buildings produced block-dwelling equivalency.

Some census blocks had fewer buildings than dwelling counts. In instances when building types were unknown and the dwelling counts were greater than the number of buildings, the dwelling values were redistributed. An alternative method for distributing dwelling values is similar to the dwelling distribution methods used in Chapter 3, except more data were used to isolate dwelling locations. The dwellings were distributed within the remaining area of the block using the same approach as presented in section 3.4 Identification of Dwelling Locations (page 36).

For the remainder of this chapter, the process by which the dwellings are distributed is described. The process is presented in smaller steps. A schematic of the process is illustrated in Figure 4.6, and the data utilized are listed in Table 4.1.



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Preparation of the Census Blocks

Only census blocks within 60 km of the study area were selected in order to reduce the time involved in preparing the data and also discards of blocks that not required.

Preparation of the NTDB Data

The data from the NTDB provided by Natural Resources Canada were merged together based on similar types of data (e.g., all building points, railway lines, etc.). Merging the 1:50,000 (approximately 35 x 35 km wide) layers did not affect any of the results as they are designed to edge match.

Identifying Appropriate Building Points

A Point-in-polygon analysis is conducted between the building points and census blocks layer in order to compare the number of building points that are located within each polygon. The difference is then calculated between the number of building points and dwelling values of the census block. From there each census block is examined based on the difference in dwelling values.

If the number of building points within a census block polygon is the same as the dwelling value, it is assumed that the buildings are all dwellings. Therefore, the points within these census blocks are selected and exported into a layer called buildings. In situations where census blocks have more building points than are listed in the census data, the blocks are individually examined and adjusted. Detailed methods of the adjustments are provided in the following section called Correcting for Excess Building Points. Conversely, when there are fewer building points than there are dwelling values, similar methods were utilized in the distribution of dwellings as outlined in Chapter 3 (page 36). However, here, more data (e.g., railway, transmission lines) are utilized to eliminate locations where a tower cannot be

located. The methods undertaken to correct for too few building points are detailed in Alternative Dwelling Distribution (page 80) while Figure 4.7 outlines a schematic of the methods undertaken to identify dwelling locations in a detailed manner.

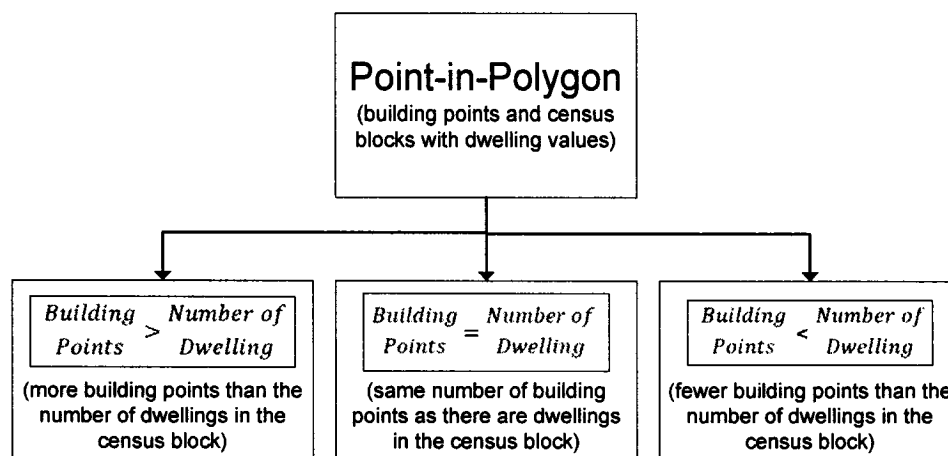


Figure 4.7. The three methods in which the location of dwellings are identified and processed based on the number of building points are located within a census block.

Correcting for Excess Building Points

Census blocks that have a surplus of buildings are individually examined and adjusted by removing excess building points. For example, in some census blocks there are supposed to be only two dwellings located within the polygon, yet there could be four building points but represented as two clusters of two buildings each (Figure 4.8). Each cluster was considered to be one dwelling and thus one point from each cluster was removed in order to match the census block dwelling value. This correction is conducted because the NTDB building points data also contains barns and others types of structures that can typically be located in and

structures that can typically be located in and around a dwelling. After manually inspecting the census blocks and correcting the number of building points, the points were exported into a new point layer.

It is possible that the above methods introduced some errors into the analysis because the method assumes that clusters are one household. However, the census blocks that were examined were typically only a few kilometres wide and would be negligible in the overall analysis.

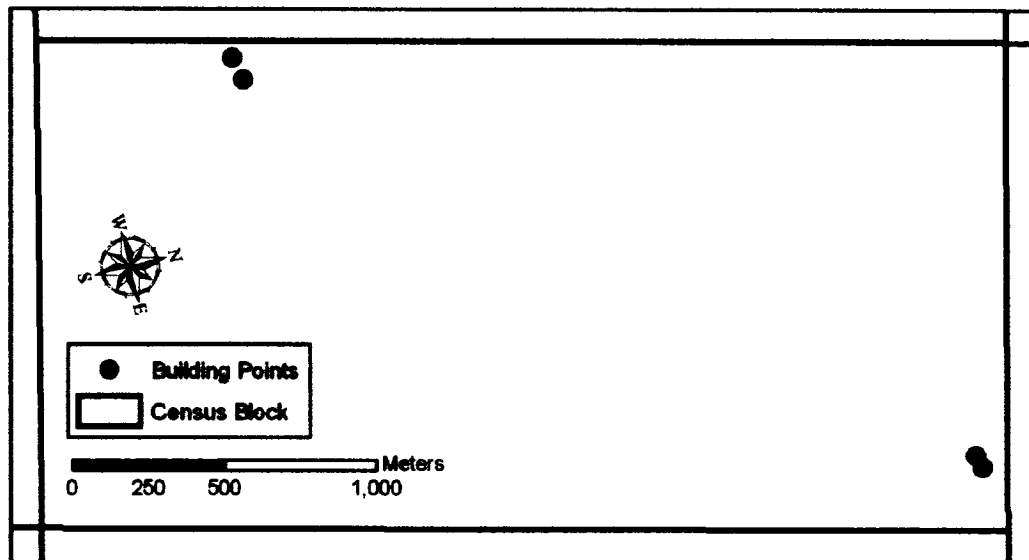


Figure 4.8. Illustration demonstrating an excess of two points when the required dwelling value of the census block is two, not four.

Convert Building Points to Raster

The two building points layers (*building1* and *building2*) had to be converted to raster. It was conducted by first merging the two building points layers together. Then, using the 90 m polygon grid, a point-in-polygon operation was undertaken to count the number of buildings

before being converted to raster. The results of this process were then set aside to be later merged with the results of the alternative dwelling distribution approach.

Alternative Dwelling Distribution

For census blocks with a greater number of dwellings than building points, a method similar to that in Chapter 3 (page 36) was employed. The difference for the FA analysis here was the utilization of more data to remove areas where dwellings cannot be located. Using the 29 datasets listed in Table 4.1, areas were erased from the census blocks. Not all data are polygons, some of them are lines (e.g., railway, transmission lines) while some are points (e.g., education, liquid depots), therefore these 0D and 1D features were assigned a buffer. Buffers were used as both zones of inclusion or exclusion around the features. The assigned exclusion zones are listed in Table 4.1.

Therefore, with the remaining census blocks, data such as rail lines, transmission lines, and grain elevators were erased from the census blocks. Then, dwelling values were distributed within a 180 m of a road after having erased the width of the road from the buffer (180m + 7.5m already buffered). A 180 m zone is used because, while conducting the manual correction to the number of building points, it was rare to find buildings located further than 180 m from a road. Once the dwellings values were distributed, the values were then converted into a 90 m raster and the results merged together with the results from the resultant raster from the previous section that converted the building points to raster.

The resultant raster is illustrated in Figure 4.9 which clearly shows how sparsely dwellings are distributed across the study region for the fine analysis (compare with Figure 3.26 of Chapter 2).

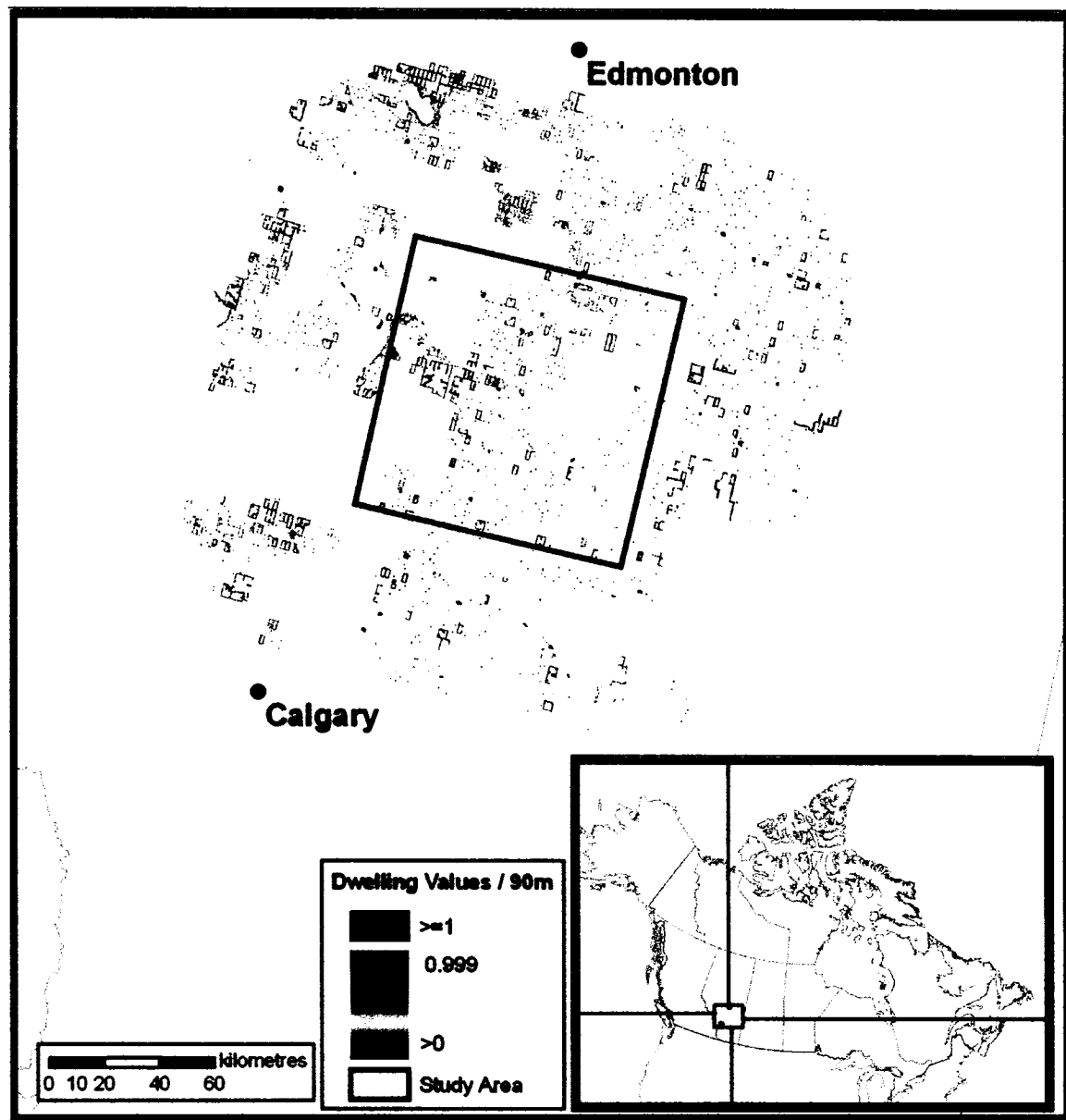


Figure 4.9. The resultant detailed dwellings raster at a 90 m resolution.

4.4 Review

This chapter has outlined the methods undertaken to produce the 90×90 m data for the Fine Analysis (FA) in the Upper Limit Scenario (ULS) and the Lower Limited Scenarios (LLS) described in Chapter 2. Unfortunately, due to the increased processing time for the LLS, the data was only produced for a 100×100 km area slightly east between Calgary and Edmonton. Slight changes to the methods in chapter 3 were required to create 90 m data containing dwelling values. These methodological changes yielded a general dwelling raster and a detailed dwelling raster. The approach undertaken to develop the general dwelling raster is similar to those steps in Chapter 2, whereas, the detailed dwelling more accurately estimates where dwellings are physically located. After having created the data from this chapter both the LLS and ULS are assessed and compared with the results of the CA and this comparison is presented in Chapter 5.

5

Results

5.1 Overview

Previous chapters outline the models used to create the Coarse Resolution Analysis (CA) and the Fine Resolution Analysis (FA) for the implementation of the line-of-sight (LOS) and non-line-of-sight (NLOS) models. However, this chapter presents the results of the Upper Limit Scenario (ULS) and the Lower Limited Scenarios (LLS) for both the coarse and fine resolution analyses. It also presents the potential locations where tower sites could be financially supported by a sufficient number of dwellings. Finally, recommendations, based on the experience gained during this research project are provided with regards to the implementation of this study's methods on a national scale. This chapter consists of five sections:

1. Results for the coarse resolution analysis;
2. Results for the fine resolution analysis;
3. Comparison of the coarse and fine resolution results;
4. Target market illustrations; and
5. Recommendations.

5.2 Coarse Resolution Analysis Results

In chapter 3, coarse 1 km data was developed for use in the ULS and LLS at 5 km and 50 km radii. Maps of results are present in Figure 5.1. The higher values in the maps illustrate that a tower could potentially provide broadband access to many dwellings. These maps also illustrate that there is a dense concentrations of dwellings around the Edmonton region without access to broadband that could be connected via wireless broadband. In some of the areas, the use of a single NLOS tower could reach more than a 1,000 dwellings at 5 km, while a tower with a reach of 50 km could reach up to 15,000 dwellings.

The ‘bulls-eye’ concentrations that can be found throughout the province demonstrate isolated municipalities with few surrounding communities. Highly evident in Figure 5.1d, the north-western part of the province has a number of these effects. Isolated communities influence these bulls-eyes because there are few dwelling values in the adjacent regions. In the 5 km LLS and ULS, these bulls-eye formations can also be found but they are smaller and less pronounced. These smaller formations are evidence of dispersed communities without access that could be connected with a communication tower.

Visually comparing the LLS (Figure 5.1a) and ULS (Figure 5.1b) at 5 km, suggests similar results. However, there are some differences which are illustrated in Figure 5.1c. Differences of up to 250 dwellings are observed at the 5 km resolution between the LLS and the ULS.

These differences point towards the idea that the use of LOS and NLOS is of concern for short radii but not for towers with large coverage's. Therefore, these seemingly small radii can have a significant impact on the marketability of a wireless enterprise.

A table for outlining the maximum, mean and standard deviation for the CA are detailed in Table 5.1. These tables show the maximum number of dwellings that a single tower could reach as well as the mean and standard deviation for each analysis using the 575,944 potential tower locations that were examined. The mean and standard deviation values were influenced by tower locations that did not have any dwellings within their search area of either 5 or 50 km. The maximum number of dwellings a single tower could potentially reach is nearly 15,000 using NLOS technology capable of reaching 50 km but most impressive was that a single 5 km LOS tower could potentially reach nearly 11,500 dwellings.

The CA results are similar to those presented in Appendix A. In Appendix A there were fewer tower sights that were examined because towers were examined only where dwellings were located. However, both results have the same 'bulls-eye' formations scattered across the province. Both also illustrate that the areas surrounding Edmonton would be a prime region to begin locating broadband wireless towers.

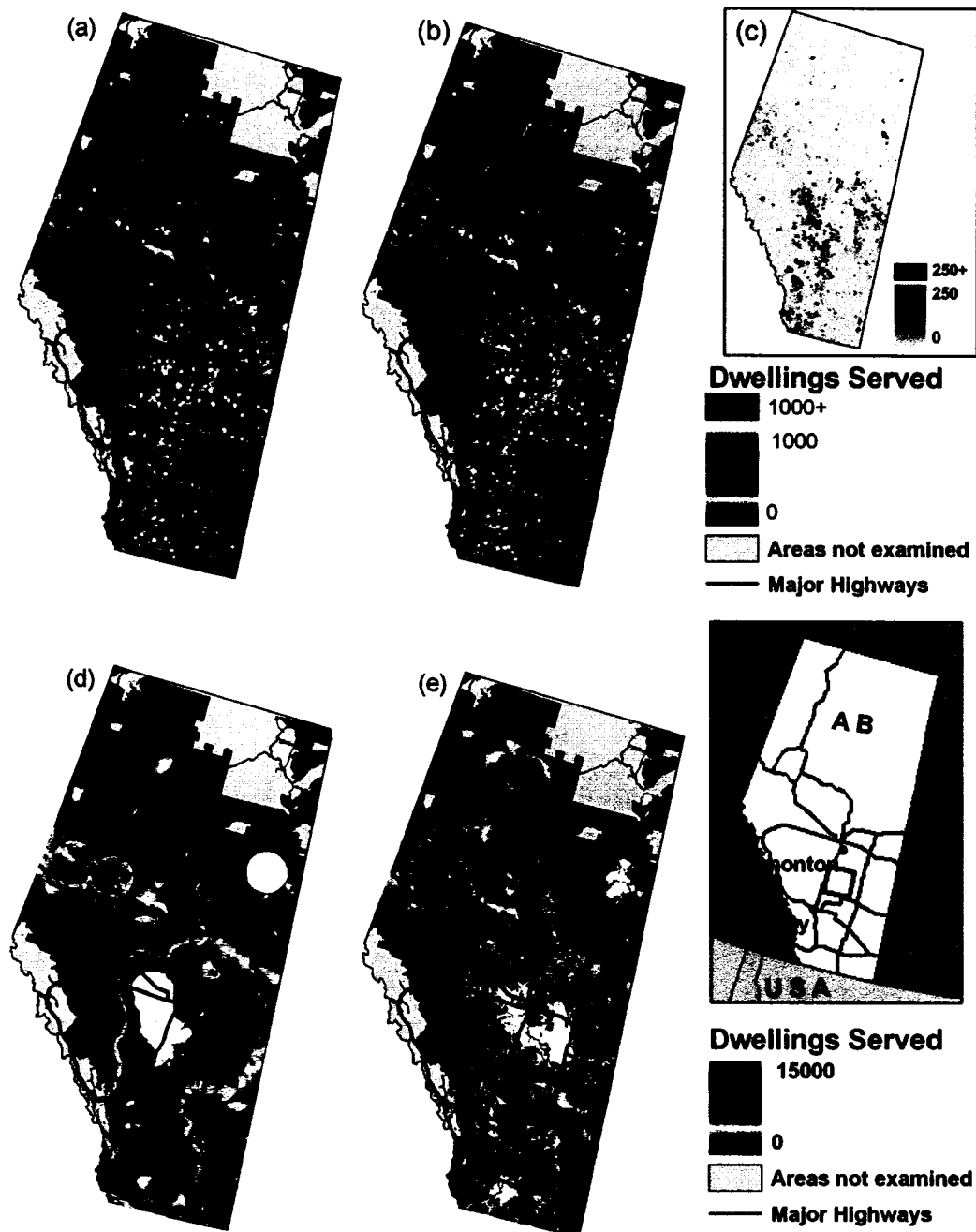


Figure 5.1. Distributions of potentially servable dwellings under different scenarios for the coarse resolution analysis: a) ULS 5 km; b) LLS 5 km; c) difference between ULS 5 km and LLS 5 km; d) ULS 50 km; e) LLS 50 km. Note the differences in the legend magnitude between the 5 km radius criterion used in (a) and (b) and the 50 km criterion used in (d) and (e).

Table 5.1 CA Numerical Summary for the Lower Limit Scenario and the Upper Limit Scenario for both 5 km and 50 km.

	Lower Limit Scenario		Upper Limit Scenario	
	5 km	50 km	5 km	50 km
Max	11,494	13,651	12,693	14,537
Mean	17	561	20	1,934
Stand Div	103	939	135	2,611

5.3 Fine Resolution Analysis Results

For the sample study region of the fine resolution analysis (FA), the results from the LLS and the ULS using both the detailed and general dwelling values at 5 km are illustrated in Figure 5.2 (data developed in Chapter 4). All four of the maps illustrate the same bulls-eye pattern with some slight differences between the LLS and ULS. The results from the LLS are influenced by topography (line-of-sight) because not all of the bulls-eye patterns are perfectly circular. In fact, in the western part of the study area, the variable elevation is noticeable.

The bulls-eyes representing the potential number of dwellings capable of being provided with wireless broadband access have a range of dwelling values. This variability in dwelling value is evident in the maps via the apparent colour ranges. Lacombe, Bashaw, Alix and the surrounding area of Red Deer are some of the communities where a tower could potentially provide service to approximately 600 dwellings. Other bulls-eyes have lower dwelling numbers.

Differences are not noticeable between the distribution of the detailed dwelling approach and the general dwelling approach. Even the values listed in Table 5.2 are very similar. This suggests that the additional data model refinement is unjustifiable.

However, two maps (Figure 5.2e and Figure 5.2f) were produced that visually illustrate the differences in values. The LLS difference map shows that the majority of the study is similar between the ‘general’ and ‘detailed dwellings rasters’ with a few exceptions. One notable exception is in the region of Lacombe where there is a difference of 475 dwellings.

When examining the ULS difference map, there is more variability. Across the study area, with the ‘detailed’ dwelling data, the ULS tended to have slightly higher dwelling numbers by approximately 20 to 30 dwellings. Although, in the Lacombe region the ‘general’ approach suggests that a tower could reach 125 dwellings more than the ‘detailed’ approach implied.

Table 5.2 Numeral summary for the LLS and ULS for the general and detailed dwelling values at 5 km.

	Lower Limit Scenario		Upper Limit Scenario	
	General	Detailed	General	Detailed
Max	520	512	612	599
Mean	44	44	56	56
Stand Div	82	81	93	94

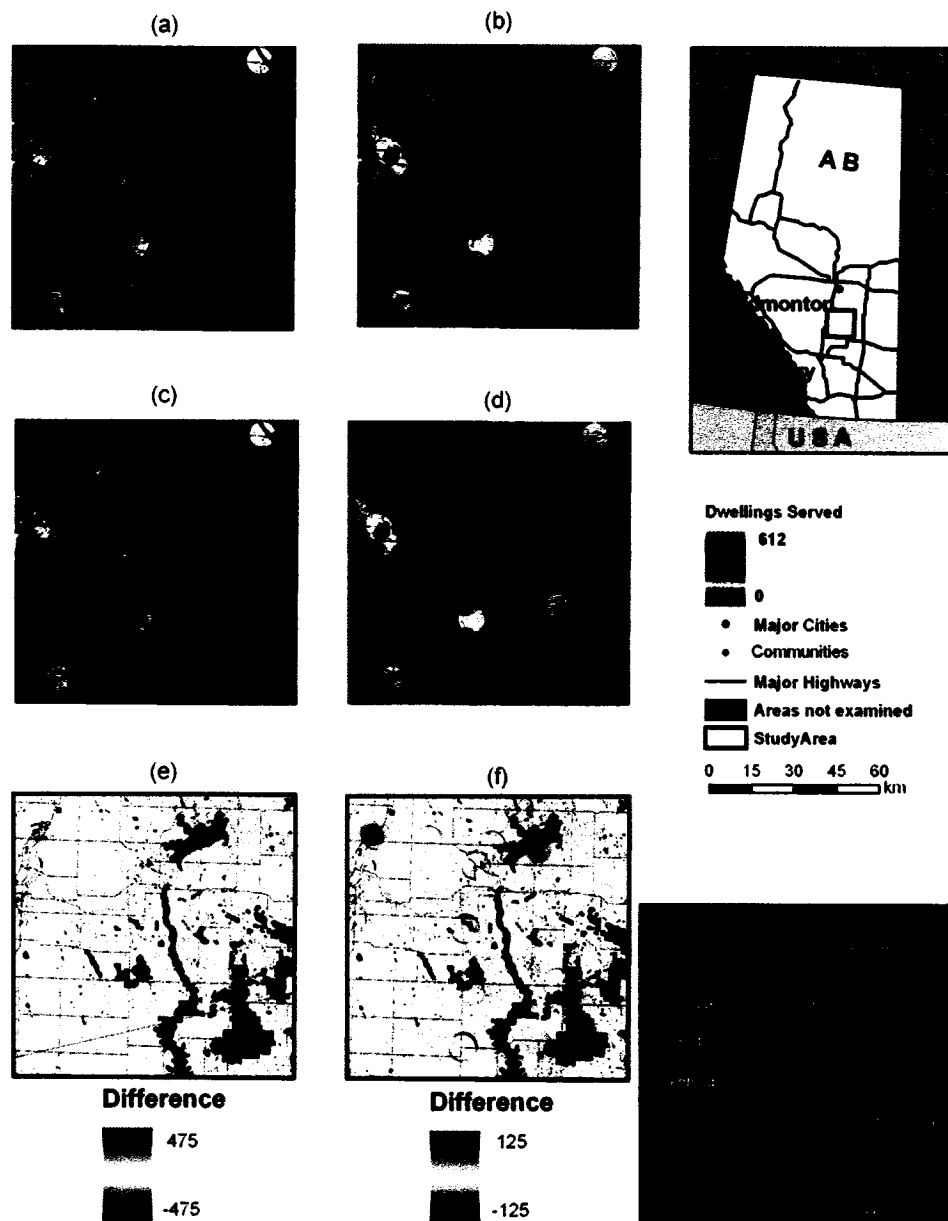


Figure 5.2. Fine Resolution 5 km (a) LLS General Dwelling (b) ULS General Dwelling (c) LLS Detailed Dwelling (d) ULS Detailed Dwelling (e) Difference between the General and Detailed Dwelling for the LLS [Difference = (a) – (c)] (f) Difference between the General and Detailed Dwelling for the ULS [Difference = (b) – (d)].

For the sample study region of the FA, the results for the LSS and ULS at 5 km using both the general and detailed dwellings are illustrated in Figure 5.2. The concentrations of potentially servable dwellings are located near the key communities. The discrepancy between the general and detailed data is also mapped.

The results for the 50 km LLS and ULS are similar for both the general and detailed dwellings (Figure 5.3). Spatially the highest concentration of servable dwellings was found in the region of Lacombe and Blackfalds, which are situated outside the city of Red Deer and just south of Edmonton. At the 50 km resolution, it is also evident that the LLS was influenced by the topography of the area. The more complex topography leads to greater effects on the LOS analysis for obvious reasons. The summary statistics comparing the general and detailed dwellings at 5 km are listed in Table 5.3.

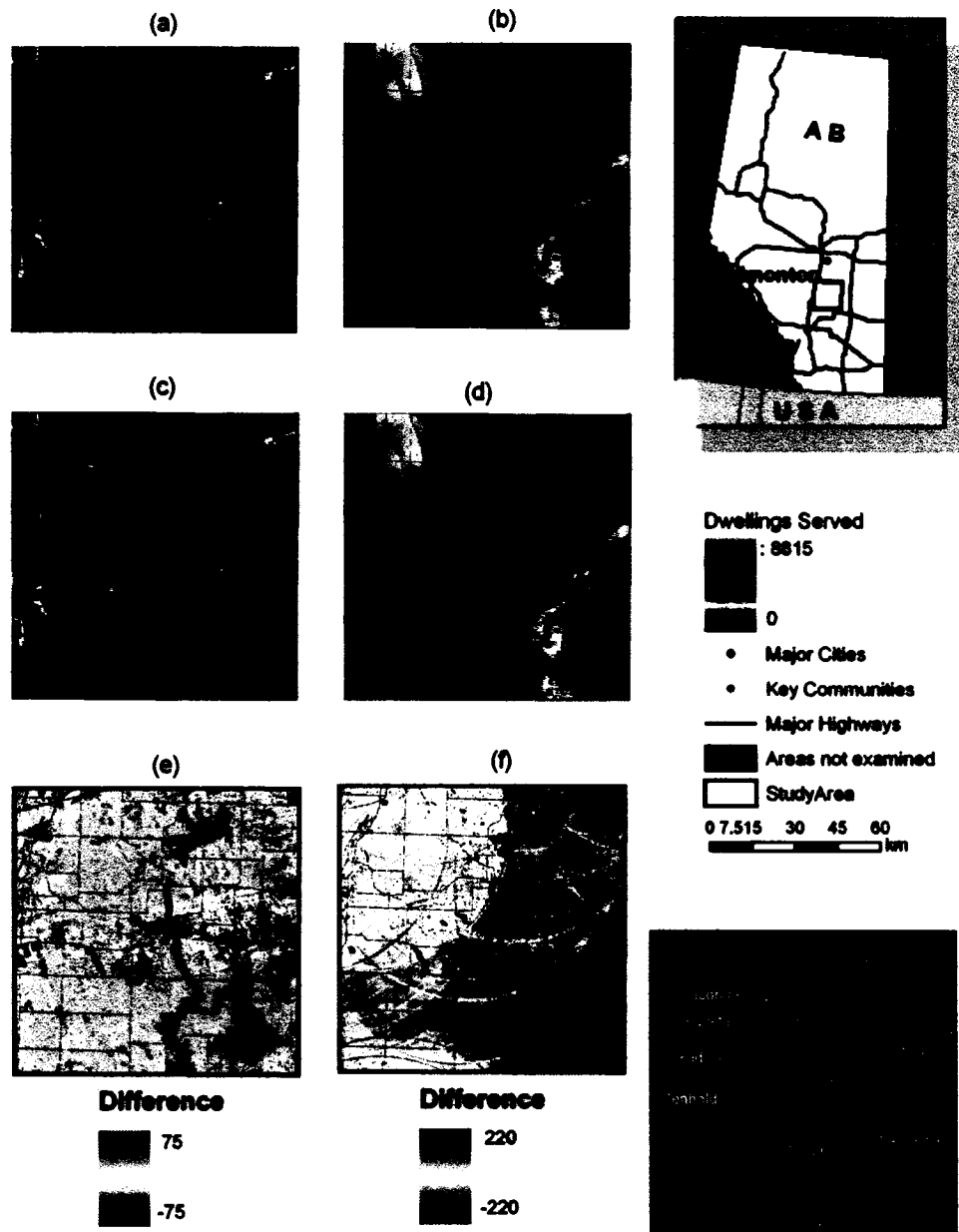


Figure 5.3. Fine Resolution 50 km (a) LLS General Dwelling (b) ULS General Dwelling (c) LLS Detailed Dwelling (d) ULS Detailed Dwelling (e) Difference between the HighLow and the High-high for the lower limit scenario (f) Difference for the LLS between the general and the detailed dwelling rasters.

Table 5.3 Numeral summary for the LLS and ULS for the general and detailed dwelling values at 5 km.

	Lower Limit Scenario		Upper Limit Scenario	
	General	Detailed	General	Detailed
Max	1,070	1,021	8,738	8,813
Mean	57	56	5,606	5,645
Stand Div	120	119	1,498	1,592

5.4 Comparison of Coarse and Fine Resolution Results

This section provides a comparison of the CA and the detailed FA. In order to compare the results, those areas of the CA that lie outside the FA's subset study area are spatially removed. Since the resolution of the FA is 90 m, there were 1,072,868 potential tower sites examined in the sample study area, whereas the CA only had 9,824 potential towers. When comparing the FA and CA, Figure 5.4 shows that FA and the CA results have identical patterns with the exception of the LLS at 50 km which is completely different (Figure 5.4e and Figure 5.4f).

The LLS at 50 km under the FA identified fewer dwellings than the CA; so much so, that on average, the CA identified 1,194 dwellings, whereas the FA averaged 56 dwellings. The northern section of the sample study area is where the high CA values were located. The results are different because the CA averaged the elevation heights and the influence of high elevations and variable topography would have been minimal at the coarser resolution.

As mentioned, the CA and FA maps are very similar with the noted exception. They both have identical patterns, values and identify similar numbers. For example, the maximum number of dwellings a single tower could provide wireless broadband access to for the 5 km

FA is 599, whereas the highest value for a single CA is 621. Even the average number of dwellings a single tower could identify is 56 (FA) and 57 (CA) (Table 5.6). Other numerical comparisons between the CA and the FA are listed in Table 5.4 – Table 5.7.

In short, the comparison of the CA and FA results suggests that the potential tower locations and market served are remarkably similar. Based on the research, it appears that there may be little real benefit from using the more sophisticated but more expensive FA approach in the study area. As such, while the spatial resolution and processing time is increased for the FA scenarios, there may be little real benefit gained in determining potential markets.

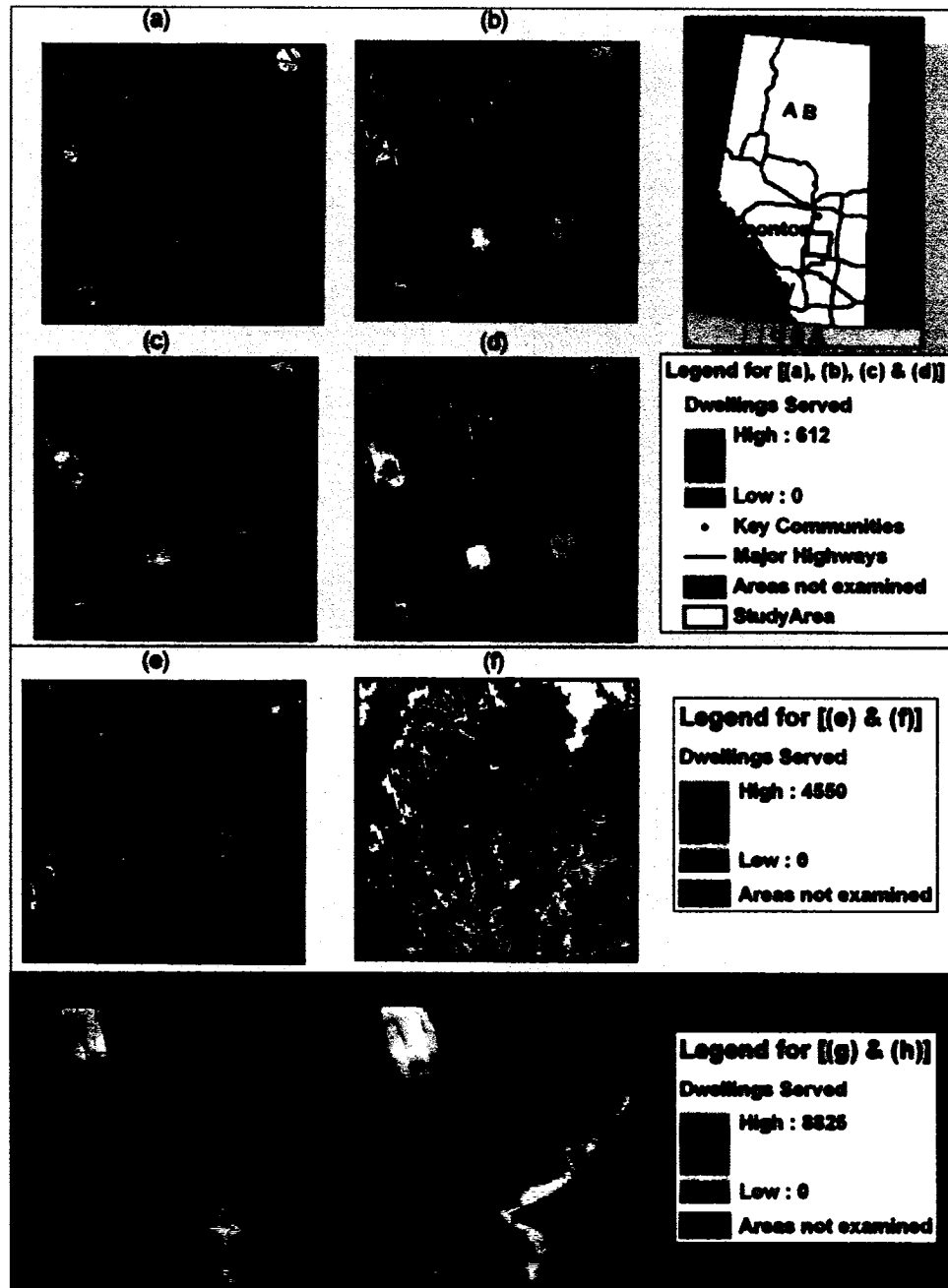


Figure 5.4. Comparison of Coarse and Fine Resolution (detailed raster) (a) LLS detailed resolution 5 km (b) LLS coarse resolution analysis 5 k (c) ULS detailed resolution 5 km (d) ULS coarse resolution 5 km (e) LLS detailed resolution 50 k (f) LLS coarse resolution 50 km (g) ULS detailed resolution 50 km (h) ULS coarse resolution 50 km. Note that there are three differences scales.

Table 5.4. FA and CA 5 km Summary Statistics for the regional subset, Lower Limit Scenario (Figure 5.4a and b).

Upper Limit Scenario	FA Detailed	CA
Min	0	0
Max	512	614
Mean	44	51
Stand Div	81	90

Table 5.5. FA and CA 5 km Summary Statistics for the regional subset, Upper Limit Scenario (Figure 5.4c and d).

Upper Limit Scenario	FA Detailed	CA
Min	0	0
Max	599	621
Mean	56	57
Stand Div	94	95

Table 5.6. FA and CA, 50 km Summary Statistics for the regional subset, Lower Limit Scenario (Figure 5.4e and f).

Upper Limit Scenario	FA Detailed	CA
Min	0	0
Max	1,021	4550
Mean	56	1194
Stand Div	119	819

Table 5.7 FA and CA, 50 km Summary Statistics for the regional subset, Upper Limit Scenario (Figure 5.4g and h).

Upper Limit Scenario	FA Detailed	CA
Min	1,558	1,587
Max	8,813	8,797
Mean	5,645	5,508
Stand Div	1,592	1,561

5.5 Target Market

This section illustrates potential target markets of where towers should be first considered for deployment of wireless broadband. Identification of potential markets for broadband

wireless access (BWA) is based on the assumption that 300 subscriptions would be the minimum number of required dwellings to support a WiMAX base station. This is based on the belief that 300 dwellings would sign up within three years of service if residential internet would cost \$35 per month for each dwelling, with an equipment rental of \$10 per month and a one-time activation fee of \$50 (Table 5.8). Based upon these figures and a start-up cost of three hundred thousand dollars (Table 5.9) (WiMAX Forum 2005) it would take approximately five years in order for the tower to breakeven (Table 5.10). Therefore, with these conservative estimates, a minimum of 300 dwellings would be required to support the construction of a tower. It must also be stated that these numbers could be adjusted to have fewer dwellings and higher costs or vice versa. These estimates also do not account for the possibility of selling access to commercial enterprises nor does it include the possibility of offering other services such as telephone access (Voice over Internet Protocol or VoIP).

Table 5.8. Upfront and Annual Cost for a Residential Wireless Broadband Subscriber (WiMAX Forum 2005).

Subscriber Cost	
Access Cost / month	35
Equipment Retail / month	10
One Time Activation Fee	50
Annual Cost for a New Subscriber	\$ 590.00
Annual Cost for Previous Customer	\$ 540.00

Table 5.9. Upfront Cost for A Service Provider and the Annual Cost for a Broadband Wireless Tower (WiMAX Forum 2005).

Initial Provider Cost	
Core & Edge Equipment	\$ 100,000
Base Station Acquisition & Civil Works	\$ 50,000
WiMax Equipment	\$ 35,000
Other Base Station Equipment	\$ 15,000
Backhaul Link (Annual)	\$ 100,000
Initial Upfront Cost	\$ 300,000
Capital Expenditure / Activation	\$ 300

Table 5.10. Balance Sheets for the total income and the total expensive towards the construction of a wireless broadband tower.

	1st Year	2nd Year	3rd Year	4th Year	5th Year
Previous Customers	0	250	300	300	300
New Customers	250	50	0	0	0
Provider Cost for Equipment	\$ 300,000	\$ 100,000	\$100,000	\$ 100,000	\$ 100,000
Capital Expenditure / Activation	\$ 75,000	\$ 15,000	0	0	0
Income	\$ 147,500	\$ 164,500	\$ 183,000	\$ 182,000	\$ 162,000
Expense	\$ 375,000	\$ 115,000	\$ 100,000	\$ 100,000	\$ 100,000
Year-to-Year Balance	\$ -227,500	-\$ 178,000	-\$ 116,000	-\$ 54,000	\$ 8,000

Assuming that 300 dwellings are required to sign up, various adoption rates are examined. Adoption rates are the number of dwellings that are required in order have the minimum number of dwellings for the provider to become profitable. For example, if 10% of the dwellings located within a potential tower service area signed up, a minimum of 3000 dwellings would be required ($3000 \text{ dwellings} \times 10\% = 300$), indicating that there is a large number of dwellings in the area but that only a small portion of the dwellings would be requiring the wireless broadband access (WBA) service. Whereas a 100% take-rate means only 300 households would be required and low dwelling numbers would be sufficient in the service area. Therefore, a range of various take-rates (Table 5.11) within the service radii are examined and illustrated in Figure 5.5 and Figure 5.6.

Table 5.11. Minimum number of Dwelling required for at different take rates in order to support a WiMAX base station.

Take-up Rate	No. of Dwellings
10%	≥ 3000
25%	≥ 1200
75%	≥ 600
50%	≥ 450
100%	≥ 300

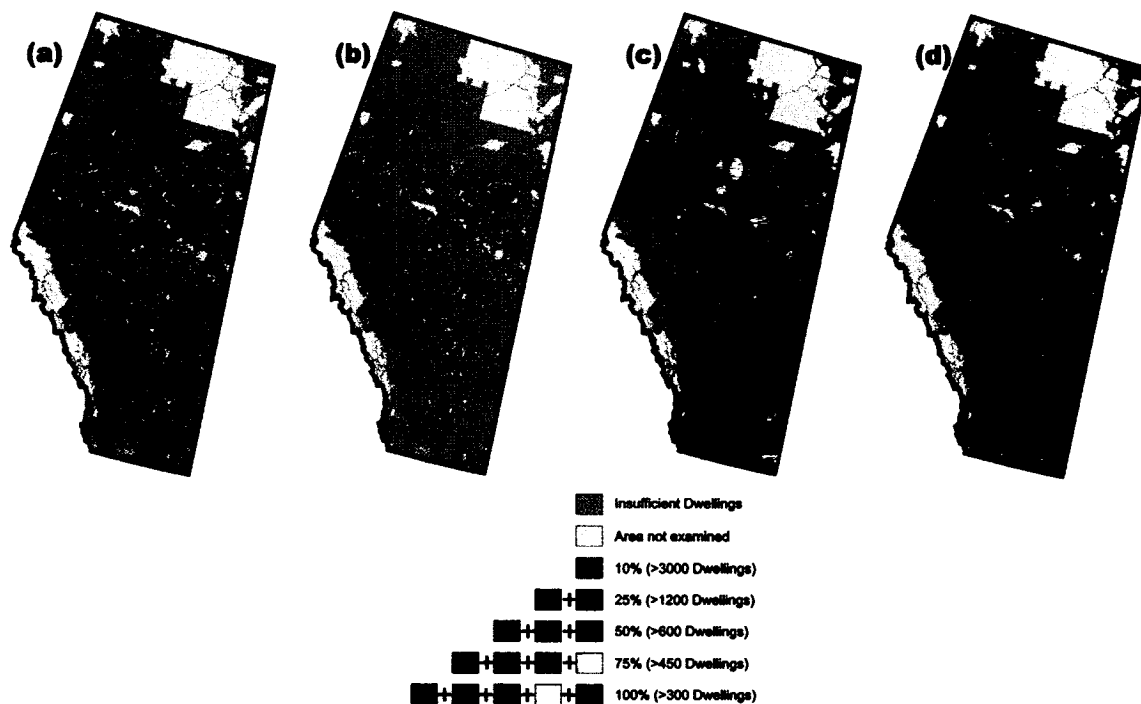


Figure 5.5. Business case scenarios based on 300 household subscribers at different market penetrations or take-rates for the coarse resolution analysis; a) ULS 5 km; b) LLS 5 km; c) ULS 50 km; d) LLS 50 km.

The maps of the adoption rates for the CA (Figure 5.5) provide a good illustration of the varying take-rates required to encourage tower construction and WBA service offerings. In the ULS at 50 km, most of the central to southern limit of the province would only require a take-up rate of 10% (indicated in red) while much of the remaining part of the province only requires 25% to 50% take-up rates. As such, almost a quarter of the evaluated tower locations in Alberta could provide access at a take rate of 10% (Table 5.12). As for the LLS at 50 km, approximately half of the province would range between a 25%-50% take-rate, while the other half would not be financially viable for tower construction. Approximately 18,000 evaluated tower sites could be constructed with a take-rate of 10% while almost 250,000 locations could be constructed with a take rate of 50% (Table 5.12).

In order to support the construction of a tower capable of providing access up to 5 km, there are few identified tower locations that would be financially exploitable. For example, examining the LLS at 5 km, Alberta has some approximately 40 communities (1344 tower locations (Table 5.12)) that would be able to support the construction of a tower at a 75% take-rate and an additional 40 communities at 100% take-rates (5900 tower sites (Table 5.12)). Spatially, these communities tend to be adjacent to the already-served regions surrounding Edmonton and Calgary, making them even more interesting because of the closer distances to the existing backbone.

Table 5.12. Summary of the number of potential towers that could be financially sustained at the 5 km radius based on percentage take rates where a minimum 300 dwellings is required.

Take Rate	No. of Dwellings	Map Colour	LLS	LLS	ULS	ULS
			Towers that could present a business case (%)	Towers that could present a business case (No.)	Towers that could present a business case (%)	Towers that could present a business case (No.)
10%	>3000	red	0.02%	100	0.02%	139
25%	>1200	blue	0.03%	183	0.05%	273
75%	>600	green	0.23%	1344	0.29%	1689
50%	>450	yellow	0.49%	2846	0.58%	3357
100%	>300	black	1.02%	5900	1.17%	6753

Table 5.13. Summary of the number of potential towers that could be financially sustained at the 50 km radius based on percentage take-rates where a minimum 300 dwellings are required.

Take Rate	Minimum No. of Dwellings	Map Colour	LLS	LLS	ULS	ULS
			Towers that could present a business case (%)	Towers that could present a business case (No.)	Towers that could present a business case (%)	Towers that could present a business case (No.)
10%	>3000	red	3.18%	18,298	23.16%	133,412
25%	>1200	blue	14.95%	86,088	43.20%	248,835
75%	>600	green	29.16%	167,942	57.31%	330,047
50%	>450	yellow	34.12%	196,496	61.95%	356,797
100%	>300	black	42.60%	245,379	68.10%	392,195

For comparison, the coarse and fine analyses are compared side-by-side in Figure 5.6 and yield similar adoption results - with the exception of the dramatic differences for LLS at 50 km. As in the previous comparison of CA and FA results (page 92) the results in the target market are the same. At the 5 km radii both CA and FA identified six areas which would require between 75-100% take-rates, whereas the remaining tower locations would not have sufficient dwellings. That is, between 1-5% of the evaluated sites could support the construction of a tower (Table 5.14 and Table 5.15).

As for the 50 km results, both the ULS from the CA and the FA provided near identical results. Both suggest that a take-rate of only 10% would be required and that approximately 95% of the evaluated tower locations would be suitable to the construction of a broadband tower (Table 5.17). As mentioned, there is notable differences in both the map (Figure 5.6e and Figure 5.6f) and the results in Table 5.17. The CA suggests nearly half of the evaluated tower sites could provide broadband access whereas the FA suggests no locations. The FA only suggests an area in the centre of the sample study area could possibly provide a take-rate of 75%. Nevertheless, as previously mentioned non-line-of-sight technology at 50 km does not yet exist but is only used for comparative purpose.

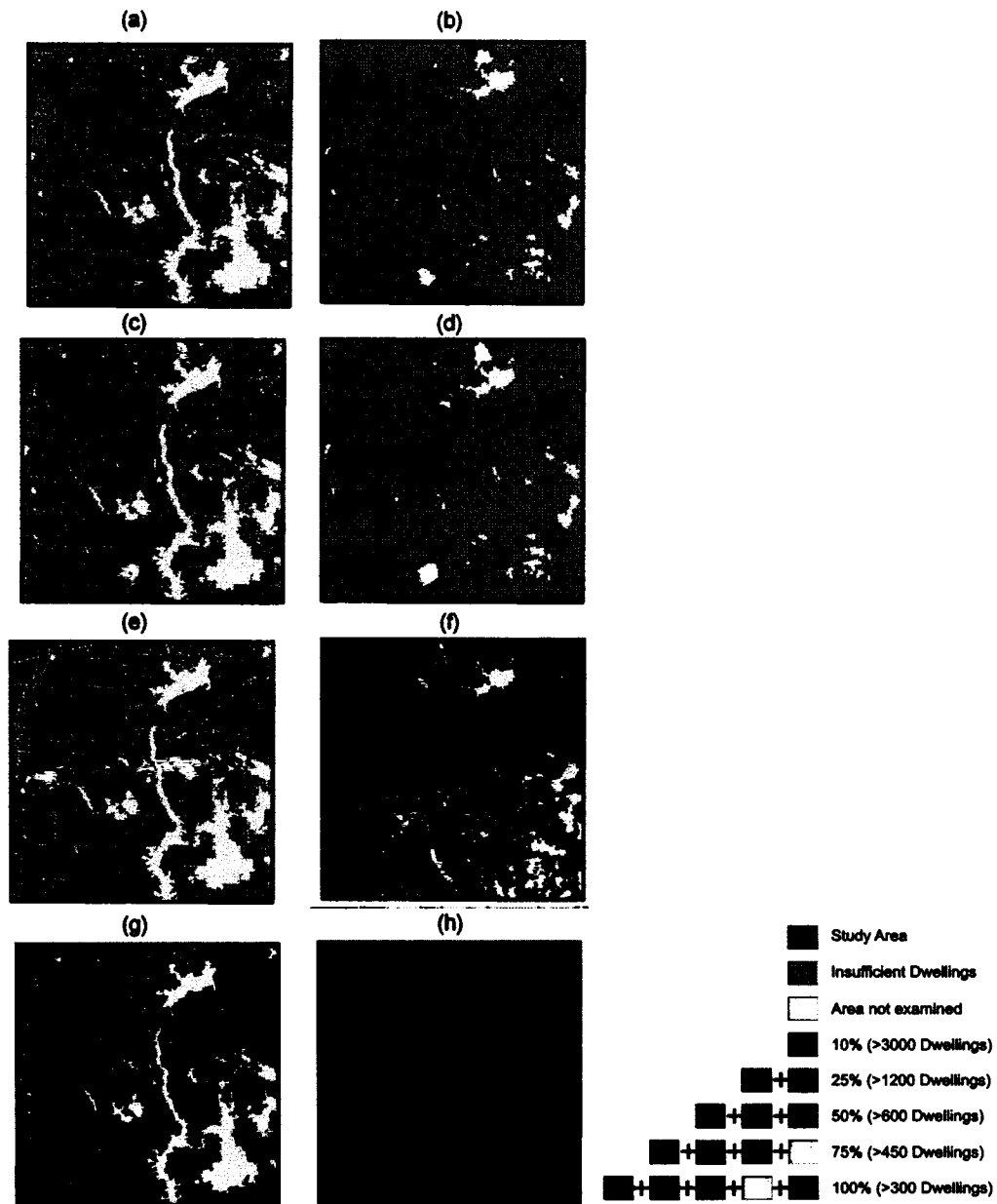


Figure 5.6. Comparison of business case scenarios between the coarse and refined (detailed dwelling) results based on 300 household subscriptions at difference market penetrations or take-rates; a) Detailed Resolution LLS 5k; b) Coarse Resolution LLS 5k; c) Detailed Resolution ULS 5k; d) Coarse Resolution ULS 5k; e) Detailed Resolution LLS 50k; f) Coarse Resolution LLS 50k; g) Detailed Resolution ULS 50k; h) Coarse Resolution ULS 50k.

Table 5.14. Comparison of business case scenarios between the coarse and refined (detailed dwelling) results based on 300 household subscriptions at difference market penetrations or take-rates for the LLS at 5 km.

Take Rate	Minimum No. of Dwellings	Map Colour	Fine Resolution (detailed)	Coarse Resolution	Fine Resolution (detailed)	Coarse Resolution
			Towers that could present a business case (%)	Towers that could present a business case (No.)	Towers that could present a business case (%)	Towers that could present a business case (No.)
10%	>3000	red	0.00%	0	0.00%	0
25%	>1200	blue	0.00%	0	0.00%	0
75%	>600	green	0.00%	0	0.02%	2
50%	>450	yellow	0.67%	7174	1.09%	107
100%	>300	black	3.41%	36546	4.27%	419

Table 5.15. Comparison of business case scenarios between the coarse and refined (detailed dwelling) results based on 300 household subscriptions at difference market penetrations or take-rates for the ULS @ 5 km.

Take Rate	Minimum No. of Dwellings	Map Colour	Fine Resolution (detailed)	Coarse Resolution	Fine Resolution (detailed)	Coarse Resolution
			Towers that could present a business case (%)	Towers that could present a business case (No.)	Towers that could present a business case (%)	Towers that could present a business case (No.)
10%	>3000	red	0.00%	0	0.00%	0
25%	>1200	blue	0.00%	0	0.00%	0
75%	>600	green	0.00%	18	0.02%	2
50%	>450	yellow	1.42%	15246	1.53%	150
100%	>300	black	4.37%	46898	4.58%	450

Table 5.16. Comparison of business case scenarios between the coarse and refined (detailed dwelling) results based on 300 household subscriptions at difference market penetrations or take-rates for the LLS at 50 km.

Take Rate	Minimum No. of Dwellings	Map Colour	Fine Resolution (detailed)	Coarse Resolution	Fine Resolution (detailed)	Coarse Resolution
			Towers that could present a business case (%)	Towers that could present a business case (No.)	Towers that could present a business case (%)	Towers that could present a business case (No.)
10%	>3000	red	0.00%	0	3.29%	323
25%	>1200	blue	0.00%	0	47.08%	4625
75%	>600	green	0.61%	6592	69.68%	6845
50%	>450	yellow	3.43%	36823	79.02%	7763
100%	>300	black	6.07%	65160	87.04%	8551

Table 5.17. Comparison of business case scenarios between the coarse and refined (detailed dwelling) results based on 300 household subscriptions at difference market penetrations or take-rates for the ULS at 50 km.

Take Rate	Minimum No. of Dwellings	Map Colour	Fine Resolution (detailed)	Coarse Resolution	Fine Resolution (detailed)	Coarse Resolution
			Towers that could present a business case (%)	Towers that could present a business case (No.)	Towers that could present a business case (%)	Towers that could present a business case (No.)
10%	>3000	red	94.59%	1014875	93.03%	9139
25%	>1200	blue	100.00%	1072868	100.00%	9824
75%	>600	green	100.00%	1072868	100.00%	9824
50%	>450	yellow	100.00%	1072868	100.00%	9824
100%	>300	black	100.00%	1072868	100.00%	9824

5.6 Review

This chapter presented the results of the CA and FA analyses for the ULS and LLS scenarios. The results were presented as both raw numbers of households served under each scenario as well as an analysis for potential markets based on 300 subscribers and take-rates in the service radii from 10-100%. Generally, it was found that the added execution time of the FA did not provide significantly different results from the CA. However, discrepancies were noticeable at 5 km radii for the ULS and LLS between CA and FA. As such, refined analysis is suggested when modelling technologies that are operating at small service radii but a CA model will certainly suffice to identify these areas of high-potential markets for subsequent fine-scale analysis. In other words, a fine-scale model does not need to be implemented over large regions like the Canadian landmass to provide results that will identify areas of BWA service potential. Finally, a next logical step in analyzing the LLS and ULS scenarios at both scales would be to include socio-economic corrections to the dwelling layer to provide even more realistic business cases. These "population corrections" could be done pre or post analysis without loss of expediency.

6

Discussion and Conclusion

The results in chapter 5 illustrate the locations of potential broadband wireless access (BWA) tower deployment sites and the locations where market support is sufficient. However, there are three caveats that need to be noted with regard to the assumptions underlying this analysis.

First, it is assumed that all tower locations can be linked to a fibre optic-based backbone that is capable of supporting bandwidth requirements. This has been left aside for future model refinements or business case scenarios. The assumption that every tower can be connected would potentially imply that the promising results of chapter 5 may be unrealistic as one becomes more distant from urban centres and the wired backbone.

The second caveat, as discussed in Appendix A, is that it is assumed that a tower could be placed within the identified unserved regions. The analysis of each potential location was conducted independently of the previous iteration. Any overlap means that the locations of potential towers have not been spatially optimized. However, and most importantly, the maps do identify hot-spot zones for potential WiMAX deployment. Essentially, this thesis does not examine the minimum number of towers required to service a region. It is concerned with Canada's northern, rural, remote and isolated regions ability to access wireless broadband internet service (BIS) and not the optimization of the BIS network layout (Sawada et al. 2006).

Using wireless technologies to provide broadband services requires the consideration of factors other than topography to be successful. As mentioned in Appendix B, line-of-sight (LOS) and non-line-of-sight (NLOS) can also be affected by some of the following: atmospheric scattering, frequency, foliage, topography, path and obstacles. These factors need to be considered individually and collectively in order to devise a plan that maximizes the number of dwellings capable of adopting wireless technology.

Numerous lessons have been learned during this study which would be useful if a similar study were done at a national scale, these include:

1. When determining target markets, the added complexity and processing time required for the Fine Resolution Analysis (FA) may not be required for a WiMAX type technology since results did not significantly change from the Coarse Resolution Analysis (CA) scenarios. More important is the inclusion of topography if LOS is required.
2. In order to expedite processing the LOS model and the Lower Limit Scenario (LLS) model, a network of computers was utilized. To help speed up processing, the

maximum number of computers available is used.²² This technique reduced the processing time of the fine resolution LLS 50 km analysis to 3.5 days. A large number of computers is absolutely required.

3. When possible it is strongly suggested that processes such as unioning, merging and erasing be conducted in small batches. This reduces the likelihood that a computer will stall or freeze-up (Appendix G).
4. It is possible to create the polygon grid without using Robert Nicholas'²³ fishnet program. By converting the elevation raster to a point dataset, then converting it to raster using the unique identification number assigned to the point dataset and finally to a polygon grid (Elevation Raster → Point → Raster → Polygon). Using this method eliminates the need for the fishnet program.

Although the results of this thesis are not spatially accurate enough to site towers, the maps illustrate where the unserved population could benefit most from BIS. Using radio propagation software is the best method to identify the optimal location for these towers at a local level. The results in this thesis should only be considered as a first-approximation which can be used to help identify candidate locations and regions that require subsequent analysis. Appendix A, (page 135) provides more detailed discussion of this topic.

Aside from the physical modelling issues described above, the third major caveat underlying this analysis involves the determination of take-rates and the dwelling count layer. Specifically, the dwelling count layer should be adjusted for those socio-demographic factors that favour/hinder the adoption of BIS. Such analysis would improve estimates of the potential profitability of a site and provide more impetus in supporting BWA service

²² The maximum number of computers used at a given time was 90.

²³ Fishnet <http://arcscrips.esri.com/details.asp?dbid=12807> Robert Nicholas (Date Accessed: 12 Jan 2006)

providers and BIS business plans. The socio-demographic modelling of BIS demand is a further step that is relevant to continue on from this work. As such, discussion of the issues surrounding the socio-economic digital divide and their distinction and relation to the geographic divide are relevant here.

Even though internet service is available in many areas, especially those which are densely populated, not all within the service area adopt internet services immediately. In Canada, more than 50% of the households have broadband services via Cable or Digital Subscriber Line (DSL) although these homes are mainly located in urban areas (Veenhof, Neogi et al. 2003). Not everyone will adopt BIS and differences in adoption rates can be traced to socioeconomic and demographic factors including income and education levels (Grubestic and Murray 2002; Grubestic 2003; Prieger 2003). For means of discussion, the key demographic and socio-economic factors important for internet adoption are summarized in Table 6.1. (Statistics Canada 2003).

Table 6.1. Leaders and trailers in the adoption of internet services (Statistics Canada 2003).

Group Characteristic	Leader Group	Trailing Group
Age of Dwelling Head	Under 35 (80%)	65 and over (25%)
Structure of Dwelling	A family with unmarried children (under 18) (84%)	One-person dwelling (40%)
Education	University Degree (88%)	Less than high school (32%)
Income	Highest Quartile (\$70,000 and more) (90%)	Lowest Quartile (\$23,000 or less) (35%)

In general then, those with high levels of income and greater education are more likely to adopt BIS. The dwelling structure and the dwelling head's age can affect the rate of internet adoption (Sciadas 2002). Like many new technologies, internet service (IS) adoption lags in lower income households. In 1997, for example, only 5% of lower income Canadian

dwelling had obtained access to (adopted) internet services. In 2003 the rate increased to 26.7% (Statistics Canada 2003). This recent increase includes differences in internet service (IS) access induced by gender that has been recognized in Canada (Fritz 2004).

The major flaw of the Statistics Canada characterization of IS and BIS adoption is their lack of consideration for the spatial availability of such services. Such studies are only looking at those households that have access. Most studies examining the digital divide typically only compare use and demand versus demographic factors without considering the geographic availability of IS or BIS. As a result, geographic availability may contribute to the divide more than is generally recognized (Prieger 2003). So, the aforementioned socio-economic and demographic factors that influence a household's desire and/or ability to adopt BIS do not overshadow the spatial inequality of BIS access which is the primary issue for living in rural and remote Canadian (Sawada et al., 2006). Gbubescic and Murray (2002) recognized access inequalities within an urban context when they said that access is a prerequisite for the adoption of BIS. Put plainly, if BIS is not there to be used then all other factors in its adoption are irrelevant.

Figure 1.1 in Chapter 1 clearly illustrates the differences in availability of broadband internet between rural and urban Canada. As such, overcoming the geographic divide is necessary before BIS adoption rates are contemplated within Canada. However, and in parallel, studies should continue within regions of equal geographic access to better understand the social, demographic and economic hurdles to BIS adoption. A clear understanding of such hurdles will provide a significant amount of theory for application in rural and remote regions once access itself is no longer an issue.

The objective of this research was to determine if emerging terrestrial technologies could effectively and economically provide service to households without broadband access by

developing a Geographic Information System (GIS)-based model. The GIS model reflects the general theory of wireless communications for both line-of-sight and non-line-of-sight physical conditions. The model presented in this research is focused on assessing the capacity for different technological solutions to reach profitable population bases. In particular, WiMAX specifications were utilized as a test case because WiMAX provides for both non-line-of-sight (NLOS) and line-of-sight (LOS) technologies over much greater distances than current solutions. The model was employed for dwellings without broadband access in Alberta.

The results suggest that GIS applications can make a significant contribution to the analysis of wireless deployment planning, to the understanding of the relationships between wireless signal sources and consumers, and to the spatial configuration of terrestrial wireless broadband networks. Moreover, the importance of the social, economic and demographic factors that affect BIS adoption can be integrated into the model presented here once such factors are clearly identified and reliable. In general, the results of this work provide impetus to policy formulation and decision making that could increase access to broadband internet services in all regions of the country, and thereby provide the opportunity for all Canadians, regardless of location, to fully participate in today's Information Society.

Acronyms

BIS -	Broadband Internet Service
BLP -	Broadband over power line
CA -	Coarse Resolution Analysis
BWA -	Broadband wireless access
CDED -	Canadian Digital Elevation Data
CRC -	Communication Research Centre
CRTC -	Canadian Radio-television and Telecommunication Commission
DA -	Dissemination Area
DDA -	Dwelling Distribution Analysis
DEM -	Digital Elevation Model
DOI -	Department of Industry
DSL -	Digital Subscriber Line
EA -	Enumeration Area
FA -	Fine Resolution Analysis
GIS -	Geographical Information Systems
GPS -	Global Positioning System
IEEE -	Institute of Electrical and Electronics Engineers

IS -	Internet Service
ISP -	Internet Service Providers
LAN -	Local Area Network
LLS -	Lower Limit Scenario
LOS -	Line-of-Sight
MXD -	File extension for an ArcGIS GIS Project File
NBTF -	National Broadband Task Force
NLOS -	Non-Line-of-Sight
NTDB -	National Topographic Database
QoL -	Quality of Life
PLB -	Power line Broadband
RF -	Radio Frequencies
RPA -	Radio Propagation Analysis
RS -	Remote Sensing
SDSS -	Spatial Decision Support System
ULS -	Upper Limit Scenario
UN -	United Nations
VAT	Value Attribute Table
VBA -	Visual Basics for Applications
WiMAX -	Worldwide Interoperability for Microwave Access (IEEE 802.16)
Wi-Fi -	Wireless Fidelity (IEEE 802.11)
Mbps -	Transmission of 1,000,000 bits (megabits) per second
Kbps -	Transmission of 1,000 bits (kilobits) per second
Gbps -	Transmission of 1,000,000,000 bits (gigabits) per second
KHz -	A unit of frequency equal to 1,000 hertz (kilohertz)
MHz -	A unit of frequency equal to 1,000,000 hertz (megahertz)
GHz -	A unit of frequency equal to 1,000,000,000 hertz (gigahertz)

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A **Appendix**

ANALYSIS OF THE URBAN/RURAL BROADBAND DIVIDE IN CANADA: USING GIS IN PLANNING TERRESTRIAL WIRELESS

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ABSTRACT

Millions of Canadians residing in Canada's northern, isolated, rural and remote communities do not have broadband internet access. This situation has led to a national 'broadband divide'. That is, the deployment of wireline broadband is very limited in Canada's northern, isolated, rural and remote areas because of the significant expense of installation and maintenance of the wired infrastructure needed to reach dwellings in these locations.

Terrestrial broadband wireless technology, on the other hand, does not entail the same kind of physical infrastructure. As a result, there are dramatic changes in how spatial considerations affect the provision of broadband internet services (BIS) to areas beyond the urban zone. In particular, the spatial question is now focused on assessing the capacity for different technological solutions to reach profitable population bases, and brings to the forefront organizations that are developing non-line-of-sight (NLOS) technologies that would permit wireless internet access over much greater distances than current solutions.

We begin this paper by establishing the importance of broadband connectivity to Canada's northern, isolated, rural and remote communities. This discussion comments on the role of the Government of Canada in the provision of broadband connectivity to residents of these communities, and outlines the current regulatory issues that govern wireless services and policy formulation.

The second part of the paper illustrates the use of geographic information system (GIS) approaches in the study of wireless broadband planning and deployment. Case study findings suggest that GIS applications can make a significant contribution to the analysis of wireless deployment planning, to the understanding of the relationships between wireless signal sources and consumers, and to the spatial configuration of terrestrial wireless broadband networks. We conclude the paper by discussing how the GIS approach employed could be used to inform the public policy process in regard to increasing access to broadband internet services in all regions of the country, and thereby providing the opportunity for all Canadians, regardless of location, to fully participate in the Information Society.

INTRODUCTION

We begin this paper by briefly describing broadband and related technologies for the purpose of context. We then define Canada's urban/rural broadband divide, and distinguish this concern from issues involving the digital divide. Next, we establish the importance of broadband connectivity to Canada's northern, isolated, rural and remote communities. This part of the paper considers the role of the Government of Canada in the provision of broadband connectivity to residents of these communities, and outlines some of the current regulatory issues affecting wireless services and policy formulation. The second part of the paper discusses the use of geographic information systems (GIS) methods and technologies in terrestrial broadband wireless internet service planning and deployment. To illustrate our argument, the results of a preliminary, GIS-based study of the potential market that could be served by connecting Canada's northern, isolated, rural and remote communities to terrestrial broadband wireless technology are presented. We conclude the paper by exploring several policy issues and options arising from our investigation.

BROADBAND

Broadband telecommunications in this paper refers specifically to high-speed internet access that connects an end-user to the internet backbone²⁴ (Industry Canada 2001). Individuals are typically connected to the internet through an internet Service Provider (ISP), where the transfer speeds are faster than dialing to an internet connection that has a maximum of 56-64 kilobits per second (Kbps) (CRTC 2004). In many present situations, broadband is being residentially provided in urban areas between 1 - 7 megabits per second (Mbps) which is roughly eighteen times the bandwidth of a dialup connection²⁵. In 2002, Canada was above the North American average with 30% of dwellings using broadband (Alcatel 2004). Internationally, Canada is second to South Korea in terms of broadband penetration (Phillipson 2004). Drawing a parallel with earlier assessments of how changes in technology are affecting individuals and institutions (Wellar 1983), having broadband in a dwelling at the present time represents a major advance in promoting and achieving time-efficient interaction with the internet's products, processes, and participants.

Broadband Technologies

There are numerous types of broadband technologies that can be classified as either wireline or wireless links (Table A.1). Wireline technologies like Digital Subscriber Line (DSL) (Cybertron 2005) and Cable Modem (Vicomsoft 2005) are the most commonly known, however, power-line (Tongia 2004) and fibre-optics also exist. Viable alternatives to wireline include fixed wireless (WiMAX Forum 2004) and satellite (Industry Canada 2004). Some of these technologies are new and emerging, while others are in early development. Table A.1 provides a framework for a brief discussion of these broadband technologies in terms of two performance criteria pertinent to remote locations, that is, location of use and range of coverage. Readers interested in detailed discussions of the respective technologies are invited to consult the references.

Table A.1. Comparison of broadband technologies.

	Technology	Primarily location of use	Coverage distance
Wireline	DSL	Urban	7.2 km
	Cable Modem	Urban	48 km
	Power line	In Development	In Development
	Fibre Optic	Urban	120 km
Wireless	Satellite	Rural / Remote	National
	Fixed Wireless	Rural / Urban	50 km

²⁴ The internet backbone is the wireline and wireless network infrastructure that links all the parts of the internet together.

²⁵ Rogers High Speed internet <http://www.shoprogers.com/Store/Cable/internetContent/extreme.asp> (Date Accessed: 30 June 2005); Shaw High-Speed Xtreme-I: <http://www.shaw.ca/en-ca/ProductsServices/internet/ShawHighSpeedXtremeI/> (Date Accessed: 30 June 2005).

Each of these technologies has advantages and disadvantages. In the interests of space, we identify a limited selection of features that are relevant to this paper, beginning with DSL in the wireline group. This technology, using high frequencies via unshielded telephone wires (Peden 2001), is limited spatially because of susceptibility to interference (Czajkowski 1999). DSL is not well-suited for locations distant (> 2 km) from telephone exchanges or central offices (Mitchelle 2004). Cable modems utilize high frequencies within shielded coaxial cable, and allow for greater geographic range/coverage than does DSL. However, cable is a shared medium, and signal delay of distant modems can cause transmission collisions with other signals (Dutta-Roy 2001). Further, cable is not available in most northern, isolated, rural and remote areas of Canada. The use of power-lines for broadband (PLB or BLP - Broadband over power line) is compromised by issues of interference within and outside the network (Baugh and Matyjas 2004), and massive investments are required to overcome the problem (Tongia 2004). Fiber optics, a major part of the internet backbone, can transport massive amounts of data over long distances without interference or signal degradation. However, fabrication and installation of optical fibre is very expensive, making this technology inappropriate for dwellings in rural areas (Frigo, Reichmann et al. 2003).

The most promising technologies for northern, isolated, rural and remote areas, primarily because they do not require wireline infrastructure, are the two technologies in the wireless group, that is, satellite and fixed wireless access. In this paper, we limit our discussion to the fixed wireless access component.

Broadband wireless access (BWA) is the most flexible technology for serving dwellings which are not readily connected to a financially-viable and time-efficient wired solution.²⁰ Standards (IEEE 802.16-2004) set by the Institute of Electrical and Electronics Engineers (IEEE) are designed to provide for non-line-of-sight connections, low latency links²¹, and coverage to a radius of up to 50 km (Alvarion 2004; WiMAX Forum 2004) using both licensed and unlicensed frequency spectra (Wingfield 2004). Further, in the near future mobility extensions will be introduced to the standards, namely IEEE 802.16e, and IEEE 802.20 (WiMAX 2004). With these extensions, the infrastructure deployed for fixed BWA will be re-used for mobile services such as cellular phones, resulting in major deployment cost reductions in remote regions.

Among the design features that make fixed BWA especially pertinent to this study is its ability to deal with connections on a link-by-link (or connection-by-connection) basis. Further, different modulation schemes are able to account for varying amounts of signal losses as well as the different data rate demands of various applications (Fujitsu Microelectronics America Inc 2004). Finally, BWA is purported to be appropriate for areas of low population density (WiMAX Forum 2005), and capable of providing access “for millions of subscribers who would otherwise be left out” of the digital revolution (Alvarion 2004). As a result of those design considerations, BWA is an appropriate ‘test bed’ for assessing the contribution that GIS could make to closing Canada’s broadband divide.

CANADA'S URBAN / RURAL BROADBAND DIVIDE

Canada is one of the most highly urbanized countries in the world, with more than 80% of its 32 million residents living in urban areas. However, the urbanized population occupies only about four percent of the landmass. Further, almost two-thirds of the entire population is concentrated in 27 major urban centers located within a few hundred kilometres of the U.S. border (Statistics Canada 2002; Natural Resources Canada 2005). Or, to re-phrase for emphasis, less than 20% of the population is spread out over 96% of Canada's vast expanse, with many of these dwellings located in the northern, remote and isolated reaches of rural Canada (Wellar 1989; McNiven and Puderer 2000).

These numbers demonstrate that Canada's urban/rural divide is significant in terms of the numbers of dwellings involved, as well as the spatial divide aspect, that is, urban concentration versus rural dispersal. As for the relationship between the population divide and the broadband divide, it is intimate and significant: approximately 5 million people (as of late 2004) of varying socioeconomic and demographic backgrounds live within northern, isolated, rural and remote regions where no broadband internet services currently exist other than satellite (Figure A.1) (Industry Canada 2003).

The broadband access problem is acute in Canada's northern and/or isolated communities, especially those located in the Arctic, and an urgent need exists to solve the access problem in those locales (Industry Canada 2001). As a result of broadband's superior ability to overcome physical or geographic distance with regard to communications, the argument can be made that broadband contributes to increased quality of life (Industry Canada 2001). The basis of the argument, which is similar in structure to societal assessments of previous advances in information technology (Wellar 1977; Wellar 1983), is that individuals who can fully utilize bandwidth-intensive websites for data/information gathering and other communications-based services, are enabled to perform or function at higher individual and community levels (Industry Canada 2001; Gómez-Barroso and Pérez-Martínez 2005).

As a result, and again in parallel with assessments of previous milestone developments in the field of computers/communications (Wellar 1977; Wellar 1983; Wellar 1983), broadband technologies are now generally perceived to be part of the essential infrastructure that is necessary for the effective and efficient operation of enterprises and organizations in the Information Society. That is, broadband connectivity is deemed to be essential for the delivery of programs such as e-medicine, e-health, e-education, e-governance, and e-entertainment, all of which are available to urban residents (Industry Canada 2004). With that premise as our overall term of reference, the goal of our paper becomes mission-oriented: to provide guidance on how to achieve broadband connectivity as a means of e-program delivery to communities and dwellings in Canada's northern, rural, remote and isolated areas.



Figure A.1. Current availability of broadband internet access in Canada is shown by the shaded areas.

The Digital Divide and Current Canadian Broadband Situation

As indicated by Figure A.1, the availability of broadband internet in Canada is strikingly different between rural and urban areas. Over half of Canadian households have broadband services via Cable or DSL but are mainly in urban areas (Veenhof, Neogi et al. 2003). In addition to the availability of service question, however, it is necessary to briefly consider internet adoption characteristics that led to a digital divide that temporally preceded and overlapped the widespread BIS offerings. Internet adoption characteristics offer lessons for the existing broadband digital divide, and as a result affect the policy recommendations presented later in the paper.

In densely populated urban areas, and within areas where internet service (IS) is available, not all dwellings immediately adopt IS offerings. As might be expected from the experience of previous computer/communications eras, differences in adoption practices can be traced to socioeconomic and demographic factors (Grubestic and Murray 2002; Grubestic 2003; Prieger 2003). Income and education are the main drivers that positively encourage the adoption of IS. Also, the structure and age of the dwelling head can affect IS adoption (Sciadas 2002). IS adoption, like any new technology, lags behind in lower income households. By way of illustration, in 1997 only 5% of lower income dwellings had obtained access to (adopted) an internet service(s), whereas the rate increased to 26.7% in 2003

(Statistics Canada 2003). More recently, gender differences in IS access have been recognized in Canada (Fritz 2004).

Key factors for internet adoption are highlighted in Table A.2 (Statistics Canada 2003). However, because studies examining the digital divide typically only compare use and demand versus demographic factors, the divide may actually be influenced more by the geographic availability of a given IS or BIS than is generally recognized (Prieger 2003).

Table A.2. Leaders and trailers in the adoption of internet services.

Group Characteristic	Leader Group	Trailing Group
Age of Dwelling Head	Under 35 (80%)	65 and over (25%)
Structure of Dwelling	A family with unmarried children (under 18) (84%)	One-person dwelling (40%)
Education	University Degree (88%)	Less than high school (32%)
Income	Highest Quartile (\$70,000 and more) (90%)	Lowest Quartile (\$23,000 or less) (35%)

As a result, and notwithstanding the factors that might affect a dwelling's ability or desire to adopt IS or BIS, it appears clear that the geographic distribution of BIS is the first issue to address when considering the matter of access in Canada. It is clear that access is the prerequisite for BIS adoption (Grubestic and Murray 2002). That is, it is logical, and necessary in our view, to first deal with questions about how to overcome the geographic divide, and to then contemplate questions, concerns and public policy strategies about how to increase adoption rates.

It is appropriate to note in closing this section that the United Nations has recognized that the geographic divide is an important policy matter that the needs to be addressed by member countries. At the last summit on the Information Society (12 December 2003), a number of the proposals for improving global connectivity and access were explicitly tied to the idea of linking localities and spatially-distributed groups to the internet (United Nations 2003) as a pre-condition for effectively dealing with issues underlying the digital divide.

RECORD OF THE GOVERNMENT OF CANADA IN SUPPORTING BROADBAND CONNECTIVITY TO COMMUNITIES

The first Canadian National Broadband Task Force (NBTF) in 2001 recommended that every Canadian community should be provided with BIS access by the end of 2004 (Industry Canada 2001), and emphasized that aboriginal communities are to receive accelerated focus. The NBTF report resulted in Industry Canada's Broadband for Rural and Northern Development Pilot Program²⁶, www.broadband.gc.ca. The goal of this portal

²⁶ In 2004, with the addition of the national satellite initiative, the website now reflects the broader goal of "High-capacity internet for all Canadian communities".

is to help distribute broadband internet to rural, northern or remote communities where market forces alone have insufficient incentives for BIS development (Industry Canada 2001; Hamilton 2002; Industry Canada 2002). Industry Canada has developed two programs to help provide required infrastructure. In the Broadband for Rural and Northern Development Pilot Program, \$79-million was invested in organizations representing 1380 communities (Industry Canada 2004). The second program, National Satellite Initiative, was established for communities where satellite is the only possible means of delivering broadband. Various partners contributed \$155 million to help cover the high cost of satellite technologies and equipment. However, a 'community connection' is expected to be available for only 10 – 15 years, which is the lifespan of the satellite (Industry Canada 2004).

Current Regulatory Issues Affecting Wireless Services and Policy Formulation

The Department of Industry (DOI) has many responsibilities, including the important mandate of making "Canadians more productive and competitive in the knowledge-based economy, [in order to improve] the standard of living and quality of life in Canada" (Industry Canada 2005). One means of achieving its mandate is by the promotion of telecommunications through the *Radiocommunication Act* and the *Telecommunications Act*.

The *Telecommunications Act* (Government of Canada 1993) instructs DOI to create policy objectives and regulatory controls, whereas the *Radiocommunication Act* (Government of Canada 1985) instructs DOI to plan the management, licensing and allocation of spectrum for communication purposes. One of the key objectives of the *Telecommunications Act* is to "render reliable and affordable telecommunications services ... to Canadians in both urban and rural areas in all of Canada" (Government of Canada 1993).

Section 46.5 (1) of the *Telecommunications Act*, "Contribution to fund" contains provisions for subsidizing telecommunication costs in areas where operating costs are high, that is, in rural areas. While it may appear that Section 46.5 (1) is applicable to broadband deployment, it is not the case. The Section applies only to basic telecommunication services, and not to internet Service Providers (ISPs). As stated in the legislation, collection of funds can only be conducted for "basic telecommunications services" (Government of Canada 1993), and broadband is not contribution-eligible. Consequently, under the current language, and contrary to the case for telecommunications, funds can not be collected from urban areas for re-distribution to support rural broadband communications.

When the Canadian Government stated in the 1997 Throne Speech that it wanted Canada to be at the forefront of the information revolution (Governor General 1997; Industry Canada 2002), Industry Canada was charged with achieving this goal. In the past few years and in various phases, the agency has auctioned blocks of prime spectrum (2.3, 3.5, 24 and 38 GHz) that would allow various wireless technologies to be used (Industry Canada 2004; Industry Canada 2004). However, the fact is that broadband internet access is still basically limited to the urbanized regions of the country (as illustrated by Figure A.1), which means that a number of public policy, regulatory, technical, and economic/financial matters remain to be addressed.

GEOGRAPHIC APPROACHES IN THE STUDY OF BROADBAND PLANNING AND DEPLOYMENT

Accessibility to terrestrial broadband wireless technology is a spatial issue, and the problem to be resolved can be expressed as a classic market or demand-supply task: That is, to ascertain the ability of different technologies to reach a base of consumers which is large enough to financially sustain the service.

Two kinds of specialized software for analyzing and planning of wireless technologies are pertinent to this paper in regard to the spatial connections between communications towers and dwellings – the potential BIS market. Radio propagation software can accurately estimate the signal reach of a communication tower. However, due to computational limitations, radio propagation software appears to be best suited for application in small regions. As a result, since the area involved in this study is the large land mass covered by Canada's rural, remote and isolated regions, it is appropriate to utilize the software and procedures contained within GIS for first approximation purposes. The radio propagation software can then be brought in to site the individual towers.

Geographic Information Systems

GISs are a component of the science of geomatics, a multi-disciplinary field that encompasses such disciplines as geography, mathematics, and remote sensing among others, and involves a range of computer/communications devices including global positioning systems (GPS). The most salient structural and functional features of GIS for this are "... computer software, hardware, and peripherals that transform geographically referenced spatial data into information on the locations, spatial interactions, and geographic relationships of the fixed and dynamic entities that occupy space in the natural and built environments." (Wellar 1993)²⁷. Although there are many variations on aspects of the above definition of GIS, there is general agreement as to its main features, namely, a database of map layers defined by spatial and attribute data, and software with capabilities to analyze and synthesize the relations between features distributed among different layers (Sawada 2002).

In the United States, various ventures are using GIS to support the deployment of broadband. For example, the Oregon Economic and Community Development Department provides a map of Digital Subscriber Line (DSL) Access, and a map of Oregon cities where broadband is provided by cable companies. In a related vein, an Oregon consortium used GIS to map infrastructure and services, including the telecommunications component. Cai (2002), recently analyzed the ability of the Pennsylvania telecommunications infrastructure to supply particular bandwidth demands. Cai's research was undertaken in the context of a policy related to school multimedia accessibility, and illustrated that GIS analysis can contribute to policy formulation and investment decisions for non-connected regions.

²⁷ Also quoted in Introduction to GIS, URISA 2000. (www.ci.bothell.wa.us/html/FAQ/GIS/WhatIs.htm)

The pertinence of GIS to this study is established by noting that spatial considerations are at the center of the wireless broadband service-dwelling relationship. That is, such tasks as delimiting market areas, locating towers, and calculating/estimating signal ranges involve the geographic concepts of distance, direction, location, accessibility, proximity, adjacency, containment and spatial coincidence (overlay) among features on the earth's real and modeled surfaces. These kinds of tasks are, by definition, at the heart of GIS applications (Wellar 1993). Further, the power of GIS means that *every* location on the landscape (natural or built) can be visited and at each location a broadband tower deployment can be simulated. For each simulated deployment, the number of dwellings provided access within a given service radius (a function of radio frequency, system hardware, customer premise equipment (CPE) and software among other factors) can be estimated and/or calculated.

GIS CASE STUDY: WiMAX MARKET POTENTIAL IN ALBERTA

Estimating the number of dwellings that can be serviced can be done under two scenarios: first, service via non-line-of-sight or NLOS technology and, second, service by line-of-sight or LOS technology. The upper and lower bounds of the potential market can be approximated by the two scenarios. In this study, we explore the contribution that GIS can make to deploying broadband internet services by utilizing Worldwide Interoperability for Microwave Access (WiMAX) wireless technologies as the demonstration vehicle. The design of WiMAX (also called the IEEE 802.16-2004 standard) incorporates both NLOS and LOS services, and its performance features are sufficiently well specified at the conceptual level that we can use the features to illustrate how a GIS capability can contribute to the analysis, planning and deployment of terrestrial wireless broadband services.

Figure A.2 (Grabianowski and Brain 2004) provides a schematic representation of a WiMAX communication network. Some of the key characteristics of the 802.16a standard are that it has a NLOS range of 8 km; a LOS range of up to 50 kilometres²⁸ (WiMAX Forum 2004); and, a high spectrum utilization of 3.8 bit/Hz where each base station can transmit up to 280 Mbps securely, depending on the user's antenna distance from the base station (Alvarion 2004). We now use those WiMAX design features to conduct the GIS case study illustrating how GIS can help to deliver WiMAX-type services to unserved dwellings in Canada's rural, remote and isolated regions.

²⁸ These numbers require that certain hardware is used by the service provider and consumer. The reader is referred to detailed documents from the WiMAX forum cited herein

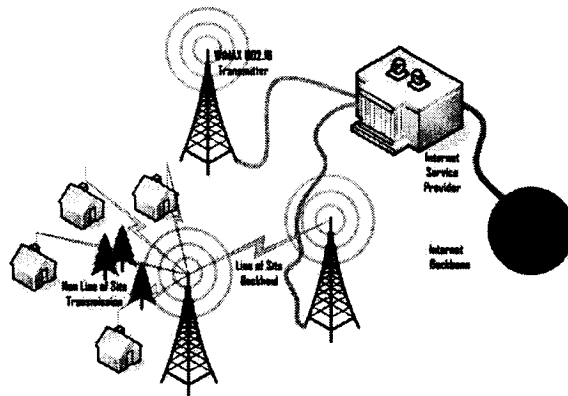


Figure A.2. Schematic of a WiMAX Communication Network (Grabianowski and Brain 2004).

Study Area and Data

The study area chosen to demonstrate the utility of a GIS approach is the Province of Alberta, which comprises a large part of the Canadian land mass with a large rural/remote population who lack broadband access (Figure A.1). The types of data required for the study (as well as the data sources) are noted by Sawada *et al.* (Sawada, Cossette *et al.* 2005), and are briefly described as follows (Table A.3).

Table A.6.2. Data required and land use along with the resolution/scale and source.

General Description	Type of Data	Resolution / Scale	Source
Census dwelling count Dissemination Area (DA)	Polygon	1:50,000	Statistics Canada
Rivers and Lakes	Polygon	1:50,000	DMTI Spatial Inc.
Communities ⁶⁴ with access and without access (served / unserved)	Table	Variable	Department of Industry
Provincial Boundaries	Polygon	1:50,000	DMTI Spatial Inc.
Digital Elevation Model (DEM)	Raster	300 m	Center for Topographic Mapping, Natural Resources Canada

Data on the spatial location of dwellings in the unserved (study) area were obtained from the Canadian census. Dwelling counts were derived from the 2001 geographic census reporting unit known as the Dissemination Area (DA). Typically a DA provides demographic data for 400 to 700 dwellings.

There are more than 52,000 DAs in Canada (the U.S. equivalent of a Canadian DA is the Block Group). In reality, dwellings tend to be clustered in particular parts of a census unit; the necessary assumption made here is that the values measured within a census unit are uniformly distributed across the polygon. Provincial boundaries are used to delineate an outline of Canada, and the rivers and lakes are used to eliminate locations where dwellings do not normally exist. As such, the spatial accuracy of the dwelling data was increased by

using GIS operations to remove (cookie-cut) water bodies and other areas where people and dwellings do not physically reside.

With those basic operating rules, we distributed the dwellings within and across the DAs into a systematic grid of 1 km² resolution (Figure A.3). The redistribution of dwellings within a GIS is described in Sawada et al (2005)³, and for Alberta resulted in over 320,000 cells containing just over 152,000 dwellings. Cai (2002) discusses in detail the issues and approaches to spatial data integration and transformations in the context of telecommunications analyses in GIS.

The data on communities²⁹ with access to BIS, and without access to BIS, were provided by the Department of Industry (DOI) and were current as of November 2004. Spatially within the GIS, through a process similar to that depicted in Figure A.3, we derived a layer of served and unserved dwellings for the 1 x 1 km grid.

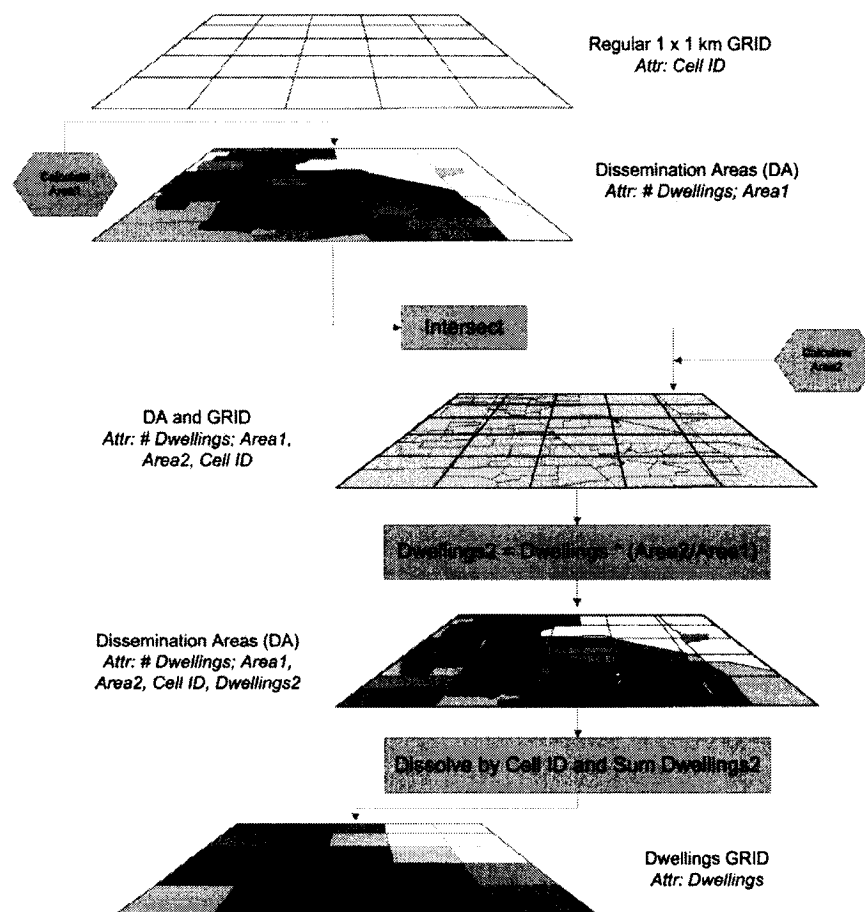


Figure A.3. Process of deriving the regular 1 x 1 km grid of dwelling counts from irregularly shaped dissemination areas (DAs). This process begins once all waterbodies and rivers have been cut-out of the DA layer. If the number of dwellings input equals the number in the output then the process is validated.

²⁹ The term "community" is loosely defined as a locality with "...a name, a distinct physical location and territory, and a population....for purposes of defining infrastructure gaps." Industry Canada Broadband Technical Team (2003). Understanding broadband wireless access. Industry Canada. Ottawa..

Finally, a digital elevation model (DEM) was used to conduct the line-of-sight (LOS) examination³⁰. Within GIS, LOS analyses are conducted using specialized functions that compute viewsheds surrounding a given observation point (Burrough 1986; Franklin 2002). A viewshed is defined as the terrain surrounding an observation tower that is directly visible (Figure A.4). Viewsheds have been used extensively for LOS analyses in the planning and deployment of radio communication towers (Dodd 2001; Rose 2001; Franklin and Guth 2005). However, viewsheds can differ among GIS systems given the various algorithms that exist (Dean 1997).

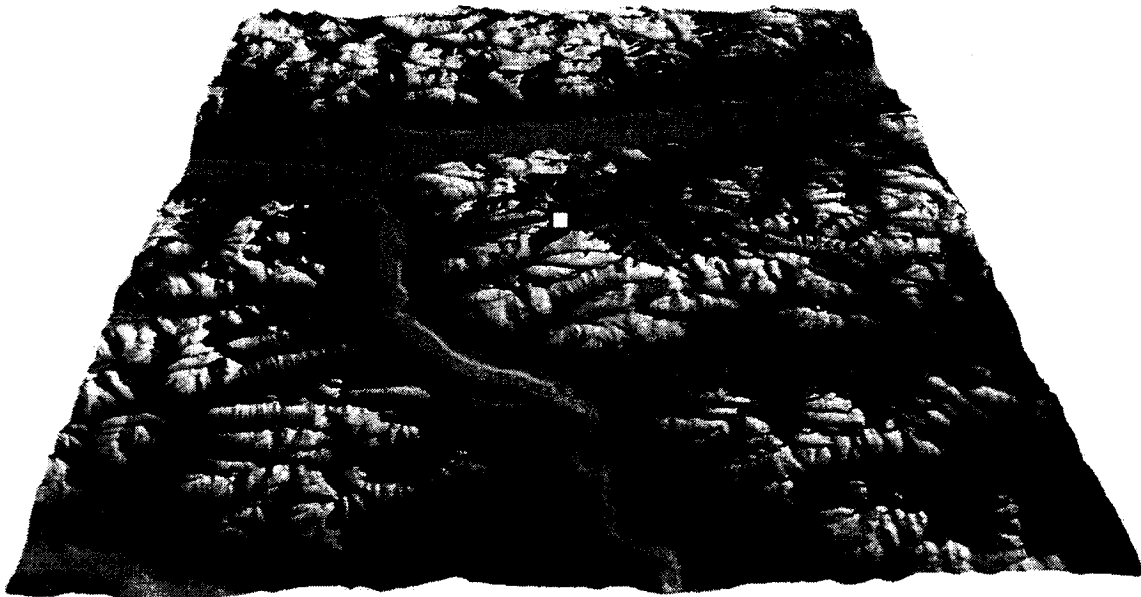


Figure A.4. Example of LOS examination for a proposed tower location within the Nelson, British Columbia region. Black patches represent areas visible from the communication tower (White Square).

Methodology

GIS software has the ability to provide a count of the number of dwellings within a distance radius of each potential communications tower location by either line-of-sight (LOS) and/or non-line-of-sight (NLOS). Two BWA scenarios were run for this analysis within the GIS:

Upper Limit Scenario (ULS): The market potential procedure uses dwelling distribution analysis (DDA) for each 1 km² cell in Alberta. This approach calculates the number of dwellings that could potentially be reached by NLOS technologies operating at 5 km and 50 km. The resulting estimate represents the upper limit of the potential market for the existing design specifications of WiMAX technology at 5

³⁰ Also known as 'intervisibility analysis'.

km. The 50 km NLOS scenario is used here for comparative purposes. NLOS technology within 50 km from a communication tower does not currently exist within the WiMAX specification.

Lower Limit Scenario (LLS): For Alberta, at the same radii, the dwellings that could be serviced using only LOS technology are identified. This analysis yields an estimate of the lower limit of the potential market for BWA for existing WiMAX specifications.

It is appropriate to emphasize that we could also have included a likely limit scenario (LLS). However, discussion of differences among the three limits or cases would have taken us away from our primary interest of demonstrating how GIS can contribute to BIS analysis, planning and deployment. That said, we are confident that our methodology is sound since the WiMAX technologies and extensions proposed by the IEEE would, upon becoming operationalized and implemented, effectively have the potential to serve a market that is somewhere between the upper and lower limit scenarios.

As for using the province of Alberta for the LOS analysis, that was not the result of a sampling process. Rather, Alberta was selected as the test bed for this project because it has topographic characteristics that are replicated across much of the Canadian landmass, it contains only two major urban centers (Calgary and Edmonton), and it has a significant rural population. In our experience, those reasons are more than sufficient to justify choosing Alberta as the locale for the GIS case study demonstration.

Upper Limit Scenario (ULS): NLOS Dwelling Distribution Analysis

We assume that each dwelling is a possible subscription unit to a wireless broadband service. Again, we emphasize that we are concerned with geographic accessibility of BIS rather than the digital divide. For this non-line-of-sight (NLOS) analysis, the terrain is assumed to be completely flat. Under such circumstances, and with the exception of the earth's curvature, all cells would have a clear line-of-sight with a potential communication tower. Each cell within the unserved dwellings region is visited, and the number of dwellings is summed within a 5 km radius and a 50 km radius (Figure A.5).

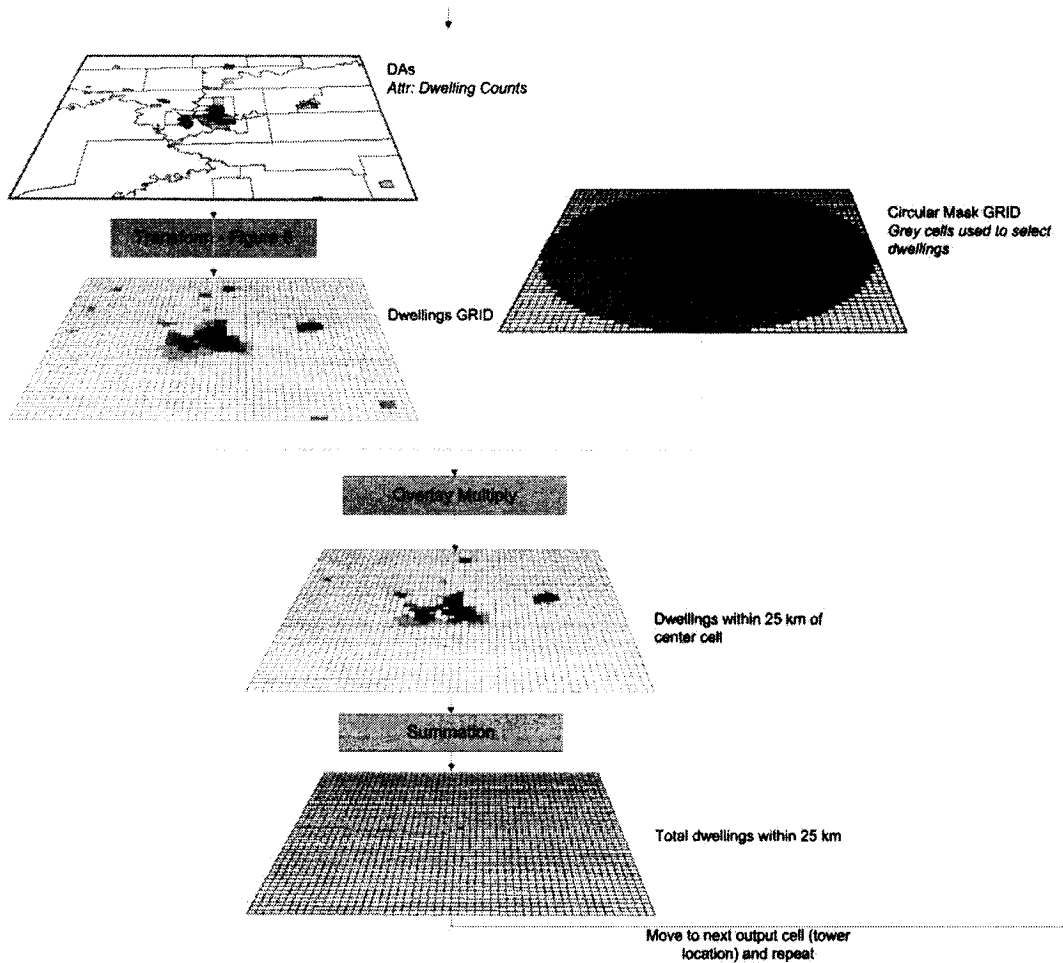


Figure A.5: Process of deriving the upper limit scenario (ULS) for the non-line-of-sight (NLOS) case. This example is for a 25 km radius surrounding the potential tower location at the center of the study region.

Lower Limit Scenario (LLS): Line-of-Sight Dwelling Distribution Analysis

The same dwelling dataset was utilized in this scenario and, in addition, a 1 km² digital elevation model (DEM) was also employed to identify the dwellings visible from each tower by direct line-of-sight.

By way of brief explanation, in order to count the number of dwellings we visit each cell that could be provided with broadband internet service (BIS) based on the establishment of line-of-sight (LOS) communication with other cells within a fixed radius of 5 and 50 km. Each observation point is a 1 km² cell with a tower of 30 m height above the terrain elevation, and includes a 3 metre offset for the dwelling antenna. If a cell does have LOS communication capability with the currently visited cell (observer point), then it is assumed that provision of wireless BIS is possible, and the dwelling counts for the visible cell are added to the tower's total of dwellings served (Figure A.6).

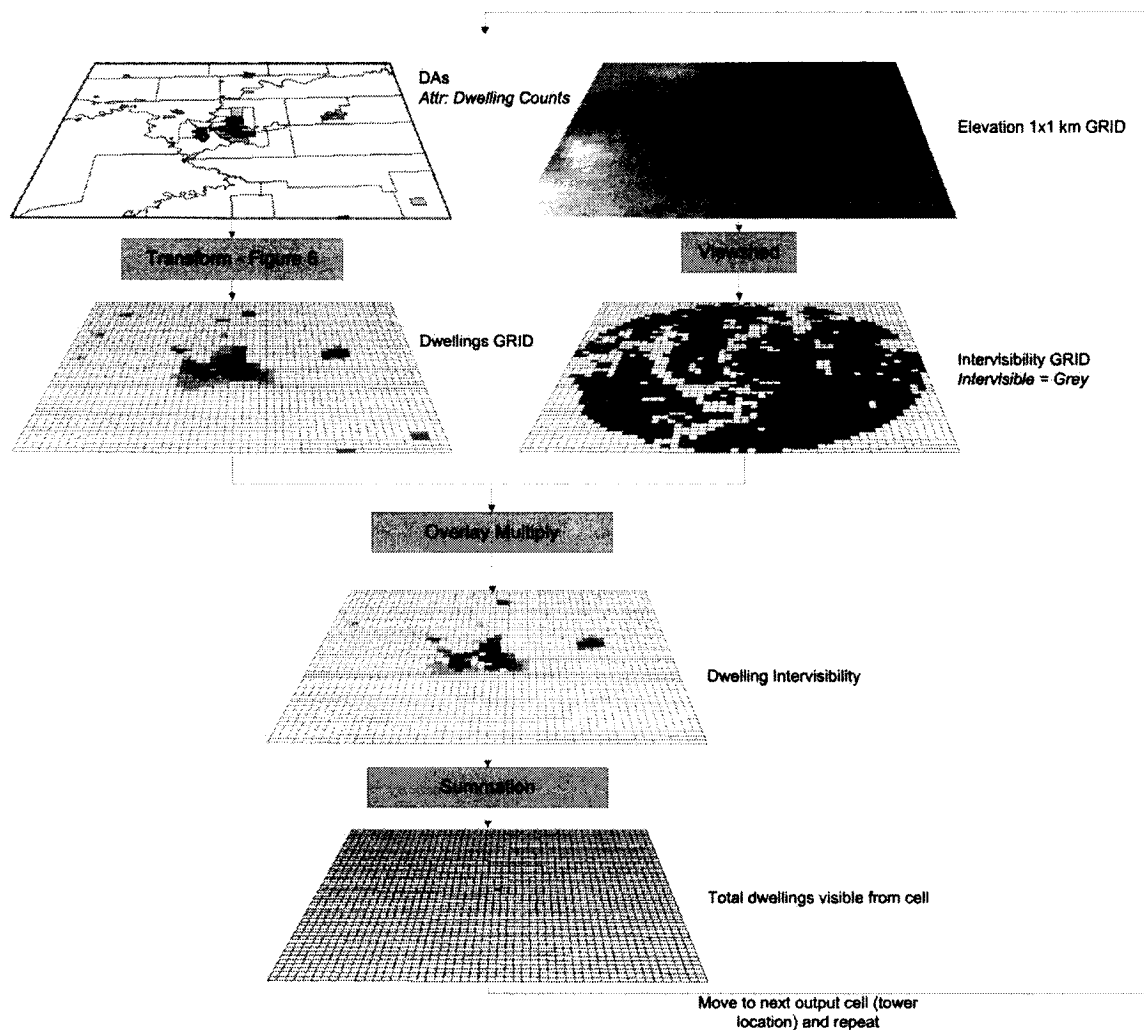


Figure A.6: Process of deriving the number of dwellings potentially served by WiMAX using LOS and viewshed analyses. This example is for a 25 km intervisibility analysis with the potential tower location at the center of the study region.

For all cells that are visible within the fixed radius, the dwelling counts are summed and assigned to the cell being examined. The resultant maps illustrate the number of dwellings that could be served if a tower was placed at each cell. Alternatively, to re-phrase the comment, the maps represent a prediction of the potential market for wireless BIS in Alberta.

From a public policy perspective, decisions regarding subsidization may be considered for remote areas where wireless BIS markets are unlikely to be profitable in the short term. In order to provide a potential guide as to where such subsidizations may be warranted or not warranted in the short-term, we consider the proportion of households potentially served in our study region based on a minimum sustainable business case scenario. Specifically, we assume that a wireless BIS deployment will need a minimum of 300 households, a number loosely based on a realistic WiMAX business plans for deployment in urban and rural areas (WiMAX Forum 2005).

We utilized ArcGIS 9.0 (Build 580) and ArcObjects RasterSurfaceOp coclass, ISurfaceOp2 "visibility" method to automate the analysis of the millions of individual locations whose viewsheds required determination. A custom application was written in Visual Basic for this purpose.

Results

Spatially, the highest concentrations of potential servable dwellings are concentrated around the Edmonton region of the province, and in the municipalities along major roadways (Figure A.7).

To illustrate the target market, we assume that 300 dwelling subscriptions are the minimum required to support a WiMAX tower base station. Given this assumption, we can consider adoption rates within the service radius ranging from 100% to 10%. In the LLS at 50 km, adoption rates as low as 10% (indicated in red on Figure A.8d) illustrate large areas within the unserved populations of Alberta that could be profitable. Spatially, these tend to be adjacent to the already-served regions surrounding Edmonton and Calgary (see inlay on Figure A.7 for reference). Observations at the 5 km intervals (Figure A.8a & b) suggest that adoption rates tend towards 50-75% for marketability. Figure A.8c represents the ULS at 50 km, which is unrealistic given today's technology but serves as a means of comparison only. The required NLOS technology operating at a 50 km radius is unlikely to emerge.

Turning now to the overall numbers as a means of summarization, at the lower bounded estimate, given by the LOS analysis in the lower limit scenario (LLS), and as shown in Table A.4 (last row), three-quarters of the (unserved) Alberta dwellings could be reached by WiMAX technology if the existing design features were implemented and operationalized. Further, and again on the premise of a fully functional WiMAX technology, even a 5 km radius provides broadband internet access for 37% of the unserved population (Table A.4, top row).

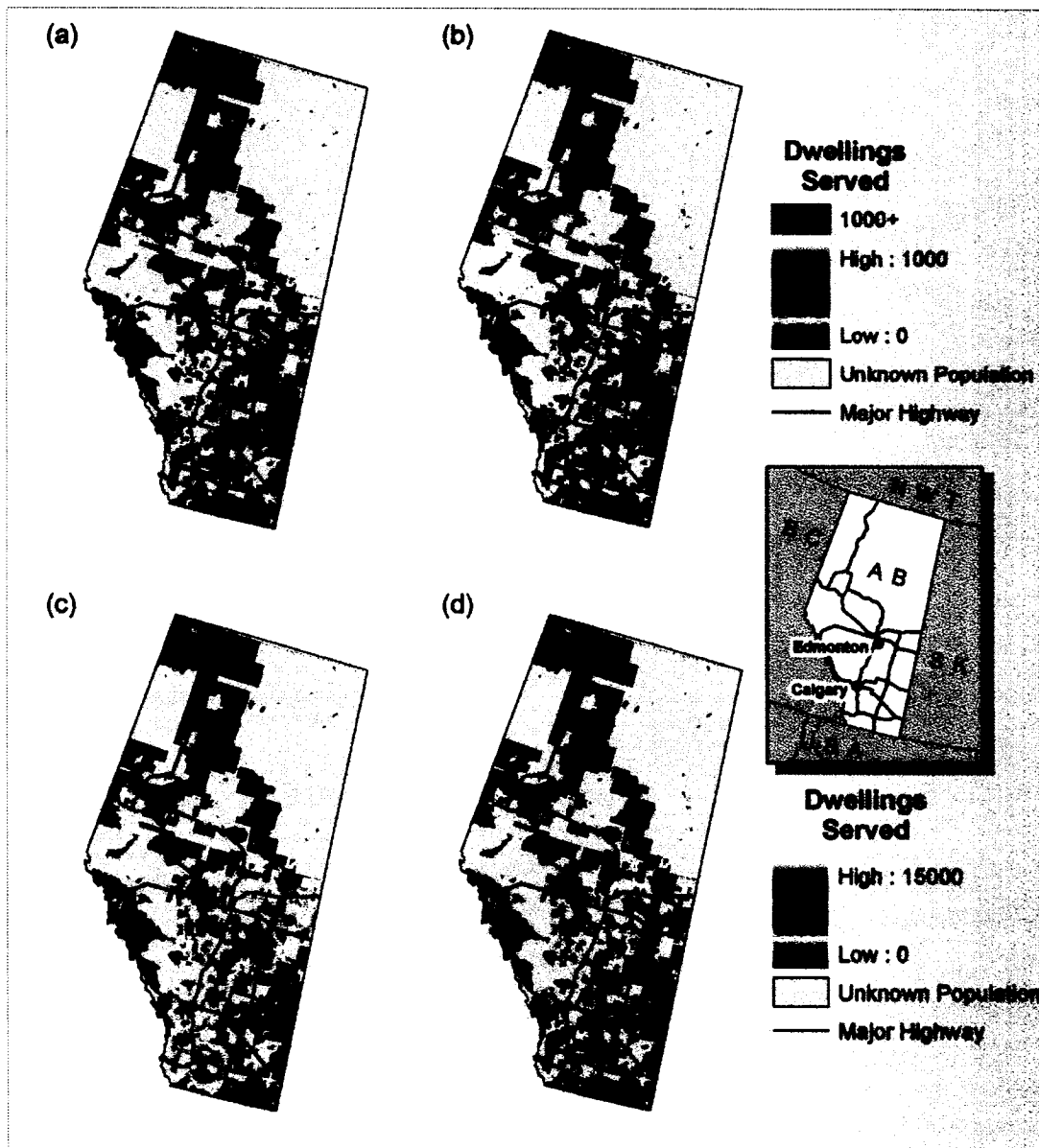


Figure A.7: Distributions of potentially servable dwellings under different scenarios: a) ULS 5 km; b) LLS 5 km; c) ULS 50 km; d) LLS 50 km. Note the differences in the legend magnitude between the 5 km radius criterion used in (a) and (b) and the 50 km criterion used in (c) and (d).

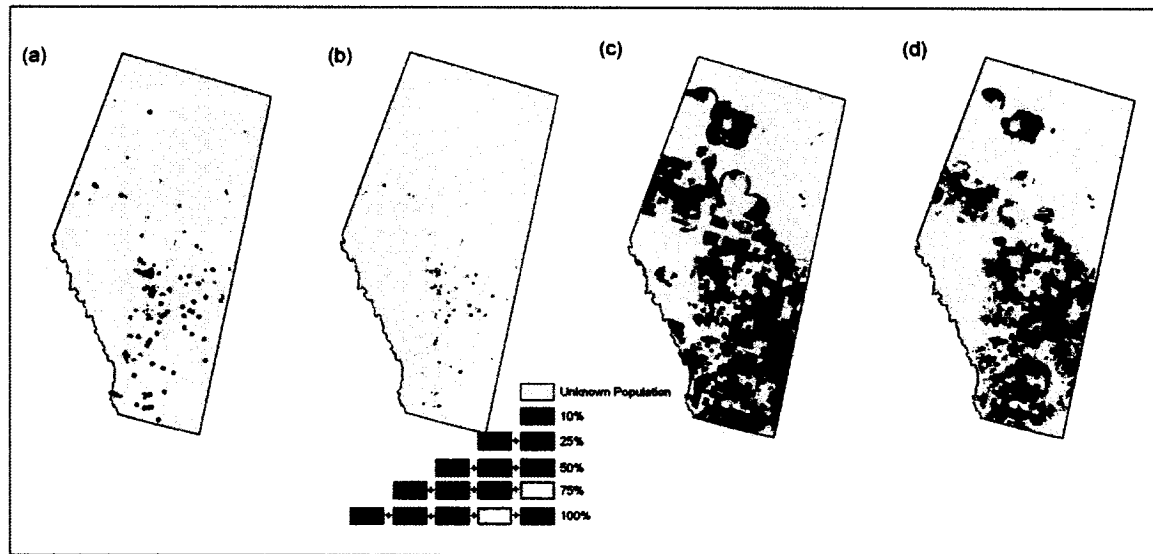


Figure A.8: Business case scenarios based on 300 household subscriptions at different market penetrations or take-rates; a) ULS 5 km; b) LLS 5 km; c) ULS 50 km; d) LLS 50 km.

Table 6.3: Summary of results for Alberta under ULS and LLS assumptions.

Scenario	km	% of 152493 households	
		Served	Unserved
ULS	5	41	59
LLS		37	63
ULS	50	99	1
LLS		86	14

We might now consider a viable WiMAX scenario, where NLOS is operational at 5 km (8 km is NLOS in the specification³¹) and LOS is operational to 50 km³¹. In this case, as much as 90% of the unserved households could benefit from WiMAX technologies operating at specification. While this percentage is promising, it should be considered a first approximation in because of other confounding variables that have not been considered.

DISCUSSION

Our results illustrate where BWA tower deployments could potentially be placed and have sufficient market support. However, there are several caveats that need to be explicitly noted with regard to the data used, the spatial resolution of the study, and the assumptions underlying the analysis. From the research design and operational perspectives, the caveats are a guide to the informed use of the maps within the decision-making and planning process and are intended to contribute to further model refinement. In addition, however, the caveats also serve as warning signals or advisories to public policy researchers and decision makers,

³¹ Because the analyses at 50 km in both the ULS and LLS include the household data at the 5 km analysis, we can subtract the 5 km LLS from the 50 km LLS and add the result to the 5 km ULS to produce a number that conforms to WiMAX specifications for NLOS and LOS services.

and others who are evaluating or deliberating WiMAX deployment plans or proposals from industry or other interest groups.

To begin with, we have assumed that a tower, when placed, will be able to establish a link with the fibre optic-based backbone. Where tower deployments are concerned, the necessity of a backhaul/backlink point-to-point transmission system via microwave from each potential hub (tower) is not addressed in this research. We leave this assumption as an item for explicit inclusion in future model refinement, or for particular business case scenarios.

Moreover, we have assumed that a tower could be placed anywhere within the unserved regions except in water bodies, and analyzed each potential location or cell independently of the previous iteration. Any overlap between the serviced areas of each cell means that the locations of potential towers have not been spatially optimized. However, the maps in Figure A.7 do illustrate the hot-spots for potential WiMAX deployments that would capitalize on the number of dwellings serviced.

The point being emphasized is that this paper does not deal with the minimum number of towers required to service a region. Rather, we are concerned at this stage with accessibility to wireless BIS in Canada's northern, rural, remote and isolated regions, and the matter of network layout optimization is a different task. Additionally, we have not addressed the possibility of alternate configurations for wireless networks such as mesh layouts⁷³ or build-outs from the urban/suburban periphery. Finally, we do not address the issue of different bandwidth requirements for different markets (Cai 2002) (business, government, residential etc.) since our present focus is on BIS access for residential dwellings.

It is also important to establish that at the local scale (1-2 km²) our results do not provide the accuracy needed for tower siting. To undertake that task, the identified regions could be analyzed utilizing higher resolution data with the same methodology. As noted above, our datasets were aggregated to 1 km² of spatial resolution for reasons of consistency and computational efficiency within GIS. One square-kilometre is far too coarse to determine a definitive placement for a radio communications tower. However, our maps illustrate where the unserved population could benefit from BWA deployment and higher resolution analyses.

Further, using wireless technologies to provide broadband service requires consideration of factors other than topography and LOS that affect the strength and quality of transmission signals. The following comments indicate how some of these factors can affect BWA access speed and carrying capacity:

Antenna Height – Affects an antenna's range and effectiveness. Increasing the height allows for further range.(Louis 2002) However, increasing the height will also increase the interference, which is critical for cellular systems. Typical heights range from approximately 50 to 150 meters (Tamir 1967).

Atmospheric Scattering –Significant amounts of water vapor, humidity or rainfall can decrease signal strength and increase signal scattering and absorption. Precipitation in the

form of fog, hail and snow can cause serious reduction in signal strength (NAVEDTRA 2002) as it can “collect on the leaves of trees and produce attenuation until it evaporates” (Inpath Devices 2004).

Frequency – The higher a frequency the less likely a connection can be NLOS. Also, with higher frequencies come smaller geographical ranges, as there is an inverse relationship between frequency and service range (eg., 20 GHz – 23 GHz – 2 km; 800 MHz – 6 GHz – 45) (Louis 2002).

Foliage (Vegetation Factor) – The presence of vegetation or forest cover causes a decrease in radio frequency (RF) energy (Tamir 1967). Different types of trees have varying influences. For example, coniferous trees affect RF signal more than deciduous trees (Inpath Devices 2004).

Topography (mountains, hills, earth’s curvature) – Mountains and varying types of terrain or even the curvature of the earth can cause signals to be reflected, which in turn can cause signal echoes and path fading (Driessen 2000).

Obstacles – Man-made obstacles and reflective surfaces (buildings, roadways) can affect both the range and path of a transmission signal (Louis 2002).

Path – Depending on the environment, various paths from the transmitter to receiver may be possible. When combined at the receiver, these paths may create interference, reducing the signal quality.

These factors need to be considered individually and collectively in order to devise a plan that maximizes the number of dwellings potentially capable of using wireless technologies. While it is possible to integrate the above factors within a GIS, there are limitations to the use of GIS packages in conducting large-scale radio propagation analysis (RPA). Specifically, while GIS packages contain functions for visibility analysis, the capabilities to integrate such factors as the determination of radio signal strength are absent. However, integration of radio propagation can be done by means of custom application development or by combining geographic information systems (GIS) and radio propagation analysis (RPA) software.

Combining GIS and RPA allows for factors known to cause signal degradation to be considered at the regional/local level, while the role of GIS is found in conducting examinations of potential market locations at the national scale. Based on that methodology, our results should be considered a first-approximation that identifies candidate locations/regions for subsequent specialized RPA software analyses, or GIS analysis with higher resolution data.

POLICY IMPLICATIONS

There activities of several national governments have moved to the forefront in terms of making major investments in broadband infrastructure. South Korea and the United

Kingdom surface on the leading edge, and we briefly note elements of their BIS policies that make them 'countries to watch and learn from'.

South Korea is presently the leading country in terms of the rate of broadband uptake, and now ranks as the most connected country in the world. In 1998, only 14,000 dwellings had broadband, whereas in 2005 the number has risen to over 12 million out of 15 million dwellings (eMarketer 2005). South Korean BIS growth can be linked to a number of factors, but the primary factor is that the national government aggressively promoted and launched various infrastructure initiatives. It began laying a framework for information promotion in 1995, with the objective of making BIS affordable and accessible to all South Koreans.

In the United Kingdom (UK), the UK government is working towards providing broadband to all those who desire the service. Already the UK has 99% coverage for mobile phones and 96% coverage for broadband (Ofcom 2005).

We draw on those initiatives to suggest that our study provides a rationale and a route for the Government of Canada to follow when formulating and implementing policies and programs designed to enable Canadians residing in northern, rural, remote and isolated areas to actively and equitably participate as full members of the Information Society (Governor General 1999; Governor General 2001).

Policy Message for Canada

While the goal of providing all Canadians broadband internet access (BIS) access by the end of 2004 (Governor General 1999; Governor General 2001) has not been reached, the uniqueness of the Canadian situation in the context of connecting citizens to the Information Society needs to be recognized. On the one hand, Canada has the second largest northern, isolated, rural and remote area among countries, and its expanses of unpopulated land and low-population densities are unlike those in the U.S., the UK, or South Korea. On the other hand, however, and despite the difficulty of providing BIS access to all Canadians, it needs to be borne in mind that Canada is a world leader in the field of telecommunications, and since 1999 federal policies have provided the majority of Canadians – those living in urban areas – with BIS access.

In this study, we demonstrate how geographic information systems (GIS) can assist the Government of Canada, as well as provincial and territorial governments and the broadband industry, to narrow and then eliminate Canada's urban-rural broadband divide (National Selection Committee 2004). That is, by means of a case study, we show how GIS can contribute to the analysis, planning, and deployment tasks involved in providing broadband internet services in Canada's northern, remote and isolated regions. It is our belief that the research underlying the case study has due and appropriate regard for the social, technological, economic, and geographic aspects of the broadband divide, and that as a result it could serve as a basis for launching public policy initiatives to ensure that all Canadians, including those located in the rural, northern, remote and/or isolated regions have equal access to broadband internet service.

CONCLUSION

We began this paper by establishing the importance of broadband connectivity to residents, businesses, institutions and other entities in Canada's northern, isolated, rural and remote communities. That part of the presentation includes a commentary on the role of the Government of Canada in providing broadband connectivity to residents of these rural communities, and outline of the current regulatory issues that govern wireless services and shape the policy formation and program implementation processes.

In the second part of the paper we discuss why and how to use a geographic information system (GIS) approach in studies involving broadband internet service analysis, planning and deployment. Our GIS-based analysis permits rapid assessment of terrestrial broadband wireless markets in northern, isolated, rural and remote regions with minimal data requirements.

Initial results indicate that a large proportion of Canada's rural communities located beyond the urban zone could potentially be served by wireless systems operating with current WIMAX specifications. We believe that these results are of direct political, social, and economic consequence to millions of Canadians in northern, remote and isolated regions of the country who at present do not have access to broadband internet service. In addition, and very importantly, we believe that the results and the research underlying their derivation provide evidence and direction for the Government of Canada to consider in its deliberations over how it can best proceed in order to achieve the national objective of all Canadians having full and equitable access to broadband internet service.

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B Appendix

A GIS APPROACH FOR ASSESSING BROADBAND WIRELESS MARKET POTENTIAL FOR RURAL AND REMOTE CANADIAN COMMUNITIES DEPLOYMENT

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Main Description

There are still millions of Canadians without broadband access and the majority of these reside within the rural and remote communities of Canada. This situation has led to an urban/rural 'broadband divide'. Barriers exist to the deployment of wireline broadband for rural and remote regions: there is a significant expense involved in the installation and maintenance of a wired infrastructure to reach remote dwellings and businesses. In such situations the costs will outweigh the benefits of such wireline access. By way of illustration, arctic communities are very small and the distances between them are often hundreds of kilometres. In these situations the connectivity or network architecture is essential for delivery of applications such as e-health, e-education and e-governance, no matter what the cost may be. The Canadian government has policy commitments to remove the rural and remote broadband divide. Thus, research has been initiated by Industry Canada and the Communications Research Centre (CRC) into wireless broadband solutions in the form of terrestrial and satellite technologies.

Accessibility to terrestrial broadband wireless technology is a spatial question that involves the capacity for different technological solutions to reach profitable population bases. Various standards organizations such as the Institute of Electrical and Electronics Engineers (IEEE) are working on the development of technologies that would permit broadband wireless internet access over much greater distances than that permitted by the current technologies and without requiring line of sight with the base station. Benefits of such new technologies include rapid deployment, flexibility, scalability and not having to physically connect to the subscriber.

Here we use a geographic information systems' approach in conjunction with public and private data sources to determine the number of people and potential market that could be served by these new technologies in Canada. We identify those areas where deployments would be most profitable from both a business and access point of view. These findings are significant for determining subsidization policies in particular, within Arctic regions of Canada. Results suggest that a considerable proportion of the Canadian population could be served by these new systems and this is of interest to the unserved population, service providers, telecommunication manufacturers and policy and frequency regulators in Canada.

Short Description

Differences in internet accessibility have led to an urban/rural 'broadband divide' in Canada. We utilize GIS to determine the potential market for new wireless technologies in rural and remote communities.

Introduction

Intimations of an information society existed in the early 1960's (Wellar 1985), and considerable discourse today focuses on an emerging knowledge society. In addition to the edification of societies and the support of research and development, efficient and effective media and communications, information technologies and services are required for to complete a knowledge society (Rai and Lal 2000; Bertot 2003). As such, a knowledge society cannot exist in a vacuum and is unavailable without an efficient means of communicating both data and information (Wellar 1989) and becomes unattainable for those who have not yet stepped onto the information stage. An information or knowledge-based society requires broadband communications for essential delivery of programs such e-health, e-education and e-governance, among others, in addition to regional development and e-business (Bertot 2003; Xavier 2003). One might argue that the Information Age matured in the 1990's with the large-scale deployment of wireline and wireless broadband telecommunications technologies, in particular the wholesale uptake of the internet (Mansell 1999) around the turn of the century. For those countries, regions and individuals who have not entered the information age, accessibility to broadband telecommunications technology is the primary issue.

Within regions of sparsely distributed population, accessibility to terrestrial broadband wireless technology is a spatial question that involves the capacity for different wireless technologies to reach profitable population bases in order to attract service providers (Prieger 2003). In planning for the rural and remote deployment of wireless broadband services, Geographic Information Systems (GIS) provide a comprehensive toolset that can be used over extremely large regions to assess the market potential for existing, new and emerging broadband wireless technologies. Thus, a GIS approach can help both define and provide the impetus for bridging urban/rural broadband divides in developing regions. Therefore we show how both GIS and broadband wireless technology contribute to the promotion and extension of the knowledge based society.

Herein, we provide a brief description of geographic information systems (GIS) for those who are unfamiliar with this technology; we define broadband in general terms as well as the issues of technological accessibility and discuss the specific Canadian regulatory mechanisms that exist to address broadband accessibility. Finally, assuming a market demand model of broadband deployment for rural and remote regions, we outline a specific method and approach that uses GIS technology to address the market potential for wireless broadband internet technologies for the landmass of Canada, the second largest country in the world.

Background

Broadband

What is broadband? Broadband telecommunications in this paper refers specifically to broadband internet access. Broadband can be defined as a "high-capacity, two way link between the end user.." (NBTF 2001) and the internet backbone "...capable of supporting full-motion interactive video applications" (NBTF 2001). In other words, the end-users

receive and send data faster than a 56 Kbps (Kilobits per second) dialup connection based on analogue telephone wires (so called narrowband). Broadband is widely available within major urban centres with speeds ranging from 1 - 5 Mbps (Megabits per second). These data transfer rates, also called the "bandwidth", are 17-89 times faster than an analogue dial-up connection. Broadband provides fast bi-directional (symmetrical) data transfer and as such produces a more interactive experience with internet content. Broadband access within a household adds to the Quality of Life (QoL) by allowing communicating, information gathering and entertainment through real-time interaction with bandwidth intensive websites (NBTF 2001).

For businesses, broadband allows for lowering operating costs, opening new markets, increased sales, increased productivity, efficient communication between retail outlets, as well as the flexibility to pursue new opportunities³². The majority of businesses that have adopted broadband, report that broadband has been a positive investment that has become indispensable to their business³³. Using narrowband dialup internet is too limiting for today's internet content. As such, broadband technologies are fundamental for effective and efficient operation within today's information based society.

GIS

Accessibility to terrestrial broadband wireless technology is a spatial question that involves the capacity for different technological solutions to reach profitable population bases. While specialized software for the analysis and planning of wireless technologies exist (e.g., PlanetEV³⁴ by Marconi Corporation plc.) and provide very accurate modeling of radio propagation, these types of software, are however, designed for application in small regions. Such specialized software represents a second tier of analysis when one is ready to determine placement of broadband towers at local levels. At the scale of the Canadian landmass we can utilize, as a first approximation, the software and procedures contained within GIS to address spatial questions of accessibility and determine likely areas for system planning and deployment for rural and remote access.

Geographic information systems are a component of the science of geomatics, itself a multi-disciplinary field that includes global positioning systems (GPS), remote sensing (RS), cartography cadastral surveying, geodesy and photogrammetry. Today, the geomatics field is estimated to be worth between \$45-65 billion annually (CDN) and is led by the US and Canada respectively³⁵. A GIS is comprised of: 1) A database of map layers defined by spatial and attribute data, and; 2) Software with capabilities to analyze the relations between features among different layers (Sawada 2002). A GIS is involved in the creation of information and knowledge through its capacity as a decision support system (DSS) (Wynne and Perkins 1995).

³² Ferndale Broadband Campaign Website. Benefits of Broadband. 2003.

<http://www.btinternet.com/~broadband4ferndale/benefits.htm> (Date Accessed: 21 June 2004)

³³ Macklin, Ben and Butler, Steve. The Benefits of Broadband Report. summary page. e-Business & Technology from Around the World. May 2002. <http://www.insurance-canada.ca/ebusiness/other/EmarketBB200205.php> (Date Access: 21 June 2004)

³⁴ <http://wnp.marconi.com/PlanetEV/index.shtml>

³⁵ Natural Resources Canada, <http://www.nrcan.gc.ca/statistics/geomatics/default.html>

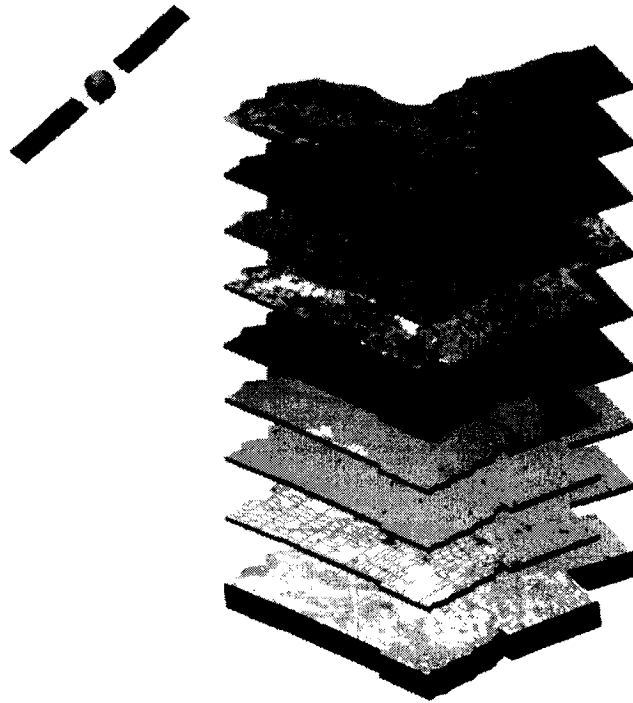


Figure B.1. A visual representation of a GIS database illustrating the decomposition of observable entities from a 'real-world' representation (such as a topographic map sheet bottom) into individual layers such as roads, elevation, census data etc. The layers represented here are in Ottawa, Canada.

Spatial data are the digital map layers containing features observed on the earth's surface (Figure B.1). Attributes are the physical or social observations at each feature within each layer. For example, a layer of points could represent the location, proposed or otherwise, of radio telecommunication towers; a layer of lines may represent roads with attributes of surface type and number of lanes; an area layer could represent dissemination areas with the attributes of population and income level for each DA. Together, spatial and attribute data comprise the GIS database which can be quickly mapped and visualized.

A GIS is far more than an automated mapping technology because it allows for analysis among the different layers so that spatial questions can be addressed. Spatial questions deal with the concepts of distance, direction, location, accessibility, proximity, adjacency, containment and spatial coincidence (overlay) among features in space. For example, every location in space can be visited, and at each location a virtual broadband tower can be placed and the number of households within a given service radius (a function of frequency) can be determined.

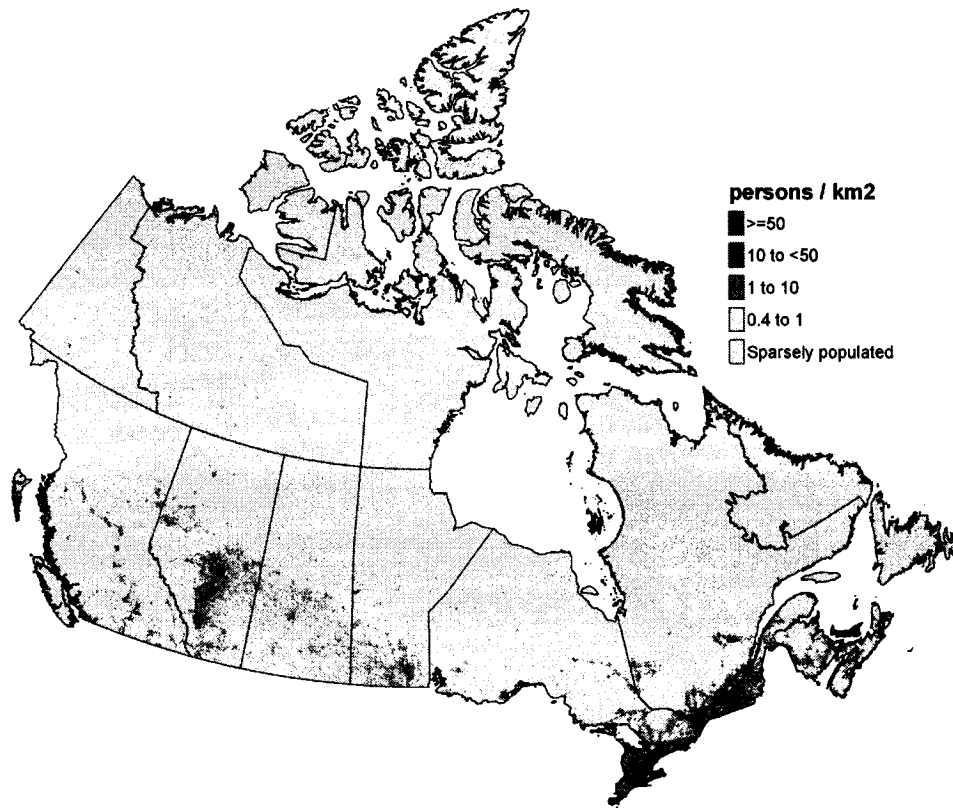


Figure B.2. Population Density Map of Canada at a 1 km² resolution.

There is a long history of GIS as a knowledge support tool, particularly, where society is concerned, GIS systems, their expert application and synthetic capabilities lead to a natural spatial decision support system (SDSS) (Wynne and Perkins 1995). In this paper we utilize GIS as a SDSS that provides maps that can be used as impetus in both the policy and private arenas for the purpose of planning rural and remote broadband wireless deployments.

Methods and Data

The study area for the project extends to all areas where the Canadian population resides. Figure B.2, illustrates the population density of Canada at a resolution of 1 km². We utilize the smallest 2001 geographic census reporting unit in Canada called a Dissemination Area (DA). A DA provides meaningful demographic information which typically represents 400 to 700 households. There are more than 52,000 DAs in Canada³⁶. We utilized 2001 dwelling counts for each DA. Data pertaining to the availability of Broadband internet, in the various DAs, were provided by the Department of Industry (DOI) and are current as of November 2004. Figure B.3 shows the Canadian population base and indicates that a large portion of rural and remote communities remain unserved for broadband telecommunications.

³⁶ The U.S. equivalent of a Canadian DA is the Block Group.



Figure B.3. Canadian Population with and without broadband internet Access at a 1 km² resolution.

Methodology

Our primary inputs into the analysis within the GIS are dwelling counts. We assume that each dwelling is a possible subscription unit to a wireless broadband service. Given that the spatial data for the census boundaries are general maps, the accuracy of the maps was increased by removing (cutting-out) water bodies and other areas where people and households cannot physically reside (Figure B.4). While in reality households will tend to be clustered in particular parts of a census unit, the necessary assumption made here is that the values measured within a census unit are distributed equally across the census unit. As such, we distributed the households within and across units into a more organized and systematic grid.

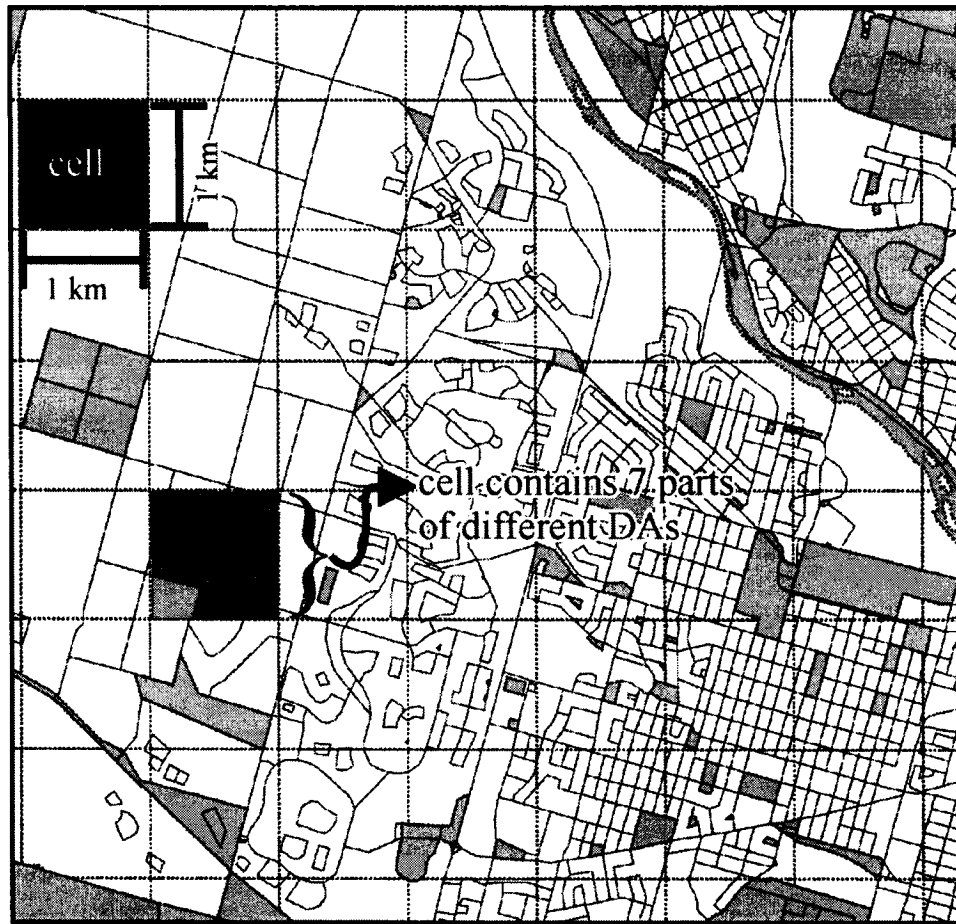


Figure B.4: Example of regular grid overlaid on dissemination areas (DAs); light grey areas are the DAs, darker grey areas are Waterbodies or DAs without populations that were removed from analysis; dotted lines represent the 1 km cells (one is highlighted in black with dimensions); one example is given of how one cell intersects seven different DAs and as such, the number of households assigned to the cell is equal to the sum of households taken from the proportional population assigned to each piece of the 7 DAs intersected by the cell.

The irregular shapes of the DA dwelling data were converted into discrete non-overlapping 1 x 1 kilometre (km) grid cells (Figure B.4). The 1 km resolution produced more than 20 million grid polygons and pushed the limits of the processing power for the eight computers used in analysis³⁷. The method used in distributing households from irregular DAs into regular grid cells is as follows:

- Linkage of Dissemination Area's with data provided by the Department of Industry to determine those DAs which are currently unserved, here called DA Population;
- Removal of the DAs without dwelling counts;
- Removal of areas with access to internet broadband services;
- Removal of lakes and river areas of each DA;
- Calculation of the area of each DA, here called Area of the DA;

³⁷ We used Dell Precision 650 Workstations each with two Xeon 3.2 GHZ processors and 4 GB of RAM.

Creation of a 1 x 1 km grid with a unique identifier for each cell spanning the bounding coordinates of Canada.

The grid created in step six is unioned with the layer representing unserved DAs. This results in the creation of numerous polygons where more than one DA intersects a grid cell. Each new polygon contains the grid cell identifier and DA dwelling count.

The areas of all new polygons are calculated, here called Area of Split Polygon;

The population of each new polygon is calculated as:

$$New\ Population = \left(\frac{Area\ of\ the\ Split\ Polygon}{Area\ of\ the\ DA} \right) \times DA\ Population ;$$

Using the unique identifier, the New Population is the summed for each cell identifier and dissolved back into 1 x 1 km cells for subsequent analysis.

Total dwelling counts from step ten are compared to the unserved dwelling counts in step 1 for Canada to ensure process validity.

Finally a neighbourhood function³⁸ is applied to each cell to determine, within a given radius from the cell center, the number of households that could potentially be served by a wireless broadband equipped tower.

This procedure is depicted in Figure B.5 as a flowchart³⁹ that outlines the logic of the analysis process.

³⁸ These are also known as focal functions in some GIS literature.

³⁹ In GIS this type of a flowchart is more often called a cartographic model as it defines the individual layers and operations required for mapped output.

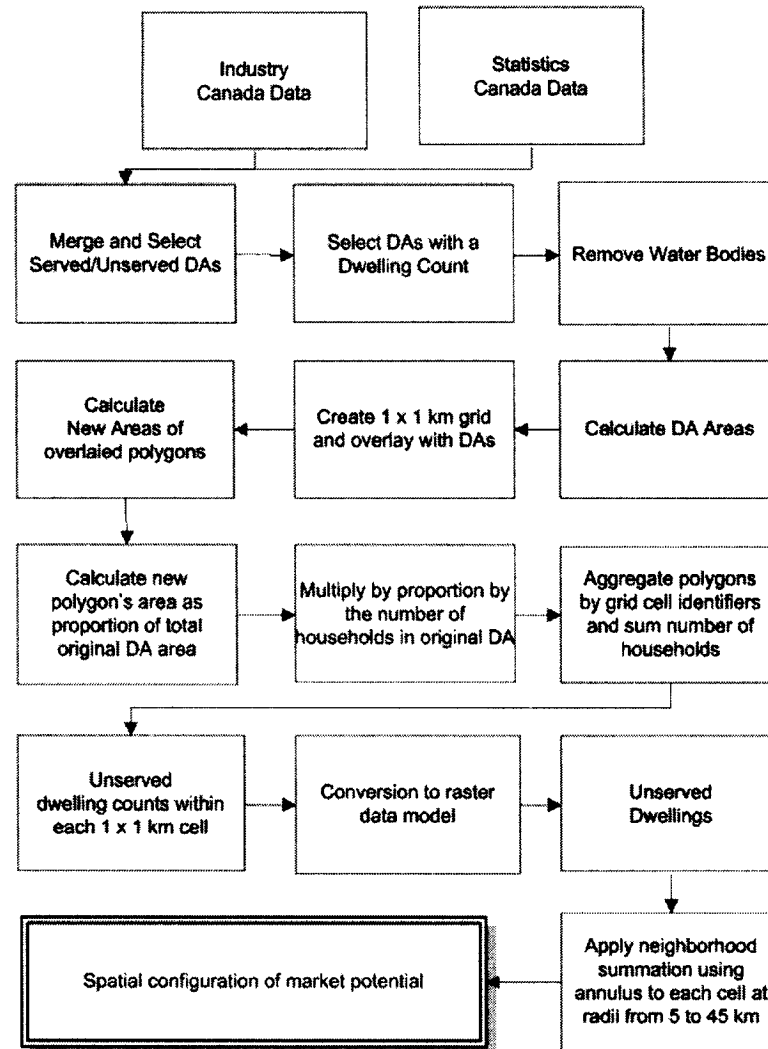


Figure B.5. Cartographic model representing the method used for analysis.

Minimum Sustainable Size

With the households distributed within the 1 km² grid cells, our next step was to estimate the minimum number of dwelling-based subscriptions required for a telecommunications tower to be profitable. The key input is the minimum number of dwellings that can financially sustain the construction of a telecommunications tower (Figure B.1) through paid subscriptions for wireless broadband services.

We assume that 200 dwellings at minimum could support the construction of a broadband tower if after five years at least thirty percent of the dwellings with access have subscribed to the technology (Figure B.2). Moreover, after 4 years, there would be a total take rate of 25% and the tower would be paid for after six years. The reason for such a high cost of the tower is largely due to questions of accessibility within rural and remote regions.

Broadband Technology

Newly developing standards by the Institute of Electrical and Electronics Engineers (IEEE) are expected to allow for non-line-of-site connections, support low latency links (WiMAX 2004), and the ability to service radii of up to 50 km⁴⁰ using both licensed and unlicensed portions of the frequency spectrum (Wingfield 2004). One of the features that makes BWA a solid system is that it deals with connections on a link-by-link bases and has varies modulation schemes in order to adapt to the signal quality⁴¹. BWA is appropriate for lightly populated areas (as well as urban areas) and is able to provide access “for millions of subscribers who would otherwise be left out”⁴².

Figure B.0.1. Network Cost and generated revenue for the construction for a communication tower.

Cost		Revenue	
Base Station Equipment ⁴³	\$30,000	Household connection fee	\$200
Tower Construction / Property	\$30,000 (est)	Monthly	\$50
Connection Rates / Maintenance	\$12,000 (est)		

Figure B.0.2. General Calculations of the Payback Period for Construction of a UHF Wireless Tower.

Year	Cost	Take	Number of Subscribers	Initial Revenue	Totalled Monthly Revenue	Balance
1	\$72,000	10%	20	\$4,000	\$12,000	-\$56,000
2	\$12,000	15%	30	\$2,000	\$18,000	-\$48,000
3	\$12,000	20%	40	\$2,000	\$24,000	-\$34,000
4	\$12,000	25%	50	\$2,000	\$30,000	-\$14,000
5	\$12,000	30%	60	\$2,000	\$36,000	\$12,000
6	\$12,000	30%	60	\$0	\$36,000	\$36,000

Analysis

Once the household data within the irregularly shaped enumeration areas (EA) were distributed within the grid regular cells we converted these cells to a raster GIS model representation with the same dimensions. The raster data model allows for more efficient calculations. The only data contained in each raster cell was the number of dwellings without access to broadband telecommunications. We then used our GIS system to visit each cell and count the number of dwellings contained within varying radii that included 5, 15, 25, 35 and

⁴⁰ Alvarion. Introducing WiMAX: The next broadband wireless revolution. 2004. (Date Accessed: 23 July 2004) http://www.alvarion.com/RunTime/Materials/pdf/Wimax_wp.pdf

⁴¹ Fujitsu Microelectronics America, Inc. White Paper. WiMAX Technology and Deployment for Last-Mile Wireless Broadband and Backhaul Applications. August 2004. <http://www.fujitsu.com/us/services/edevice/microelectronics/wpbwa.html> (Date Accessed: 15 September 2004)

⁴² Alvarion, *ibid*.

⁴³ Brewin, Bob. Wireless vendors plan low-cost, high-speed metropolitan networks. 08 April 2003. Computerworld. <http://www.computerworld.com/mobiletopics/mobile/story/0,10801,80157,00.html> (Accessed 10 April 2004)

45 km. Here we are making an implicit assumption regarding our choice of broadband wireless technology: that within 5 km a WiMAX equivalent technology will provide the best wireless service and fastest bi-directional response (lowest latency). Therefore, those dwellings within 5 km will most likely provide the strongest subscription base. If there were an insufficient number of households (< 200) within 5 km then these cells (households) were left within the analysis for the next larger radius search (e.g., 10 km). This procedure was repeated to 45 km. As such, the resulting map shows those locations where a cell tower with a WiMAX like technology could be placed profitably.

After this process, each value in a cell represented the number of surrounding dwellings that could potentially subscribe to a service if a tower was installed at the focal cell of interest. Figure B.6 illustrates how the value of each cell in the raster grid is calculated using this technique. Our assumption here is that a communication tower is fully able to transmit to other cells at the indicated radius and overall, a tower can be placed anywhere within the unserved rural and remote regions.

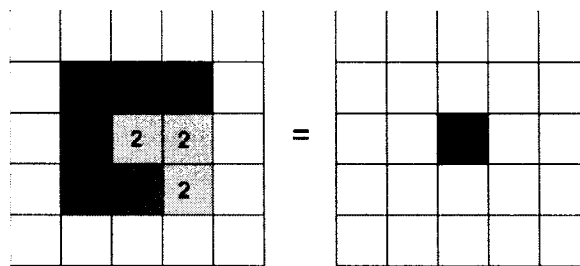


Figure B.6. A simple neighbourhood summation calculation within a raster grid.

Results

Approximately 85% of rural and remote Canadian households could be effectively serviced using a WiMAX type wireless broadband technology capable of non-line-of-sight (Figure B.3).

Beyond the 45 kilometre radius, approximately only 15,000 dwellings (~40,000 persons) would be unserved if wireless technology could not reach them. Various standards organizations such as the Institute of Electrical and Electronics Engineers (IEEE) are working on the development of technologies that would permit broadband wireless internet access over much greater distances than that permitted by the current technologies and without requiring line of sight with the base station.

Figure B.0.1. Number of dwellings reached with broadband wireless technology at various radii from potential communication towers.

Province/Territory	5 km	15 km	25 km	35 km	45 km	Unserved > 45 km
Nunavut	4,261	1,945	245	0	0	1,726
Northwest	39,585	939	0	0	0	1,466
Yukon	818	216	0	207	0	1,023
Quebec	527,200	17,088	3,152	2,134	687	4,375
Newfoundland and Labrador	84,073	9,081	3,436	1,517	495	1,535
Saskatchewan	26,752	39,519	7,808	2,485	0	2,393
British Columbia	123,940	17,180	6,916	4,286	1237	5,326
Alberta	93,463	48,069	5,651	1,931	609	2,775
Manitoba	73,561	25,866	1,441	761	0	3,439
Ontario	505,479	29,112	2,915	2,470	3312	4,056
New Brunswick	139,482	6,177	1,644	339	0	6,25
Nova Scotia	92,848	12,033	1,118	294	0	5,81
Prince Edward Island	22,958	0	523	0	0	37
CANADA	1,734,420	207,224	34,850	16,424	6,340	29,356

Discussion

Broadband wireless access (BWA) is the most flexible technology for serving those out of reach of a financially viable and time efficient wired solution (Intel, 2003).

The digital and geographic divides

Alarms of a "digital divide" were set off in 1996 when the internet was in its early stages of commercial development and fear of leaving individuals behind existed. In Canada, there is evidence that the digital divide exists along gradients of income (Statistics Canada 2003) and group penetration rates (Sciadas 2002). Penetration is faster in higher-income households. Eventually the penetration rate of lower-income households will grow faster and catch up. Presumably also, in areas of dense population, sufficient numbers of early adopters and competition eventually lead to falling costs as the market becomes saturated by both subscribers and competitors (Prieger 2003). Our research focuses on those regions without access rather than the differences in uptake within regions that already have access to broadband communications technologies.

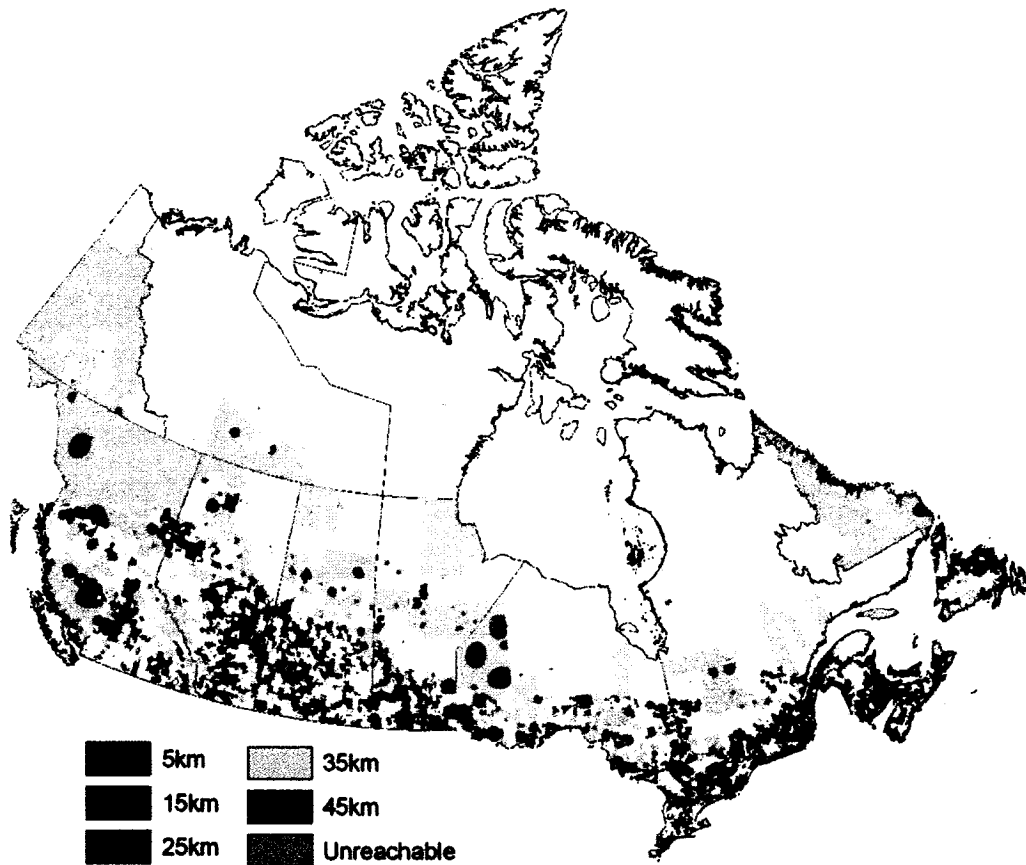


Figure B.7. Unserved dwellings that potentially could be provided with fixed wireless broadband internet using various technologies with varying ranges in reach.

It is important to distinguish our present work from those studying the “digital divide”. We have dealt herein primarily with an absolute geographical divide of accessibility. The “digital divide” would be a second step in this analysis, that is to say, studying the potential market for socioeconomic and demographic characteristics, as mentioned above, that lend themselves to broadband uptake in the short and long term. In other words, with respect to broadband adoption, the digital divide has the potential to exist within the unserved Canadian population but presently remains an unknown quantity due to the absence of service. Utilizing GIS as a spatial decision support system by integrating demographic and economic factors into our model would provide predictive capabilities for planning potentially profitable broadband wireless system deployment.

Given that access is a prerequisite to adoption, understanding the nature of existing digital divides in currently serviced regions of Canada and the US can provide important insights for the modeling of demand within a refined national model. Sciadas (2002) discusses the many connotations of the digital divide with respect to information and communications technologies. Within densely populated regions of Canada, disparities in broadband uptake are evident due to socioeconomic and demographic factors (Grubestic and Murray 2002; Grubestic 2003; Prieger 2003). Within Canada, both income and education are positively associated with subscription to broadband services (Sciadas 2002). However, when only

demand and use are considered in conjunction with demographic characteristics it is clear that in some cases the “digital divide” may have more to do with geographic access to services (Prieger 2003).

Our general modelling approach can help to alleviate what Prieger (2003) terms “profit-based discrimination” through providing insight into the rural and remote regions of Canada where specific wireless technologies could succeed in producing a profit. Many studies of broadband uptake have failed to account for supply when looking at the digital divide and compared demand and use characteristics without any controlling factors while ignoring the fact that “availability is a precondition for access” (Prieger 2003). This perceived ignorance could be due in part to the lack of availability or difficulty in obtaining information on the spatial rollout of broadband internet from private industry (Prieger 2003).

Rural and Remote

Canada comprises some thirty-two million people of which 64% are concentrated in 27 major urban centres located within a few hundred kilometres of the US border (Statistics Canada 2002). Approximately 96% of Canada's area can be considered rural and remote (McNiven and Puderer 2000). In Canada, approximately 5 million people of varying socioeconomic and demographic backgrounds live within rural and remote regions of Canada where no broadband internet services other than satellite currently exist.

There are numerous definitions of what may be considered a rural or remote region (Venkatachalam and McDowell 2003). Rowe (2003) suggests a simple definition of rural as areas as regions where there is “...a lot of dirt between computers...”. Broadband internet access is particularly absent where cable television does not exist and where DSL is not available due to distance from central switch offices and/or where the ageing wireline infrastructure would require more boost stations that lead to higher deployment costs that would be passed on to the end-user (Prieger 2003; Venkatachalam and McDowell 2003). How much would a household in a rural and remote region be willing to pay? In general the low population densities in rural regions (e.g., households, persons per unit area) yield a sparse and dispersed market base with little incentive to service providers (Rowe 2003; Venkatachalam and McDowell 2003).

While the digital divide within regions currently with access to broadband exists for a number of reasons (Bertot 2003), the study of these disparities are fundamental for effective policy formulation in both Canada and elsewhere. However, in Canada a separate yet equally important broadband divide exists: a spatial divide between urban and rural/remote regions. Access to broadband internet infrastructure is absent over the majority of Canada's area. Inaccessibility to broadband services produces “have’s and have not’s” because of geographic location, despite any demographic or socioeconomic factors that might affect service uptake. In other words, availability is a pre-requisite for access (Prieger 2003) and must be dealt with before concerns of a digital divide can be properly addressed.

Broadband policy in Canada: bridging the divide

The Canadian Federal Government announced a rural and remote regions broadband access policy in 2000 and charged Industry Canada and the Canadian Communications Research Center with its completion⁴⁴. The Canadian Department of Industry (DOI) has many responsibilities and objectives and the important mandate of making “*Canadians more productive and competitive in the knowledge-based economy, [in order to improve] the standard of living and quality of life*”⁴⁵. One method of achieving this mandate is through prompting telecommunication via the Radiocommunication Act and the Telecommunications Act. The Telecommunication Act (1993, c. 38, as amended) compels the DOI to create policy objectives and regulatory controls while the Radiocommunication Act (1985, c. 17, as amended) compels them to plan the management, licensing and allocation of the radio spectrum for communications. One key objective of the Telecommunication Act is to “render reliable and affordable telecommunications services to Canadians in both urban and rural areas in all of Canada” (c. 38, 7 (b), 1993). When the Canadian Government stated that it wanted Canada to be at the forefront of the information revolution (1997, Speech from the Throne), Industry Canada has been advancing towards this goal (Industry Canada, 2003). In the past few years and in various phases, Industry Canada has auctioned blocks of prime spectrum (2.3, 3.5, 24 and 38 GHz) that would allow varying wireless technologies to be developed and used (Strategies, Auction of 24 GHz ..., 2004).

Industry Canada’s broadband portal (www.broadband.gc.ca) was created to help rollout broadband to rural, northern or remote communities where “market forces alone will not take broadband”⁴⁶. Industry Canada has initiated two programs to develop broadband infrastructure. In The Broadband for Rural and Northern Development Pilot Program, \$79-million was invested into organizations representing 1380 communities⁴⁷. The second program, The National Satellite Initiative was established for communities where satellite is the only possible method of delivering broadband. Various partners contributed \$155 million to help cover the high cost of satellite technologies and equipment; however a ‘community connection’ is expected to be only available for 10 – 15 years - the lifespan of the satellite⁴⁸. These policy initiatives of the Canadian Government will eventually ensure broadband service to the rural and remote regions of Canada.

Errors of Omission and Commission

In this first study at the Canadian scale, we utilized a number of rudimentary assumptions. First, we approximated the broadband market potential using simple dwelling counts without regard for the socioeconomic status of these units. Second, we did not incorporate distance decay effects in broadband serviceability that are potentially caused by exogenous factors affecting signal quality from wireless technologies operating at different frequencies. These

⁴⁴ The U.S. Federal Telecommunications Act of 1996 aimed to provide advanced telecommunications services to all regions of the U.S. (Compaine and Weinraub 1997).

⁴⁵ Industry Canada. Mandate. 2004. (Date Accessed: 13 September 2004)

<http://www.ic.gc.ca/cmb/welcomeic.nsf/ICPages/Mandate>

⁴⁶ Rock, Allan. Speech. Allan Rock and Andy Mitchell Launch Broadband for Rural Northern Development Pilot Program. Bracebridge, ON. 5 September 2002.

⁴⁷ Industry Canada: Broadband. Broadband for Rural and Northern Development Pilot Program. (Date Accessed: 13 September 2004) <http://broadband.gc.ca/pub/program/bbindex.html>

⁴⁸ *Ibid.*

latter factors are primarily focused on dwelling location with respect to topography, macroclimates and landuse in rural and remote regions. Third, we modeled those locations where a cell tower with a WiMAX-like technology could be placed profitably based on a minimum number of dwellings.

Our criteria make no distinction between the potential market variability beyond the minimum dwelling count requirement. That is to say for example, if there are at least two-hundred households within 5 km of a potential communications tower site then we considered this serviceable and profitable after 5 years. However, it would clearly be more profitable if there were two-thousand dwellings within 5 km of a potential site – more potential subscribers equates to a faster turn to profitability. Fourthly, we assumed that a tower could be located at its center at the center of any of the 1 km² raster cells. However, because of property law, the presence of existing infrastructure and/or landuses that are already present in a region an unrestricted spatial frame is unrealistic. A more refined analysis is a valid next step and should incorporate both the social and economic factors affecting broadband uptake (income, marital status, ethnicity etc.), the physical factors affecting signal degradation, the variability of market size for different broadband frequencies and the valid locations where towers could be placed in Canada.

Acknowledgments

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C

Appendix

SOFTWARE SPECIFIC METHODS FOR NLOS: UPPER LIMIT SCENARIO

Overview

This appendix describes the methods utilized to conduct the upper limit scenario (ULS) entirely conducted using the Raster Calculator from the Spatial Analyst extension of ArcGIS. For this non-line-of-sight (NLOS) analysis, the terrain is assumed to be completely flat. Under such circumstances, and with the exception of the earth's curvature, all cells would have a clear line-of-sight with a potential communication tower. Each cell within the unserved dwelling within its region is visited, and the number of dwellings is summed within either a 5 km radius or 50 km radius (Figure 2.2). In order to make sure that every cell is examined, the potential tower sites are incorporated into this process. As such, this appendix describes the preparation of the datasets and then the procedures used to conduct the analysis.

Preparation of the Data

When conducting the analysis, we only conducted focal summations for cells that had values, (i.e., dwelling values). Therefore, to make sure that the results from the LLS and ULS are comparable, the locations from the potential tower sites have to be incorporated into the dwelling raster. Even if the value cells have a value of zero, the focal summation will still be conducted for those cells.

Thus, the first step is taking the potential towers sites (point) and creating a new field, called temp (type Short Integer). Automatically each field is assigned a value of zero (0). Then, the options for the Spatial Analysis extension of ESRI's ArcGIS are setup where both the extent and cell size are assigned the same values as the elevation raster (used here for convenience because the DEM has the needed cell size and extent for analysis). Next, we convert the potential tower sites to raster using the 'Convert to Raster' function within Spatial Analyst using the same cell size as the elevation raster. Finally, the rasters for the dwelling and the tower sites are merged together using the raster calculator. The function is listed in Table C.1.

Table C.1. The formula used to merge the Dwelling raster and the Potential Tower Sites raster together using the Raster Calculator in the Spatial Analyst extension.

merge([Dwelling - Raster], [Potential Tower Site - Raster])

Analysis

Now that the data has been prepared the analysis can be run. The focal summation is conducted using the raster calculator. The only variable that has to be set is the radius. The formula is listed in Table C.2. Note that the radius is not based on distance but is based on the number of cells. Therefore, when conducting the analysis at the fine resolution, the radius needs to be adjusted accordingly.

Table C.1. The formula used to conduct the upper limit scenario where the focalsum function from the Spatial Analyst extension is used.

FocalSum([merged], circle, 50, DATA)

Post Processing

When preparing the data, the potential tower sites were incorporated into the process in order to make sure that all of the potential tower sites were analyzed. However, there are some cells in the resultant raster that are not locations where a potential tower could be placed. For example, some of the cells might contain a dwelling value but are not a suitable location for a tower. Most importantly, these excess cells are removed which permits the results to be easily compared with the LLS because both scenarios will have had the same locations and number of potential towers sites examined. Therefore, to remove the excess cells from the resultant raster we reclassify the raster cells of the potential tower sites from zero to one (0 to 1). Then, the newly created raster is multiplied with the resultant focal raster.

This cycle is repeated for each of the radius.

D

Appendix

VISUAL BASIC CODE FOR LOS: LOWER LIMIT SCENARIO

A custom application was written in Visual Basic for the purpose of conducting the LLS. The code does not have a graphical user interface (GUI) but is instead embedded into an ArcGIS document (MXD). When the ArcGIS document is opened, it automatically adds the point shapefile and then begins processing the points (Viewshed, Intervisibility, Overlay and Summation of visible dwellings). After each point is processed, the number of dwellings that are visible for each tower point are exported into a resultant text file along with the XY location for each tower point. The XY location is exported so that the results can be mapped. Once all the points (tower sites) have been processed, ArcGIS self-terminates. The VBA code used to carry out the process is listed in Table D.1.

Software

ArcGIS 9.0 (Build 580) and ArcObjects RasterSurfaceOp coclass, and ISurfaceOp2 "visibility" method were used to automate the analysis of the thousands of individual locations whose viewsheds required determination.

Table D.1. The VBA and ArcObject code used to conduct the lower boundary scenario.

```
Sub Calculate_viewshed3()
AddShapeFile

Dim pTextName As String
Open "d:\Processing\Series.txt" For Input As #1
Line Input #1, pTextName
```

```

Close #1

Dim TextOutPath As String
TextOutPath = "D:\DKresult\" & pTextName & ".txt"

'Get the focused Map from MapDocument
Dim pMxDoc As IMxDocument
Set pMxDoc = ThisDocument
Dim pMap As IMap
Set pMap = pMxDoc.FocusMap

'Get the input raster from the first layer in ArcGIS
Dim pLayer As ILayer
Dim pRasLayer As IRasterLayer
Dim pinraster As IRaster

Set pLayer = pMap.Layer(1)
If Not TypeOf pLayer Is IRasterLayer Then Exit Sub

Dim pHRaster As ILayer
Dim pHouseRasLayer As IRasterLayer
Dim pHouseRaster As IRaster

Set pHRaster = pMap.Layer(2)

'Get Point Layer
Dim player2 As ILayer
Set player2 = pMap.Layer(0)
Dim pfeatlayer As IFeatureLayer
Dim pFeatClass As IFeatureClass
Dim pinobs As IGeoDataset
Set pfeatlayer = player2
Set pFeatClass = pfeatlayer.FeatureClass
Set pinobs = pFeatClass

Set pRasLayer = pLayer
Set pinraster = pRasLayer.Raster

Set pHouseRasLayer = pHRaster
Set pHouseRaster = pHouseRasLayer.Raster

'Create a RasterSurfaceOp operator
Dim pSurfaceOp As ISurfaceOp2
Set pSurfaceOp = New RasterSurfaceOp

'Set output workspace
Dim pEnv As IRasterAnalysisEnvironment
Set pEnv = pSurfaceOp
Dim pWS As IWorkspace
Dim pWSF As IWorkspaceFactory
Set pWSF = New RasterWorkspaceFactory
Set pWS = pWSF.OpenFromFile("d:\temparc", 0)
Set pEnv.OutWorkspace = pWS

Dim pCircArc As IConstructCircularArc2

```



```

Set pCircArc = New CircularArc
'get point for center
Dim pFeatcursor As IFeatureCursor
Set pFeatcursor = pFeatClass.Search(Nothing, False)
Dim pFeat As IFeature
Set pFeat = pFeatcursor.NextFeature

Open TextOutPath For Output As #1 '
'Open "d:\thecount.txt" For Output As #2
Write #1, "X", "Y", "sum", "PID"
Dim Counter As Long
Counter = 0

Dim pPoint As IPoint
Dim pCircularArc As ICircularArc
Dim penvelope As IEnvelope
Dim pqraster As IRasterDataset2
Dim ptrans As ITransformationOp

Dim pGeoHouse As IRasterDataset2
Dim ptranshouse As ITransformationOp

Dim qgeohouseraster As IRaster
Dim visrasExOp As IExtractionOp2
Set visrasExOp = New RasterExtractionOp
Dim poutraster2 As IGeoDataset
Dim a As IGeoDataset
Dim pFeatgeom As IGeometry
Dim pvispoint As IFeatureClass
Dim pOutRaster As IRaster
Dim sumInViewshed As Double
Dim rasterToDelete As IDataset

Do While Not pFeat Is Nothing
Set pPoint = pFeat.Shape
pCircArc.ConstructCircle pPoint, 50000, False

'set extent of output
Set pCircularArc = pCircArc
Set penvelope = pCircularArc.Envelope
penvelope.Expand 500, 500, False

Set ptrans = New RasterTransformationOp
Set pqraster = ptrans.Clip(pInRaster, penvelope)
'clip houseraster
Set ptranshouse = New RasterTransformationOp
Set pGeoHouse = ptranshouse.Clip(pHouseRaster, penvelope)
Set qgeohouseraster = pGeoHouse.CreateFullRaster

'clip house to circle
Set a = qgeohouseraster
Set poutraster2 = visrasExOp.Circle(a, pCircularArc, True)
Set qgeohouseraster = poutraster2

Set pFeatgeom = pPoint

```

```

Set pvispoint = makeshapefile2(pfeatgeom)

'Get Viewshed for current point
Set pOutRaster = pSurfaceOp.Visibility _
(pqraster, pvispoint, esriGeoAnalysisVisibilityFrequency)
SetPixelValue pPoint, pOutRaster

'Get sum of households within viewshed
sumInViewshed = RasterMultiply(pOutRaster, poutraster2)
Write #1, pPoint.x, pPoint.y, sumInViewshed, Counter

'detele rasters and free variables
Set qgeohouseraster = Nothing
Set a = Nothing

Set rasterToDelete = pqraster
If rasterToDelete.CanDelete Then
rasterToDelete.Delete
End If

Set rasterToDelete = pGeoHouse
If rasterToDelete.CanDelete Then
rasterToDelete.Delete
End If

Set rasterToDelete = pvispoint
If rasterToDelete.CanDelete Then
rasterToDelete.Delete
End If

Set pvispoint = Nothing
Set pGeoHouse = Nothing
Set pOutRaster = Nothing
Set poutraster2 = Nothing
Set pqraster = Nothing
Set pRLayer = Nothing
Set ptrans = Nothing

'goto next point for new viewshed
'counter = counter + 1
'Write #2, counter
Set pFeat = pfeatcursor.NextFeature
Loop
Close 1
'Close 2

If 1 = 1 Then GoTo Shutdown
ErrorNotice:
Dim TextNotice As String
TextNotice = "y:\Messenger\" & Environ("ComputerName") & ".txt"
'Open TextNotice For Output As #1
Close #1
MsgBox Err.Number & ": " & Err.Description, vbCritical, "Error"
If 1 = 1 Then Exit Sub

```

```

Shutdown:
' Shutdown of Application
Dim pMxDocument As IMxDocument
Dim pApplication As IApplication
Dim pDocumentDirty As IDocumentDirty2
Dim pDocumentEvents As IDocumentEvents

Set pMxDocument = ThisDocument
Set pDocumentDirty = pMxDocument
Set pApplication = Application

pDocumentDirty.SetClean
Application.Shutdown
End Sub

Public Sub AddShapeFile()
Dim pWorkspaceFactory As IWorkspaceFactory
Dim pFeatureWorkspace As IFeatureWorkspace
Dim pFeatureLayer As IFeatureLayer
Dim pMxDocument As IMxDocument
Dim pMap As IMap
'Create a new ShapefileWorkspaceFactory object and open a shapefile folder
Set pWorkspaceFactory = New ShapefileWorkspaceFactory
Set pFeatureWorkspace = pWorkspaceFactory.OpenFromFile("d:\DK\Pop", 0)
'Create a new FeatureLayer and assign a shapefile to it
Set pFeatureLayer = New FeatureLayer
Set pFeatureLayer.FeatureClass = pFeatureWorkspace.OpenFeatureClass("Pop")
pFeatureLayer.Name = pFeatureLayer.FeatureClass.AliasName
'Add the FeatureLayer to the focus map
Set pMxDocument = Application.Document
Set pMap = pMxDocument.FocusMap
pMap.AddLayer pFeatureLayer
End Sub

Function makeshapefile2(theIPointCollection As IGeometry) As IFeatureClass
'On Error GoTo EH
Dim strfolder As String
Dim strName As String ' Dont include .shp extension
Const strShapeFieldName As String = "Shape"
strfolder = "d:\temparc"
strName = "tmpxxxs"
' Open the folder to contain the shapefile as a workspace
Dim pFWS As IFeatureWorkspace
Dim pWorkspaceFactory As IWorkspaceFactory
Set pWorkspaceFactory = New ShapefileWorkspaceFactory
Set pFWS = pWorkspaceFactory.OpenFromFile(strfolder, 0)

' Set up a simple fields collection
Dim pFields As IFields
Dim pfieldsEdit As IFieldsEdit
Set pFields = New Fields
Set pfieldsEdit = pFields

Dim pField As IField
Dim pFieldEdit As IFieldEdit

```

```
' Make the shape field
Set pField = New Field
Set pFieldEdit = pField
pFieldEdit.Name = strShapeFieldName
pFieldEdit.Type = esriFieldTypeGeometry

Dim pGeomDef As IGeometryDef
Dim pGeomDefEdit As IGeometryDefEdit
Set pGeomDef = New GeometryDef
Set pGeomDefEdit = pGeomDef
With pGeomDefEdit
    .GeometryType = esriGeometryPoint
    Set .SpatialReference = theIPointCollection.SpatialReference
End With
Set pFieldEdit.GeometryDef = pGeomDef
pfieldsEdit.AddField pField

Set pField = New Field
Set pFieldEdit = pField
With pFieldEdit
    .Type = esriFieldTypeInteger
    .Name = "OFFSETA"
End With
pfieldsEdit.AddField pField

Set pField = New Field
Set pFieldEdit = pField
With pFieldEdit
    .Type = esriFieldTypeInteger
    .Name = "OFFSETB"
End With
pfieldsEdit.AddField pField

Dim theIFeatureclass As IFeatureClass
Set theIFeatureclass = pFWS.CreateFeatureClass(strName, _
pFields, Nothing, Nothing, esriFTSimple, strShapeFieldName, "")

Dim theIPoint As IPoint
Set theIPoint = theIPointCollection
' Dim pIndex As Long, vertindex As Long
' theIEnumVertex.Next theIPoint, pIndex, vertindex

Dim theIFeatureCursor As IFeatureCursor
Dim theIFeatureBuffer As IFeatureBuffer
' +++ open the feature cursor and feature buffer
Set theIFeatureCursor = theIFeatureclass.Insert(True)
Set theIFeatureBuffer = theIFeatureclass.CreateFeatureBuffer
' +++ get the list of fields
Dim theZFieldIndex As Long
Dim theIFields As IFields
Set theIFields = theIFeatureclass.Fields
theShapeIndex = theIFields.FindField("shape")
theZFieldIndex = theIFields.FindField("OFFSETA")
theZFieldIndex2 = theIFields.FindField("OFFSETB")
```

```

'go through each point and populate fields
theIFeatureBuffer.Value(theShapeIndex) = theIPoint
theIFeatureBuffer.Value(theZFieldIndex) = 30
theIFeatureBuffer.Value(theZFieldIndex2) = 3
theIFeatureCursor.InsertFeature theIFeatureBuffer
Set makeshapefile2 = theIFeatureclass
End Function

Function RasterMultiply(vshedRaster As IRaster, _
popRaster As IRaster) As Double
Dim count As Long
Dim sum As Double

Dim prasCursorViewshed As IRasterCursor
Set prasCursorViewshed = vshedRaster.CreateCursor
Dim pixBlockRasViewShed As IPixelBlock
Set pixBlockRasViewShed = prasCursorViewshed.PixelBlock

Dim prasCursorPop As IRasterCursor
Set prasCursorPop = popRaster.CreateCursor
Dim pixBlockRasPop As IPixelBlock

Set pixBlockRasPop = prasCursorPop.PixelBlock

Ht = pixBlockRasViewShed.Height
Wt = pixBlockRasViewShed.Width

sum = 0
For i = 0 To Ht - 1
For j = 0 To Wt - 1

If CInt(pixBlockRasViewShed.GetVal(0, i, j)) = 1 Then
If pixBlockRasPop.GetVal(0, i, j) > 0 Then sum = sum + _
pixBlockRasPop.GetVal(0, i, j)
End If
Next j
Next i
RasterMultiply = sum
End Function

Sub SetPixelValue(tempPoint As IPoint, tempRDS As IRaster)
Dim prasterprops As IRasterProps
Set prasterprops = tempRDS
xnt = prasterprops.PixelType
prasterprops.PixelType = PT_DOUBLE
' Dim tempRDS As IRasterDataset
Dim tempR As IRaster
Set tempR = prasterprops.CreateDefaultRaster
Dim tempPB As IPixelBlock3
Dim blpnt As IPnt
Set blpnt = New DbIPnt
Set blpnt = MakePnt(1, 1)
Set tempPB = tempR.CreatePixelBlock(blpnt)

```

```

Dim Temp As Double
Dim pPnt As IPnt
Set pPnt = GetPixelPnt(tempPoint, tempR)
tempR.Read pPnt, tempPB
Dim tempSA As Variant
tempSA = tempPB.PixelDataByRef(0) 'GetVal(1, pPnt.x, pPnt.y) 'SafeArray(0)
Temp = tempSA(0, 0)

If Temp Then
' Set tempPB = Nothing
'Set GetPixelValue = tempR
Else

Dim pRasProps As IRasterProps
Set pRasProps = tempR

' Get RasterBand from the raster
Dim pBand As IRasterBand
Dim pBandCol As IRasterBandCollection
Set pBandCol = tempR
Set pBand = pBandCol.Item(0)

' QI RawPixel interface
Dim pRawPixel As IRawPixels
Set pRawPixel = pBand
pRawPixel.Read pPnt, tempPB
tempSA(0, 0) = 1
' Write the pixeldata back
Dim pCache As IUnknown
Set pCache = pRawPixel.AcquireCache
pRawPixel.Write pPnt, tempPB
pRawPixel.ReturnCache pCache
End If
End Sub

Public Function GetPixelPnt(pPoint As IPoint, prasterprops As _
IRasterProps) As IPnt
' make a point based on the raster's row & column
Dim lRow As Long, lCol As Long
Dim pPnt As IPnt, PixelWidth As Double, PixelHeight As Double
Set pPnt = prasterprops.MeanCellSize
PixelWidth = pPnt.x
PixelHeight = pPnt.y
Dim dTop As Double, dLeft As Double
dTop = prasterprops.Extent.ymax
dLeft = prasterprops.Extent.xmin
Set GetPixelPnt = New DbIPnt
GetPixelPnt.SetCoords _
Round(Abs(pPoint.x - dLeft - (0.5 * PixelWidth)) / PixelWidth), _
Round(Abs(pPoint.y - dTop + (0.5 * PixelHeight)) / PixelHeight)
End Function

Public Function MakePnt(dX As Double, dY As Double) As IPnt
Set MakePnt = New DbIPnt
MakePnt.SetCoords dX, dY

```

End Function

Function drawgraphicpolygon(x As IConstructCircularArc, y As _
IActiveView, z As IGraphicsContainer)

Dim pSegmentCollection As ISegmentCollection

Dim pPolygon As IPolygon

Dim pSegment As ISegment

Set pPolygon = New Polygon

Set pSegmentCollection = pPolygon

Set pSegment = x

pSegmentCollection.AddSegment pSegment

pPolygon.Close

Dim pGeom As IGeometry

Set pGeom = pPolygon

Dim pelem As IElement

Set pelem = New PolygonElement

Dim felem As IFillShapeElement

Set felem = pelem

Dim polysym As IFillSymbol

Set polysym = New SimpleFillSymbol

Dim pcol As IColor

Set pcol = New RgbColor

pcol.NullColor = True

Dim pline As ILineStyleSymbol

Set pline = New SimpleLineStyleSymbol

pline.Color = pcol

polysym.Color = pcol

felem.Symbol = polysym

pelem.Geometry = pGeom

z.AddElement pelem, 0

y.Refresh

End Function

Function Env2Polygon(pEnv As IEnvelope) As IPolygon

Dim pPointColl As IPointCollection

Set pPointColl = New Polygon

pPointColl.AddPoint pEnv.LowerLeft

pPointColl.AddPoint pEnv.UpperLeft

pPointColl.AddPoint pEnv.UpperRight

pPointColl.AddPoint pEnv.LowerRight

pPointColl.AddPoint pEnv.LowerLeft

Set Env2Polygon = pPointColl

Set Env2Polygon.SpatialReference = pEnv.SpatialReference

End Function

Function drawgraphicpolygon2(x As IPolygon, y As IActiveView, _
z As IGraphicsContainer)

Dim pGeom As IGeometry

Set pGeom = x

Dim pelem As IElement

```
Set pelem = New PolygonElement
Dim felem As IFillShapeElement
Set felem = pelem
Dim polysym As IFillSymbol
Set polysym = New SimpleFillSymbol
Dim pcol As IColor
Set pcol = New RgbColor
pcol.NullColor = True
Dim pline As ILineSymbol
Set pline = New SimpleLineSymbol
pline.Color = pcol

polysym.Color = pcol
felem.Symbol = polysym
pelem.Geometry = pGeom
z.AddElement pelem, 0
y.Refresh
End Function

Sub Readstring()
Dim pTextName As String
Open "d:\Processing\Series.txt" For Input As #1
Line Input #1, pTextName
End Sub

Private Function MxDocument_OpenDocument() As Boolean
Call Calculate_views3d
End Function
```


E

Appendix

NETWORK FILE STRUCTURE FOR CARRYING OUT THE LLS

Using batch files⁴⁹, folders and text files, the LLS was processed on multiple computers that were connected to the same server and loaded with ESRI ® ArcGIS 9.x.. In order for each computer to be able to examine a different set of tower sites, batch files would be used to seek datasets that needed to be examined. Figure E.1 provides a general overview of the network process while the remainder of this appendix details the files structure (Figure E.2) and the batch files utilized.

⁴⁹ A file that contains a sequence of commands that are executed in DOS.

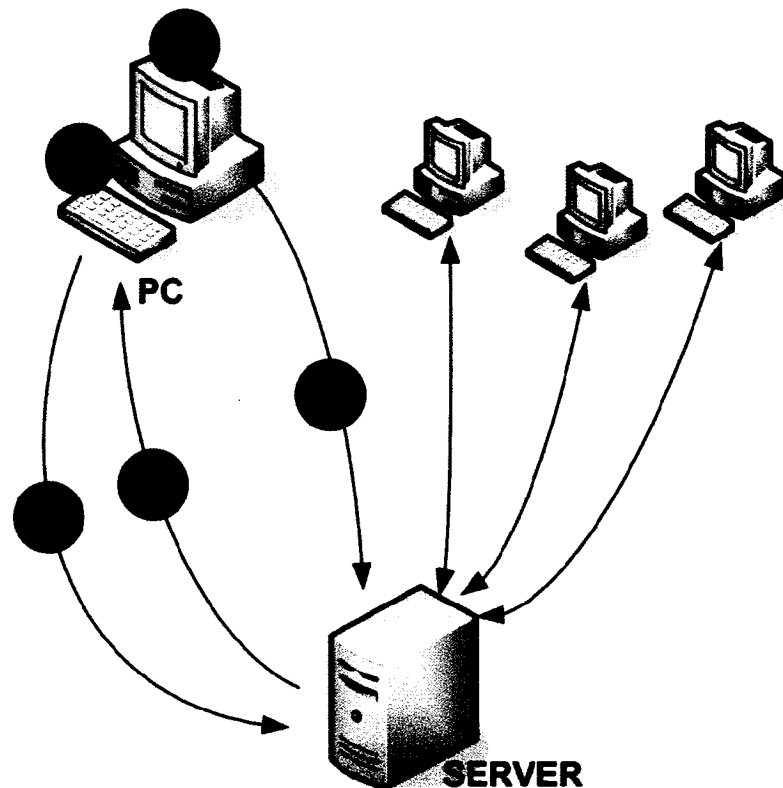


Figure E.1. A general overview of how each computer acquires the necessary files, how it processes the points using ArcGIS and then copies the results back to the server before starting the next group of points. (1) In this step the researcher logs onto a networked computer and starts the self-running program (2) The computer checks to see what group it will process (3) The computer copies the required files and its assigned tower points to its hard drive (4) The computer processes the tower sites using ArcGIS and populates the resultant values into a text file (5) After ArcGIS finishes processing a dataset, it copies the resultant text file to the server and then repeats the cycle until all the groups have been completed.

Network Organization

The organization of a file structure was devised so that all tower points were processed. The required folder, files and text files are illustrated in Figure E.2.

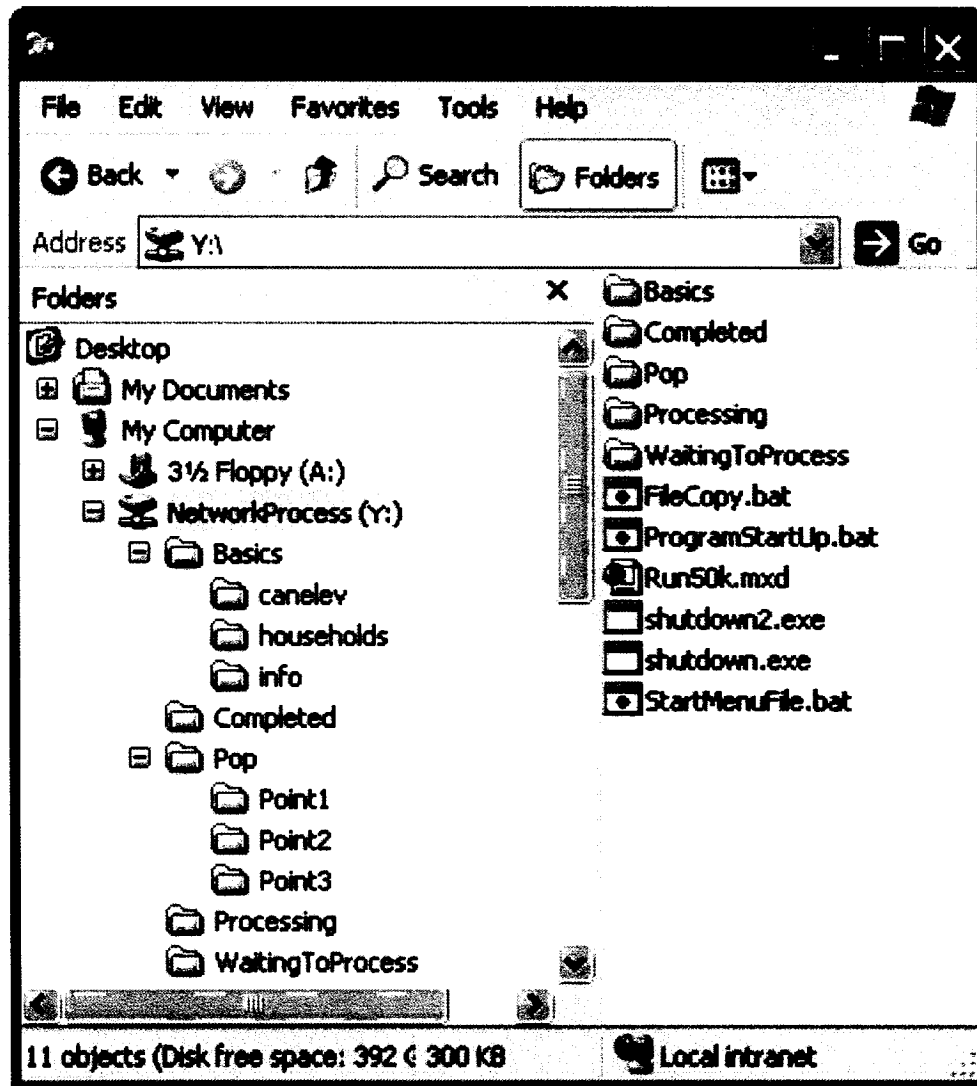


Figure E.0.1. The network file structure, for conducting the lower limit scenario.

The BASICS folder contained the raster for both the elevation (called canelev) and dwelling values (called households). These folders are labelled because these rasters were used on every computer. The COMPLETED folder is where all completed processes and results are copied. The POP folder contains subfolders housing the tower sites to be examined. Each folder is sequentially ordered, Point1, Point2, and so forth. The subfolders are populated using methods detailed in Appendix H. The last folders WAITINGTOPROCESS contains the tower sites identification files that have yet to be processed while the PROCESSING folder contains tower identification files that have either been processed or are in the process of being examined. These identification files are further explained later in the appendix.

In the root folder there are six files. Three of the files are batch files (.BAT) used for copying and moving along with general rules that the computers follows, detailed later. Two of the files are used for forcibly logging off the computer after all the groups have been processed (.EXE) while the remaining file is the ArcGIS GIS Project File (.MXD). For the remainder of the appendix we specifically outline how each of the three batch files operates, the code that was used to create them and how the files within the WAITINGTOPROCESS folder that identified the unprocessed tower sites were handled.

Batch Files

There are three batch files that are used to process the LLS on numerous computers and are labelled StartMenuFile.bat, ProgramStartUp.bat and FileCopy.bat. They are explained in the order that they are used when the self executing program begins.

StartMenu.bat

The StartMenu.bat file is copied into the Start-up folder of the Windows Start Menu. Then, when the researcher logs onto a workstation the processing begins. The code contained within this file used to establish a network connection and calls up the ProgramStartup.bat. The code for the StartMenu.bat is listed in Table E.1.

Table E.1. The code for the StartMenu.bat batch file which establishes a network connection and begin the processing.

```
Net use y: /delete /yes
net use y: \\Geg2ks1smd42\shared\ADanP /user:dcossette

call y:\ProgramStartUp.bat
```

ProgramStartup.bat

The ProgramStartup.bat file is used to copy the required files and folders to the local computer, call up the FileCopy.bat and copy the results back to the network. Specifically, it initially removes folders with identical names from a local workstation that might affect the process. Then, it copies the raster files from the server to the local hard drive and calls up the FileCopy.bat which will copy a specific set of tower sites to the local computer. Finally, it starts up ArcGIS which begins the processing. Once all the tower sites have been examined, ArcGIS has been coded to terminate which allows the batch file to copy the results to the server. After the results have been copied it starts the process over in order to conduct the LLS on another set of tower sites. If there are no tower sites left to process, than the computer logs itself off using the shutdown command. The code used in the ProgramStartUp.bat is listed in Table E.2.

Table E.2. The code for the ProgramStartup.bat.

```

rmdir /s /q d:\DK
rmdir /s /q d:\DKresult

mkdir d:\DK
mkdir d:\DKresult

rmdir /s /q d:\DK\Basics
mkdir d:\DK\Basics

rmdir /s /q d:\temparc
mkdir d:\Processing

xcopy /E y:\Basics d:\DK\Basics
copy /y y:\RUN50k.mxd D:\DK\Run50k.mxd

:Restart

mkdir d:\temparc
Call y:\FileCopy.bat

IF NOT EXIST d:\DK\Run50k.mxd goto TERMINATE
IF NOT EXIST d:\DK\Pop\Pop.shp goto TERMINATE

mkdir d:\temparc

d:\DK\Run50k.mxd

copy d:\DKresult\*.txt y:\Completed\
rmdir /s /q d:\temparc

mkdir d:\LongTerm
move /y d:\DKresult\*.txt d:\LongTerm\

rmdir /s /q d:\DK\Pop

goto Restart

:TERMINATE
y:\shutdown.exe -l -f

```

FileCopy.bat

The final batch file is the FileCopy.bat and is used solely for identifying unprocessed tower sites and copying the dataset to the computer processing the LLS. The batch file checks to see if a tower sites identification file (ie 1.txt) exists in the WAITTOPROCESS folder. If this file does not exist it checks to see if the next file is available (ie 2.txt). Once it finds a matching filename (ie 10.txt), it then moves the file to the PROCESSING folder, makes a locally renamed copy called Pop.txt and copies the appropriate tower sites to the local hard drive.

If the program is unable to find any matching unprocessed tower sites then the program will forcibly log the researcher off⁵⁰. The code used in the FileCopy.bat is detailed in Table E.3 and because FileCopy.bat is very repetitive, a short Visual Basic program was developed to create the FileCopy.bat (Table E.4).

Table E.3. The code for the FileCopy.bat. Note that there are only three points groups in because the file structure is very repetitive.

```
IF EXIST y:\WaitingToProcess\1.txt GOTO D1
IF EXIST y:\WaitingToProcess\2.txt GOTO D2
IF EXIST y:\WaitingToProcess\3.txt GOTO D3

GOTO END
:D1
MOVE /Y y:\WaitingToProcess\1.txt d:\Processing\1.txt
COPY d:\Processing\1.txt y:\Processing\1.txt
COPY d:\Processing\1.txt d:\Processing\Series.txt
xcopy /E y:\Pop\Point1 d:\DK\Pop\
GOTO END
:D2
MOVE /Y y:\WaitingToProcess\2.txt d:\Processing\2.txt
COPY d:\Processing\2.txt y:\Processing\2.txt
COPY d:\Processing\2.txt d:\Processing\Series.txt
xcopy /E y:\Pop\Point2 d:\DK\Pop\
GOTO END
:D3
MOVE /Y y:\WaitingToProcess\3.txt d:\Processing\3.txt
COPY d:\Processing\3.txt y:\Processing\3.txt
COPY d:\Processing\3.txt d:\Processing\Series.txt
xcopy /E y:\Pop\Point3 d:\DK\Pop\
GOTO END

:NOFILE
y:\shutdown2.exe -l -f -t 30
:END
REM this is to avoid the windows log off command
```

Table E.4. The Visual Basic Code that is used to create the FileCopy.bat.

```
Sub CreateFileCopyBATFile()
Open "y:\FileCopy.bat" For Output As #1

' First Loop The "IF EXIST" STATEMENTS
Dim Counter As Double
Counter = 1

Do Until Counter = 121
```

⁵⁰ There are two Shutdown commands one in the FileCopy.bat and one in ProgramStartup.bat. If we wanted all the computers to stop processing after a computer was done processing, we could simply have to remove the FileCopy.bat from the server folder.

```

Print #1, "IF EXIST y:\WaitingToProcess\" & Counter & ".txt GOTO D" & Counter
Counter = Counter + 1
Loop

Print #1, "GOTO END"

' The MOVE COPY Statement
Counter = 1
Do Until Counter = 121
Print #1, ":D" & Counter
Print #1, "MOVE /Y y:\WaitingToProcess\" & Counter & ".txt d:\Processing\" & Counter; ".txt"
' Print #1, "COPY d:\Processing\" & Counter & ".txt d:\Processing\series.txt"
Print #1, "COPY d:\Processing\" & Counter & ".txt " & "y:\Processing\" & Counter & ".txt"
Print #1, "COPY d:\Processing\" & Counter & ".txt " & "d:\Processing\Series.txt"
Print #1, "xcopy /E y:\Pop\Point" & Counter & " d:\DK\Pop\" & Counter
Print #1, "GOTO END"
Counter = Counter + 1
Loop

Print #1, ":NOFILE"
Print #1, "y:\shutdown.exe -l -f"
Print #1, ":END"
Print #1, "REM this is to avoid the windows log off command"
Close #1

End Sub

```

Creation of the Individual TEXT Files

As previously mentioned the WAITINGTOPROCESS and PROCESSING folders contain tower identification files which are simply used to represent datasets of tower sites. The files serve to indicate what tower sites have and have yet to be processed and also serves to indicate the filename to be used for the completed results. After each computer has completed its assigned tower sites, the results are copied to the server (COMPLETED Folder) using the assigned name (ie RIC5). The VBA code for creating the text files is listed in Table E.5.

Table E.5. The VBA code for creating individual text files that are used to indicate what groups have and have yet to be process and are also used to identify the resultant filename.

```

Sub CreateIndividualTXTseries()
Dim Counter As Double
Dim pPath As String
Counter = 1

Dim pText As String
Do Until Counter = 120
pText = "S:\ADanP\WaitingToProcess\" & Counter & ".txt"
Open pText For Output As #1

```

```
pText = "d:\Points\Point" & Counter & "\Point" & Counter & ".shp"  
Print #1, "CIR" & Counter  
  
Close #1  
Counter = Counter + 1  
Loop  
End Sub
```

Conclusion

Conducting the LLS on a number of computers yields many result files and these files need to be merged back together before they can be examined. Therefore, **Appendix I** is utilized to merge the text files into a single file.

F

Appendix

VISUAL BASIC CODE FOR BATCH CONVERTING DEM FILES TO RASTER

Provided in Figure F.1 is the interface for batch converting DEM files to raster while the code is listed in Table F.1. The program simply prevents a user from having to manually convert each DEM file to a raster. Note that the files have to be sequentially numbered and prefaced with the letter "A" (ie, A1.dem).

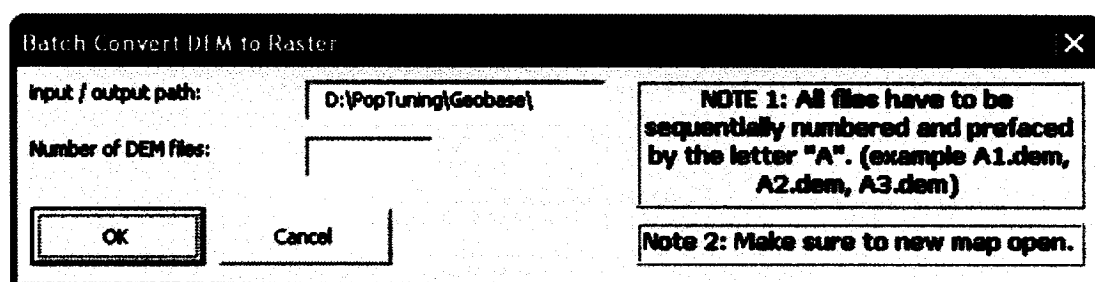


Figure F.1. Graphical user interface of the program designed to batch convert DEM files to raster.

Table F.1. The Visual Basic Code associated with Figure F.1.

```

Private Sub CmdOK_Click()
    Dim pMxDoc As imxdocument
    Set pMxDoc = ThisDocument
    Dim pMap As IMap
    Set pMap = pMxDoc.FocusMap
    Dim pLayer As ILayer

    ' Create the Geoprocessor object
    Dim GP As Object

    Set GP = CreateObject("esriGeoprocessing.GPDispatch.1")
    ' Load required toolboxes...

    GP.AddToolbox "C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Conversion Tools.tbx"
    Dim Input_USGS_DEM_file As String
    Dim Output_raster As String
    Dim NumberXP As Double, maxvalue As Double
    Dim pPath As String
    maxvalue = txtMaxFiles.Value ' Variable
    pPath = txtPath & "A" ' Variable
    NumberXP = 1

    Do Until NumberXP = maxvalue + 1
        Input_USGS_DEM_file = pPath & NumberXP & ".dem"
        Output_raster = pPath & NumberXP
        ' Process: DEM to Raster...
        GP.DEMToRaster_conversion Input_USGS_DEM_file, Output_raster, "FLOAT", "1"
        NumberXP = NumberXP + 1
        Set pLayer = pMap.Layer(0)
        pMap.DeleteLayer pLayer
    Loop

    Me.Hide
    Unload.Me
End Sub

Private Sub Cancel_Click()
    Me.Hide
    Unload Me
End Sub

```

G

Appendix

METHODS AND VISUAL BASIC CODE SPLITTING LARGE DATASETS

In many instances of this thesis, some datasets had too many polygons for a computer to process. Processing in some instances could be accelerated, or in some instances could only be achieved by sub-dividing a single large dataset into many datasets with fewer polygons. Therefore, an analytical process could be achieved by using smaller datasets. Generally subdividing a large dataset involves grouping polygons and assigning them a group number. Then the large dataset is split into a numerous datasets based on assigned group numbers. Herein, we provide a detailed method for splitting a large dataset.

PREPERATION

The first step to split a large dataset into smaller dataset is to create a text file that contains a VBA script that will assign a group number to the polygons. The program in Figure G.1 creates a text file (.txt) and the only required input from a user is how many polygons are to be in each smaller dataset, and how many polygons there are in the large dataset. e text file (Figure G.1) is then created by the program (Table G.1).

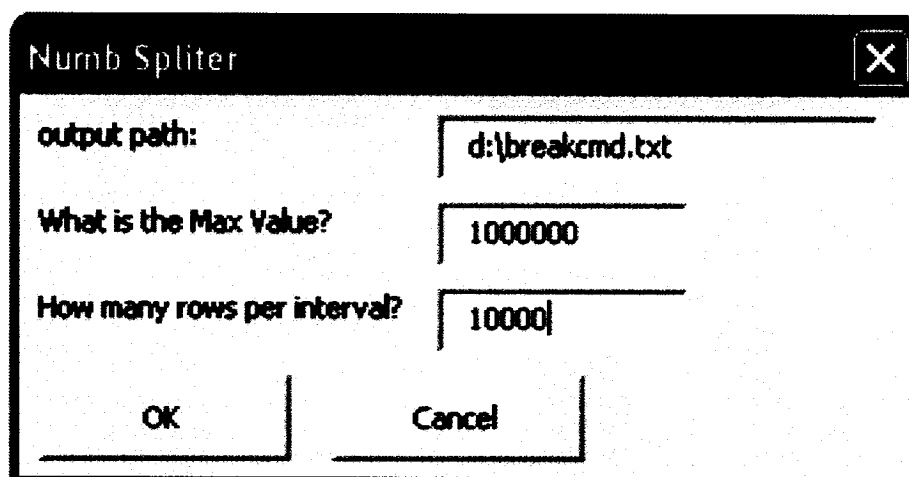


Figure G.1. Graphical user interface of the program designed to output code into text file that is can then be used in the field calculator. The code used in the field calculator assigns group numbers to polygons.

Table G.1. The Visual Basic Code associated with Figure G.1.

```
Private Sub Cancel_Click()
    Me.Hide
    Unload Me
End Sub

Private Sub CommandButton1_Click()
    Dim strPath As String, strMaxVal As String
    Dim strInterval As Double, strTemp As String
    Dim dblCount As Double, strTempHigh As Double, strTempLow As Double

    strPath = txtPath.Text
    strMaxVal = txtMaxVal.Text
    strInterval = txtInterval.Text

    dblCount = 1

    Open strPath For Output As #1 '

    Print #1, "DIM XP AS DOUBLE"

    strTemp = "If [FID] <= " & strInterval & " Then XP = " & dblCount
    Print #1, strTemp

    ' loop

    dblCount = dblCount + 1

    Do Until strTempHigh > strMaxVal
        ' If [FID] > 1000 And [FID] <= 2000 Then XP = 2
        If dblCount = 2 Then
            strTempLow = strInterval
            strTempHigh = strInterval + strInterval
```

```

Else
    strTempLow = strTempHigh
    strTempHigh = strTempHigh + strInterval
End If

strTemp = "If [FID] > " & strTempLow & " And [FID] <= " & strTempHigh & " Then XP = " & dblCount
Print #1, strTemp
dblCount = dblCount + 1

Loop

Print #1, ""
Print #1, ""
Print #1, "XP"

Close #1
MsgBox "Done"
Me.Hide
Unload Me
End Sub

```

GROUPING POLYGONS

After having created the VBA script, the attribute table of the large dataset is then manipulated. A new Field called “GroupNumbe” is created (type Double). Then the VBA script is entered and executed in the Field Calculator of newly created field. This step assigns each polygon to a group (Figure G.2).

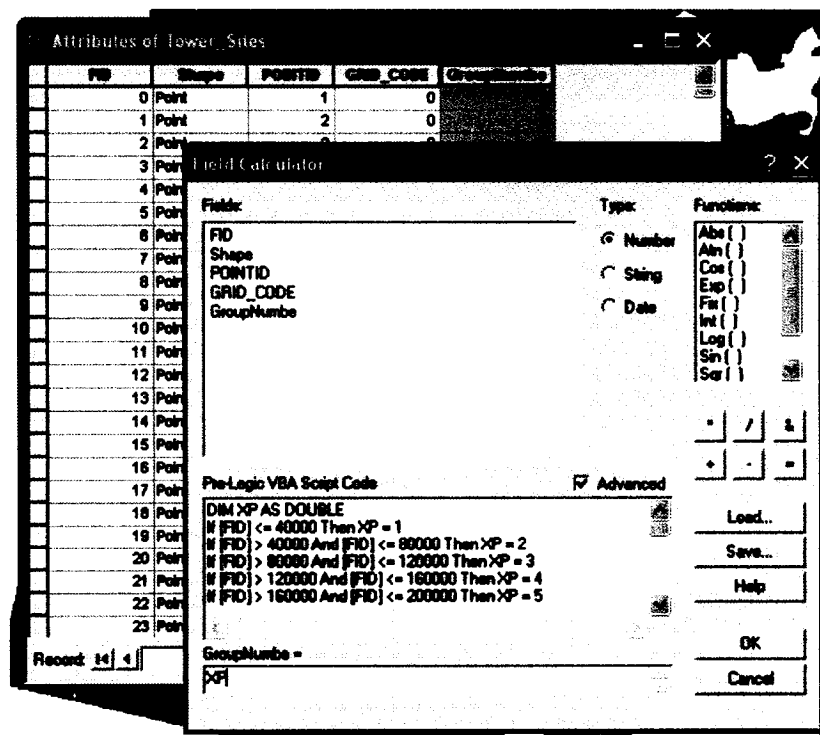


Figure G.2. An image of assigning group numbers to a point dataset using the field calculator.

SPLIT

The large dataset can be split into smaller dataset using a developed split program. The *Split Shapefile* was developed by Jeff Jenness⁵¹ for use in ArcView 3.2a and it splits datasets based on common attributes, such as Group Numbers. The same could be achieved by using standard SQL select queries and exporting the selected features however time consuming.

PROJECTION

Although the *Split Shapefile* does divide a large dataset, it unfortunately does not create a projection file for each newly created dataset. Therefore, for each new shapefile, the projection (i.e., Tower_Sites.prj) file from the original is duplicated and renamed exactly the same as the small dataset with the file extension “prj”. For example, Towers_sites.prj is duplicated and then renamed to 1.prj, etc..

⁵¹ Split Shapefile <http://arcscripts.esri.com/details.asp?dbid=12777> Jeff Jenness (Date Accessed: 12 Jan 2006)

H

Appendix

VISUAL BASIC CODE USED TO MOVE THE FILES FOR POTENTIAL TOWER SITES

This appendix details the VBA code used to create a program file that moves the files of Potential Tower Sites into the appropriate location on a network computer, described in Appendix E. An individual could move all of the files into an appropriate location; however errors could occur because of the numerous files that require handling. Specifically what happens is that the program moves the files from a folder containing all of the split datasets (Appendix G). Once the files are in their respected folders, they are renamed to “Pop”. Having the files name the same permits the LLS program (Appendix D) to add the tower sites into ArcGIS before conducting the analysis. It is also simpler to have the tower sites all named the same so that the code within ArcGIS is kept to a minimum. The VBA code used is listed in Table H.1.

Table H.1. The VBA code used to create a batch file that moves the tower points and renames them to Pop.shp.

```

Sub MoveDwellFiles()
Open "y:\MoveTowerShapefiles.bat" For Output As #1

Dim Counter As Double
Counter = 1
Dim line As String

Do Until Counter = 120
line = "mkdir y:\Pop\Point" & Counter
Print #1, line
line = "move y:\Pop\" & Counter & ".shp y:\Pop\Point" & Counter & "\Pop.shp"
Print #1, line
line = "move y:\Pop\" & Counter & ".dbf y:\Pop\Point" & Counter & "\Pop.dbf"
Print #1, line
line = "move y:\Pop\" & Counter & ".shx y:\Pop\Point" & Counter & "\Pop.shx"
Print #1, line
line = "copy y:\Pop\Proj.prj y:\Pop\Point" & Counter & "\Pop.prj"
Print #1, line
Counter = Counter + 1
Loop
End Sub

```


I

Appendix

VISUAL BASIC CODE FOR MERGING TEXT FILES INTO A SINGLE FILE

Provided in Figure I.1 is the interface for merging sequentially numbered text files, into a single text file for batch converting the DEM, while the code is listed in Table I.1.

1. Destination File:

Output File: c:\textfiles\outfile.txt

2. Source Files:

Path: c:\textfiles
(ie. "c:\textfiles")

Filename: CIR

File Numbering Range From: 1 - 77

OK Cancel

Figure I.1 Graphical user interface of the program merge sequentially number text files into a single text file.

Table I.1. The Visual Basic Code associated with Figure 5.

```

Option Explicit

Private Sub cmdCancel_Click()
    Unload Me
End Sub

Private Sub cmdOK_Click()

Dim DestTXT As String
DestTXT = lblOutput.Text

Dim Path As String
Path = tPath.Text & "\" & tName.Text

'Number of Files
Dim startnumber As Long, endnumber As Long
startnumber = txtLower.Value
endnumber = txtUpper.Value

Dim Count As Long
Count = startnumber

Dim TitleLine As String
TitleLine = Chr(34) & "X" & Chr(34) & "," & Chr(34) & "Y" & _
Chr(34) & "," & Chr(34) & "sum" & Chr(34) & "," & Chr(34) & _
&"PID" & Chr(34)

Do Until Count = endnumber + 1
    Dim SourceNum As Integer
    Dim DestNum As Integer
    Dim Temp As String
    Dim SourceName As String
    SourceName = Path & Count & ".txt"

    ' If an error occurs, close the files and end the macro.
    On Error GoTo ErrHandler

    ' Open the destination text file.
    If Count = startnumber Then
        DestNum = FreeFile()
        Open DestTXT For Output As #1
    End If

    Open SourceName For Input As #2
    Do While Not EOF(2)
        Line Input #2, Temp

        If Count <> startnumber Then
            If TitleLine <> Temp Then Print #1, Temp
        Else
            Print #1, Temp
        End If
    Loop

```

```
' Close the source file.  
Close #2  
Count = Count + 1  
Loop  
  
' Close the destination file.  
Close #1  
  
Me.Hide  
Unload Me  
Exit Sub  
  
ErrorHandler:  
    MsgBox "Error # " & err & ": " & Error(err)  
    Close #1  
    Close #2  
    Me.Hide  
    Unload Me  
End Sub
```