Dasymetric Stratification of a Flood Plain: Development and Refinement of the HAZUS Flood Mapping Tool for Canada

by

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Abstract

The high frequency and cost of flooding in Canada has demonstrated the need for effective risk assessment (Public Safety Canada (PSC), 2010). In response to this need, the United States Federal Emergency Management Agency (FEMA) developed HAZUS, a hazard risk assessment tool which relies on a geographic information system (GIS) (FEMA, 2015). Unfortunately, in many rural communities in Canada, only aggregate population data may be available. In those cases, the ability to further partition aggregated data may prove essential in generating robust and accurate risk assessments. The results of this study show that HAZUS can be adapted for use in Canada and provides a new methodology for conducting hazard estimations in areas where available data is coarsely aggregated. There was a strong relationship between nighttime light and population density. High populations were associated with developed land cover classification. These relationships can be used to increase the accuracy of HAZUS predictions.

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Chapter 1. Literature Review

1.1 Introduction

Extreme flooding is the most frequent natural hazard in Canada and is responsible for the highest economic and social losses since the beginning of the twentieth century (PSC, 2010). There are several environmental and anthropogenic factors which converge in Manitoba to create ideal conditions for periodic seasonal flooding (Bluemla, 1977). There have been several major flood events recorded, during which substantial losses were experienced, since the first European agricultural settlements were established in Manitoba (Welsted, Everitt & Stadel, 1996). Quantitative risk assessment is an important tool for developing effective strategies for mitigating losses due to flooding (PSC, 2010; Nastev & Torodov, 2013). HAZUS is a quantitative risk assessment tool developed in the United States that is currently being evaluated for its potential use for flood mitigation planning in Manitoba. As the asset inventory provided with the program relies on aggregated data, there has been concern about issues with accuracy due to the larger census units in Canada (Nastev & Torodov, 2013). Providing site-specific data allows the user to perform a building-by-building analysis however, it is not possible to generate reports using this method. Data must be gathered manually through the analysis of the shapefile generated. In order to generate more accurate estimations without sacrificing the capability of generating reports, the dasymetric approach has been suggested (Torodov, 2012). The feasibility of a dasymetric stratification approach is being explored to see if it can be used to increase the accuracy of flood loss estimations made using HAZUS (McDonald, 2016; Torodov, 2012). Dasymetric mapping is a thematic mapping methodology where ancillary data are used (from a statistical analysis or different data source) to better describe the spatial distribution of a variable of interest (Mennis, 2009). For instance, mapping variation in the density of a population within a census unit rather than defining all areas of the unit as a single homogeneous density would constitute a dasymetric map. Further dividing that unit into sub-areas using those densities would constitute a dasymetric stratification. In order to undertake a dasymetric stratification, ancillary statistical information and/or a source of finer-scale spatial variation are essential (Mennis, 2009). The population example given above is pertinent to the problem of flood risk assessment: accurate mapping of at-risk populations and infrastructure are critical and these often exhibit significant variation in spatial distribution within a census tract. Land use classifications (e.g. suburban, forested, vs. grassland land cover within a census unit) and night light spatial variation (light produced from anthropogenic sources) have been suggested as two possible variables that have the potential to be effective predictors of population (Mennis, 2009; Briggs, Gulliver, Fecht & Vienneau, 2006). These two variables were explored to determine their suitability for the use in a dasymetric stratification of population and dwelling density data in Manitoba for flood mapping in HAZUS-MH.

1.2 Literature Review

1.2.1 Frequency and Cost of Flooding in Canada

Floods are the most frequent and costly natural disaster both globally and nationally (Swiss Re, 2016). As demonstrated in Figure 1.1 (a), in an analysis of natural disaster frequency since 1900, floods occurred with more than twice the frequency of the next most common hazard (PSC, 2010). Figure 1.1 (b) shows that the number of flood disasters has been increasing during the same time period. The damages associated with these events can represent an enormous cost to the people impacted, insurance companies, and all levels of government (Swiss Re, 2016;

McNabb, 2015). During the 1990's floods in Saguenay, Quebec and along the Red River in

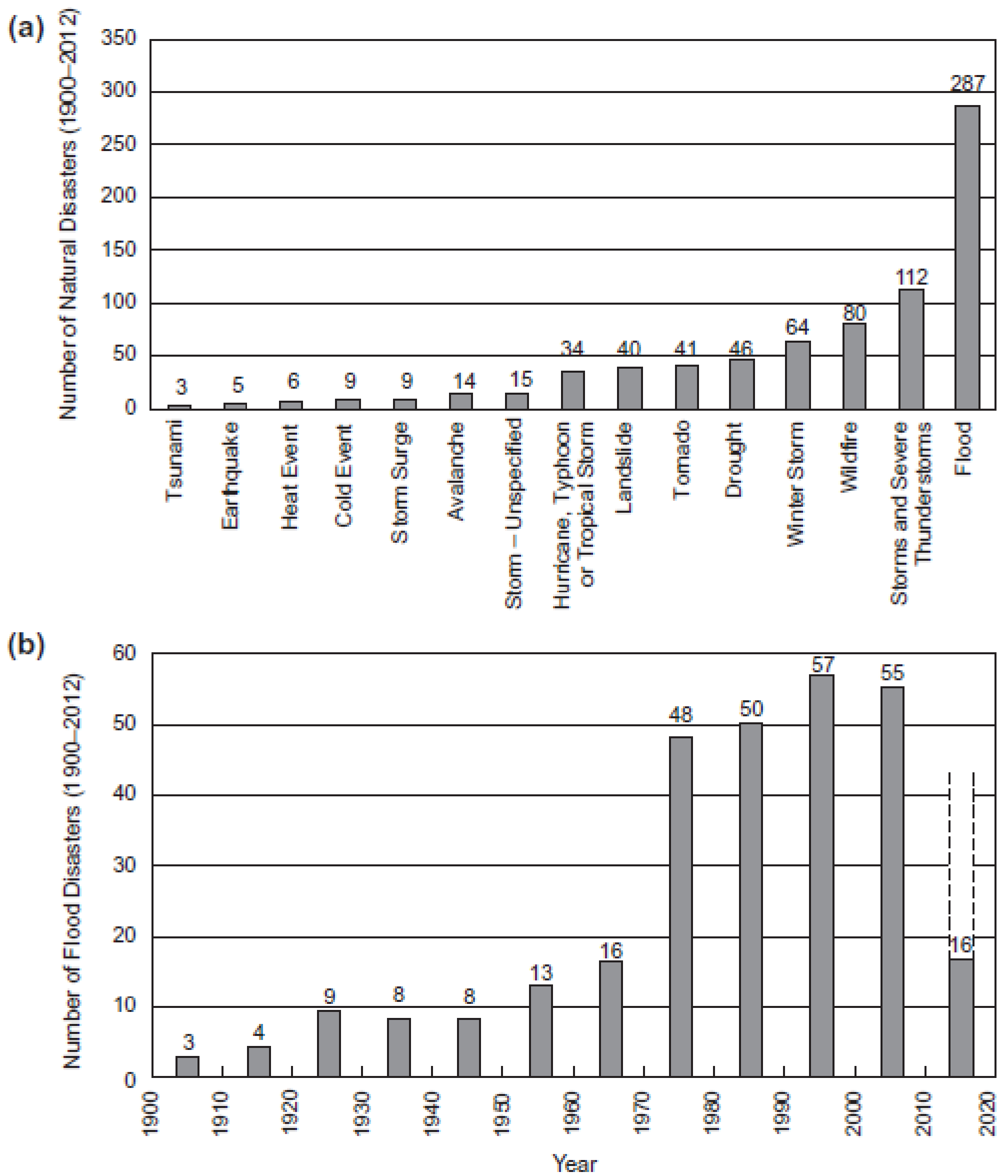

Figure 1.1 (a) Natural disasters in Canada since 1900; (b) frequency of flood disasters (Public Safety Canada (PSC), 2010. Emergency Management Planning Guide 2010-2011. Retrieved from http://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/mrgnc-mngmnt-pnnng/index-eng.aspx)

Manitoba were the two costliest floods of the century (Ashmore & Church, 2001). So far, in the 21st century, with losses exceeding five billion dollars, flooding of the Bow River in Alberta 2013 is said to be Canada's costliest natural disaster in history (Swiss Re, 2016).

Swiss Re (2016) recently reported on a Canada-wide flood model which predicted losses of $13.8 billion in the event of a 200-year flood. With such high potential losses, the need for a standardized approach to flood risk management and assessment becomes more and more important.

1.2.2 Flood-forming Conditions in Manitoba

As Manitoba is a natural floodplain, it is especially susceptible to flooding. This is due to several physiographic, meteorological, and anthropogenic factors which converge in the southern portion of the province, and the Red River Valley in particular.

1.2.2.1 Physiographic/Geologic conditions

The topography of the Red River Valley is very flat with a gradual decrease in gradient from south to north which causes a decrease in flow rate (Bluemla, 1977; Rannie, 2003). In Manitoba, the river has an average gradient of 0.0001 (Statistics Canada, 2015). It is hypothesized that isostatic rebound may exacerbate these conditions in the future as the elevation of the land north of the Red River rises. Figure 1.2 demonstrates the progression of the elevation increase in Manitoba at regular intervals from the formation of the Tyrell Sea as it retreats into the Hudson's Bay. Eventually, this trend could even cause the traditionally northward flowing river to reverse course and flow south (Brooks, Thorleifson & Lewis, 2005). This increase in elevation could also have the effect of increasing the magnitude of flooding along the river (Brooks, Thorleifson & Lewis, 2005).

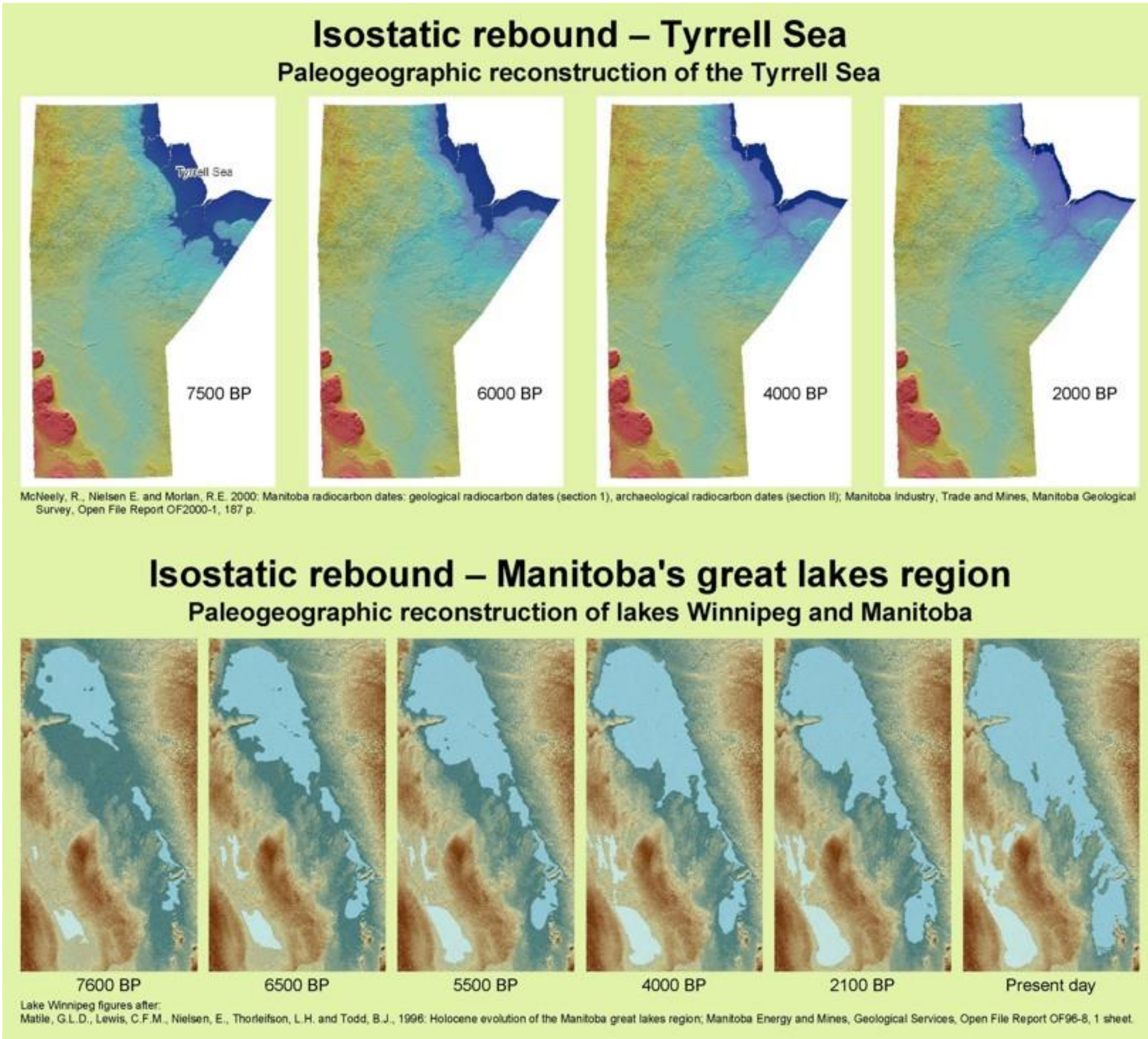

Figure 1.2 Isostatic rebound experienced in Manitoba between 7500 BP and 2000 BP (Manitoba Mineral Resources, 2013. Surficial geology compilation map series. Retrieved from http://www.gov.mb.ca/iem/geo/gis/sgcms/isostaticrebound.jpg)

The term valley, used to refer to the red river area, is a misnomer. The area is actually a lake bed, remnant from Glacial Lake Agassiz (Schwert, n.d.). The lacustrine soils found in this region were formed thousands of years ago from the sediments which precipitated to the bottom of the lake (Land Resource Unit, 1999). These type of soils are very clayey, with a fine texture which typically results in poor drainage. This means that rather than infiltrating through the soil, water has nowhere to go and so pools on the landscape, causing flooding (Land Resource Unit, 1999). The Red River is part of the Lake Winnipeg watershed which drains an area of approximately 948,200 km^2, spanning Canada and the United States (Welsted, Everitt & Stadel, 1996). With so much water draining to this one point, it is easy for the river channel to surpass its capacity resulting in flooding.

The south-north orientation of the river may also contribute to the flooding of its northern reaches. The progression of spring ice melt from the warmer latitudes of the south to the cooler latitudes of the north can result in the build-up of spring runoff from the south against still frozen areas of the river downstream, causing flooding due to ice jams (Musée du Fjord, 2002).

1.2.2.2 Meteorological conditions

Severe flooding in Manitoba is usually characterized by a particular set of meteorological conditions. An analysis of the meteorological conditions present before and during major flood events was performed by Mahmud (2015) and a summary of the common conditions and their presence or absence during major flood events is described in Table 1.1. The floods of 1826, 1950, and 1997 saw the presence of all of the meteorological conditions known to be associated with flooding which likely contributed to the magnitude of these events. Meteorological

Table 1.1 Meteorological conditions contributing to major historical floods in Manitoba by flood year

Meteorological Conditions	Flooding Year							
	1826	1852	1861	1950	1979	1997	2009	2011
Heavy precipitation in previous year	√	√	x	√	√	√	√	√
Very cold and long winter	√	x	x	√	x	√	x	√
Substantial snowfall in winter	√	√	√	√	√	√	x	x
Snowfall/blizzard in late winter	√	√	√	√	√	√	x	x
Quick melting of ice at upstream	√	x	√	√	x	√	x	x
Heavy early spring precipitation	√	√	x	√	√	√	√	√
Late and sudden thawing	√	x	x	√	√	√	√	√
Ice jam condition	√	x	√	√		√	√	√

(Source: Mahmud (2015) Compiled from Royal Commission Report, 1958; Welsted, 1996; Rannie, 1998; 2002; Bumsted, 2000; Manitoba Water Stewardship, 2006; Government of Manitoba, 2009 and 2013; Manitoba Infrastructure and Transportation, 2013; Environment Canada, 2013.)

conditions include wet conditions the year before which cause the ground to be saturated when it freezes. A late thaw in spring means the ground is still frozen and saturated and does not have the capacity to absorb the spring runoff. Combine these factors with a heavy spring rainfall and the results can be devastating for those living in the floodplain (Rannie, 1998).

1.2.2.3 Human-induced conditions

De Loe (2000) states that "although flooding has existed for many centuries, it is considered a hazard only where human settlements and livelihoods occupy the floodplain, thereby placing property and lives at risk". The rivers and lakes that encouraged settlement in the area by providing a source of transportation, food, and water, also represent a potential hazard for communities built within their floodplains.

Conversion of lands from uses capable of slowing water movement to impermeable surfaces, which prevent absorption and encourage faster runoff, have also affected the flood regime, causing surrounding watercourses to rise rapidly, thereby increasing the risk of flood (Ducks Unlimited Canada, 2011). Economic activities such as removal of forests for building materials and agricultural use have reduced the water storage capacity of the landscape (Manitoba Forestry Association Incorporated, 2011).

Wetlands have been drained at an alarming rate to create land suitable for agriculture. Wetlands are useful features for storing water on the landscape. They help to slow the flow of water and reduce the effects of flooding. The drainage of these wetlands and the contribution of the water they hold to the surrounding waterways is thought to have increased the impacts of flooding (Ducks Unlimited Canada, 2011).

Human settlement activities have also resulted in the conversion of wetlands and forests to developed areas with impermeable surfaces such concrete roadways, parking lots, and buildings. This reduces the water storage capacity of the landscape resulting in higher rates of runoff to nearby streams and rivers thereby increasing the risk of flooding. The isolation of water within built infrastructure such as pipes, sewer systems and culverts can also contribute to flood risks if the capacity of these systems is overwhelmed.

1.2.3 Major Flood Events in the Red River Basin

There are records available for several major flood events dating back to the "first devastating flood following permanent Euro-Canadian settlement in Manitoba", the flood of 1826 (Rannie, 2003). While this event is considered to be the worst flood in history, estimates of the magnitude of this flood are questionable as it predated instrumental records. Nevertheless, records from heights recorded at James Avenue have suggested that this flood reached 36.4 feet (Rannie, 2003). Figure 1.3 shows losses in billions of dollars for eight major flood events. While these figures are estimated, this data suggests that losses for the flood of 1826 were approximately 5 billion dollars, making it the costliest flood to date (Rannie, 2003). The spatial extent of seven major flood events is described by Figure 1.4. This data shows that the flood of 1826 had the largest spatial extent of any of the floods considered.

The flood of 1950 served as the impetus for the development of the Red River Floodway (Floodway Authority, n.d.). Table 1.2 shows that this flood saw the most homes damaged and the most people evacuated of any flood on record. With such devastating losses, the Premier at the time, Duff Roblin, embarked on a project to protect the city of Winnipeg from future severe

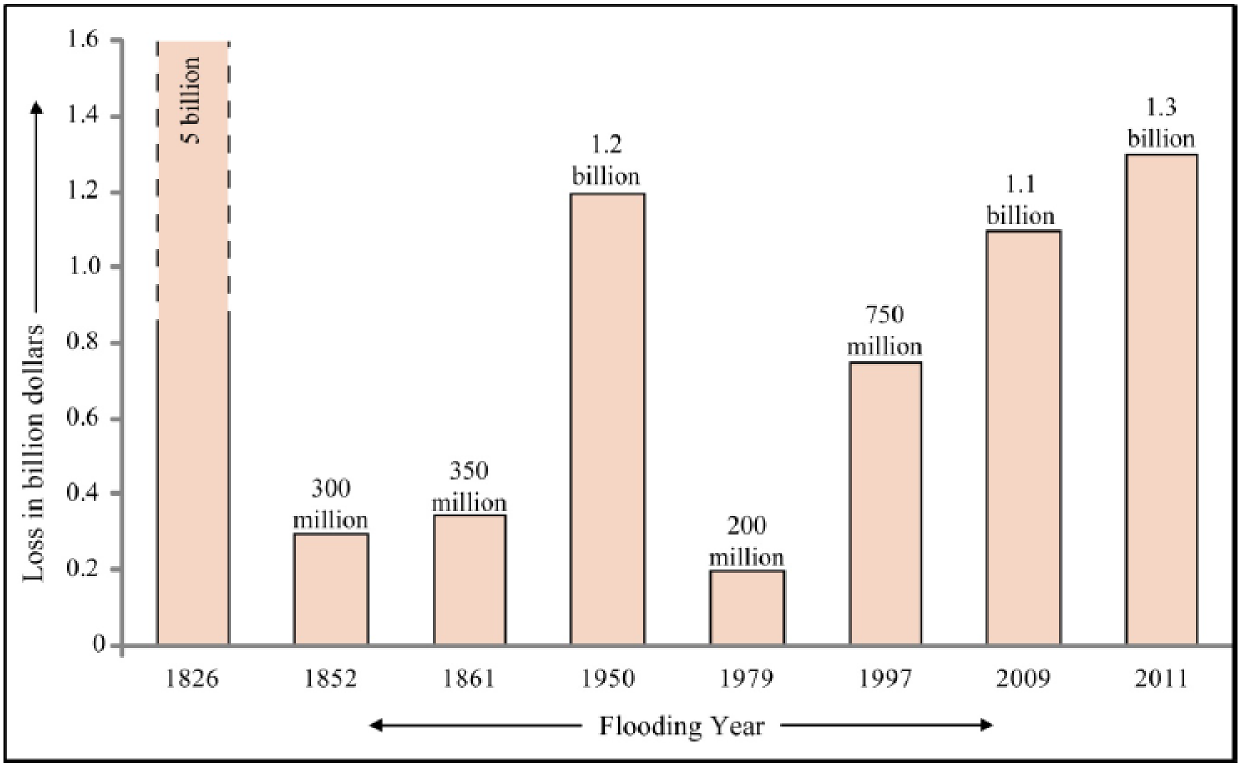

Figure 1.3 Flood-loss trend in Manitoba (cost normalized at 2014 Canadian dollars) (Source: Mahmud, 2015 Compiled from Royal Commission Report, 1958; Welsted, 1996; Rannie, 1998; 2002; Bumsted, 2000; Manitoba Water Stewardship, 2006; Government of Manitoba, 2009 and 2013; Manitoba Infrastructure and Transportation, 2013; Environment Canada, 2013.)

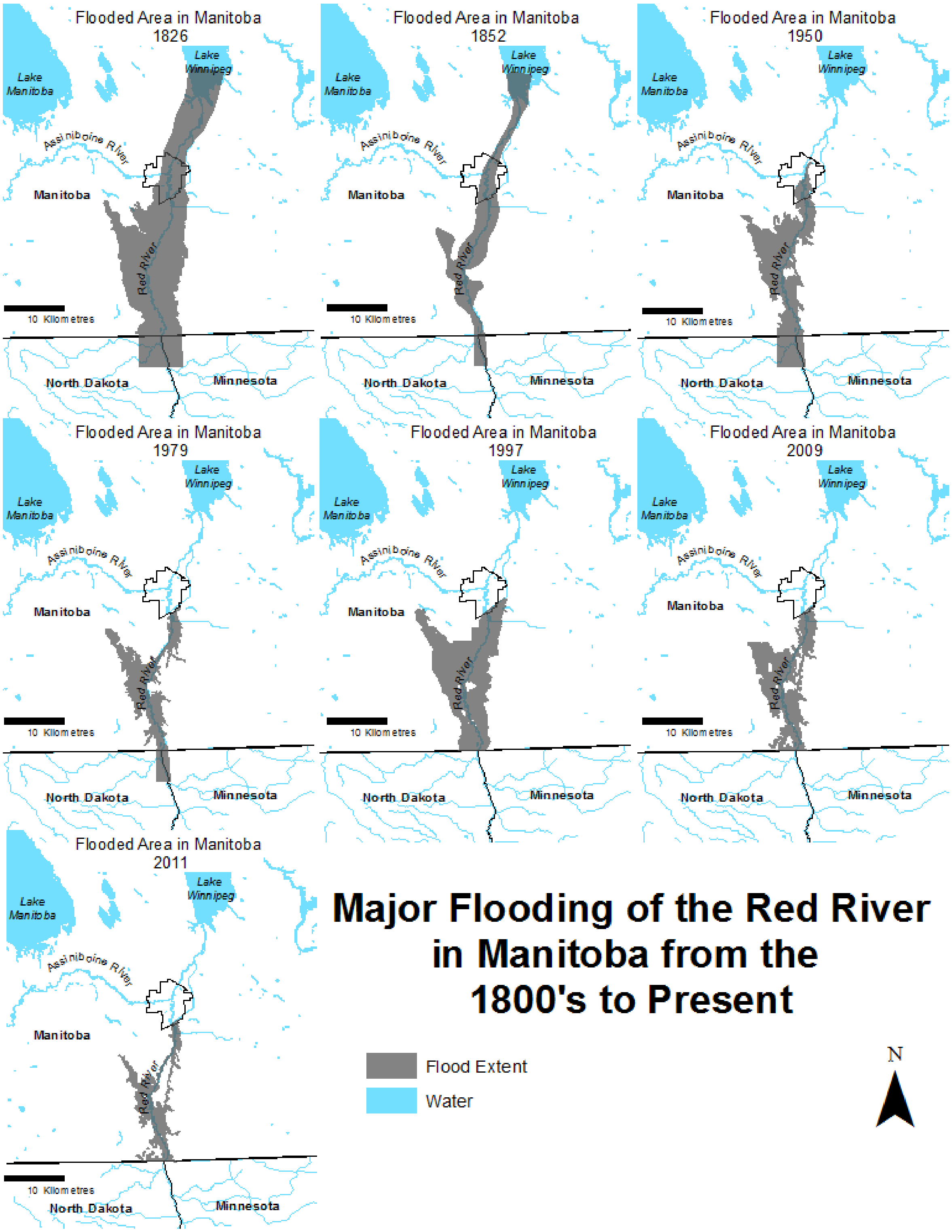

Figure 1.4 Spatial extent of major flood events in the province of Manitoba 1826, 1852, 1950, 1979, 1997, 2009, 2011. (Data for 1826, 1852, 1950, and 1979 flood extents from Mahmud (2015), for water, administrative boundaries, and 1997, 2009, and 2011 flood extent boundaries MLI (2013))

Table 1.2 Extreme 8 floods in Manitoba (benchmark of 3000 m3/s peak flow rate)

Floods	**Peak Flow Rate (m^3/s)**	**Area Inundated ($mile^2$)**	**Households Damaged**	**People Evacuated**	**Flood Cost (Estimated at 2014)**	**Return Period**
1826	6400	900	-	3,500	5 billion	667
1852	4700	380	-	2,500	30 million	150
1861	3540	310	-	2,200	35 million	45
1950	3060	640	10,000	100,000	1.2 billion	28
1979	3030	390	1,100	7,000	200 million	27
1997	4615	710	1,000	28,000	750 million	110
2009	3625	386	250	2,800	1.1 billion	33
2011	3300	140	3,500	7,100	1.3 billion	30

(Source: Mahmud K. H., 2015 Compiled from Royal Commission Report, 1958; Welsted, 1996; Rannie, 1998; 2002; Bumsted, 2000; Manitoba Water Stewardship, 2006; Government of Manitoba, 2009 and 2013; Manitoba Infrastructure and Transportation, 2013; Environment Canada, 2013.)

flooding events (Floodway Authority, n.d.). The development of the Floodway has been credited with saving the city from millions in damages during the “flood of the century” (Rannie, 1998). The “flood of the century” occurred in 1997, and is actually thought to have had a return-period between 110-120 years. While the operation of the floodway largely protected Winnipeg from the flooding, it was not able to completely save the city from flooding. Sand bagging efforts were undertaken to protect homes at risk along the river and some houses were still damaged. The majority of the damage costs were experienced outside the city in the surrounding rural areas, particularly communities south of the city (Rannie, 1998). The vulnerability of this region to loss from flooding demonstrates the need for effective quantitative risk assessment tools and methods which can be used to devise mitigation strategies.

1.2.4 Quantitative Risk Assessment

Flood risk assessment is an essential part of hazard risk reduction as well as the emergency management planning process (Nastev & Torodov, 2013). It is not enough to be aware of the type, frequency and magnitude of potential hazards, it is important to be able to determine their potential effects on people and property.

The components required for quantifying risks are data regarding the hazard, the inventory, and the vulnerability. With this information, an analysis of potential risks can be completed. The hazard refers to the type of event or disaster being assessed (Nastev & Torodov, 2013). The inventory is what is being damaged, for example, in the case of flood analyses the inventory would be the asset database and the affected population. There are several types of vulnerability, but for the purposes of this study we focus mostly on physical vulnerability. The physical vulnerability refers to the likelihood and extent of damages caused by the hazard. For flood analysis the physical vulnerability can be determined using a flood depth-damage curve (Nastev & Torodov, 2013). This curve determines the percentage of damage based on the height of water. In order to develop mitigation strategies and emergency protocols, it is important to assess the risk of the hazards present on the landscape. As technology evolves we have increasingly made use of it for risk assessment. Most recently has been the development of GIS software packages specifically created for use in hazard risk assessment.

1.2.5 HAZUS-MH Quantitative Risk Assessment Tool

The Federal Emergency Management Agency (FEMA) in the United States was established in 1979 with a mandate to "coordinate the federal government's role in preparing for, preventing, mitigating the effects of, responding to, and recovering from all domestic disasters…" (FEMA, 2016). In 1997 FEMA developed HAZUS, which stands for Hazard U.S., as a standardized hazard risk assessment program. The software runs on ArcGIS to produce flood loss estimations including reporting and mapping capabilities. Initially only the earthquake model was available, but in 2004 HAZUS-MH, or multi-hazard, introduced models for hurricanes and floods. The software was adopted for use in Canada in 2011 through agreements between NRCan, DRDC and FEMA (Nastev & Torodov, 2013; NRCan, DRDC & FEMA, 2011). Currently only the earthquake and flood models are available in the Canadian version. This software is currently being tested for its potential as a quantitative flood risk assessment tool.

1.2.6 Dasymetric approach

The aggregate data available with HAZUS is aggregated at the dissemination area level but represented at the census block level (FEMA, 2015; Nastev & Torodov, 2013). There have been some concerns raised regarding the accuracy of predictions made by HAZUS given the larger census block size in Canada (Nastev & Torodov, 2013). Table 1.3 shows that while there is a difference in census block sizes in Canada and the U. S., this difference varies from province to province. In order to address any potential issues caused by the aggregation of general building stock data, a dasymetric approach has been proposed as a possible method of disaggregating the data (McDonald, 2016; Mennis, 2009). The dasymetric approach is a way of stratifying aggregated data in order to gain more spatially precise information. It is desirable to present population data at a more precise level than the census block. Administrative units such as census blocks often contain areas in which no population can be present. In this case, another variable, such as land use classification, can be used to constrain the population data within the landscape. In this study, two variables, land use classification and night light imagery, will be examined to determine if a relationship exists with population density and dwelling density.

1.2.6.1 Land Use Classification

Land use classification is often suggested as a variable with potential for use in the dasymetric approach (Briggs, Gulliver, Fecht & Vienneau, 2006; Mennis, 2003; 2009; Seifert, Thieken, Merz, Borst & Werner, 2010; Torodov, 2012). Human populations tend to develop and settle on the landscape in different densities, avoiding some areas and utilizing others (e.g. ‘wetlands’ are avoided, arable soils developed into ‘agriculture’ that at higher densities become ‘urban’). Thus land use categories, their spatial pattern, and distributions may be used to pinpoint more precisely where humans are on the landscape. A land use class such as water will contain no population, while a class such as forest or wetland may have sparse populations. The highest

Table 1.3 Census block size in Canada and in the U.S.

Province/ Territory	Population	Area (km^2)	Population /km^2	Census Blocks	Population /Census Block	km^2/Census Block
AB	3790200	642317	5.90	66332	57	9.7
BC	4499100	925186	4.86	55505	81	16.7
MB	1233700	553556	2.23	30471	40	18.2
NB	755500	71450	10.57	15400	49	4.6
NL	525000	373872	1.40	8712	60	42.9
NS	43500	53338	0.82	15780	3	3.4
NT	944500	1183085	0.80	1492	633	793.0
NU	34200	1936113	0.02	757	45	2557.6
ON	13263500	917741	14.45	132762	100	6.9
PE	144000	5660	25.44	3569	40	1.6
QC	8007700	1365128	5.87	109443	73	12.5
SK	1066300	591670	1.80	51610	21	11.5
YT	35400	474391	0.07	1359	26	349.1
Canada	34342800	9093507	3.78	493192	70	18.4
US	311718857	9158064	34.04	11078297	28	0.8

(Data for Canada from Statistics Canada, 2005; 2016 and for United States from United States Census Bureau, 2016) populations would be found in the developed land use classes, collectively making these suitable as ancillary data to use to disaggregate population data (Mennis 2003; 2009). Portions of the census block which lie within a water classification can be eliminated so that the population is constrained to the developed area of the census block. Maantay and Maroko (2009) noted that using land use for the dasymetric approach may be of limited value in urban areas. They made the point that in high density urban areas, simply knowing that a population exits in the area may not be enough to determine the population density (Maantay & Maroko, 2009).

Mennis (2009) attempted to account for the variation in population densities within land cover classifications by introducing a third piece of ancillary data which identified regions as urban, exurban or suburban. All land cover classifications were considered to have zero population except developed and forest areas. A dasymetric algorithm was used to determine the proportion of the population density within each these two classifications. The results found that incorporating a dasymetric approach allowed for more precise mapping of populations within suburban and exurban populations, but had limited effect in densely populated urban areas (Mennis, 2009).

1.2.6.2 Night Light

Increasing access to night time light imagery has led to some interesting research into the relationship between night light and population (Liu, Sutton & Elvidge, 2011; Amaral, Monteiro, Camara & Quintanilha, 2006). Analysis of satellite imagery taken at night has discovered a relationship between night light and human factors such as population density (Liu et al, 2011), economic activity, and electric power consumption (Elvidge et al., 1997). This relationship can be used to reveal information about human populations on a finer scale then would normally be available using census data.

Currently, the most readily available source of night light imagery is the Defense Meteorological Satellite Program - Operational Linescan System (DMSP-OLS). While this imagery has been widely used it does possess several limitations. A saturation effect has been noted in urban areas due to the upper threshold caused by the 6-bit quantization which constrains the pixels values from 0-63 (Sutton, Roberts, Elvidge & Meij, 1997; Levin, Johansen, Hacker & Phinn, 2014). A phenomenon referred to as "overglow" also occurs where light from built-up areas spills over into non-lit areas, making them appear populated (Levin et al., 2014).

The relationship between light and population is not universal. For example in the developing world there may be very high populations but lack of access to electricity would result in low night time light levels. For example Pistolesi (2013) notes that light levels in South Korea correspond well with population densities, however in North Korea, even highly populated areas appear dark. This is likely for reasons connected to affluence and access to electricity.

There have also been concerns raised over light contamination from fires or airports which can cause areas with low populations to have high light intensity values (Liu et al., 2011; Amaral et al., 2006). Due to its coarse spatial resolution of 1 kilometre, estimations of population based on this imagery would be of limited spatial accuracy. Higher resolution night time imagery is available for purchase (Levin et. al., 2014) however, research suggests that higher resolution imagery does not have a significantly stronger relationship with population (Liu et al., 2011).

1.3 Research Purpose and Objectives

The overall objective of this thesis is to determine if HAZUS is a viable flood hazard risk assessment tool in Manitoba, and whether dasymetric stratification is possible based on ancillary data. There are two main objectives which will be met through this study. The first objective is to evaluate the flood loss estimations produced by HAZUS software for flood risk assessment in Manitoba using built-in aggregated data and local, user-supplied data. The second objective is to determine whether significant relationships, which are necessary for dasymetric stratification, exist between population and dwelling density, and ancillary variables land use classification and night time light intensity.

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Chapter 2. Study Area

2.1 Introduction

The study area chosen for evaluation of HAZUS and the analysis of the ancillary variables best suited to dasymetric stratification was southern Manitoba in central Canada. Manitoba is located in central Canada between Saskatchewan and Ontario (Statistics Canada, 2011). It shares a southern border with North Dakota and Minnesota and is bordered by Nunavut to the north. Central and southern Manitoba is characterized by many lakes and rivers (Welsted, Everitt & Stadel). Most of the population is concentrated in the southern third of the province with over 60% of the population residing in the city of Winnipeg (Statistics Canada, 2011). Major rivers in this area that frequently experience flood conditions include the Red and Assiniboine rivers, but in this study there was a specific focus on the Red River and in particular the RM of St. Andrews. The HAZUS analysis, in particular, was focused on Ward 1 of the RM of St. Andrews because its relatively small population provided a manageable number of buildings for the asset database and proximity to the Red River presented a source of hazard exposure for analysis. The larger area was chosen to analyze the relationship between land use classification, light, and population variables as it was characterized by a diverse enough range of light values, land use classification types, and population density patterns.

2.3 Hydrology

The Red River flows from the south where it forms the border of Minnesota and North Dakota in the United States (Red River Basin Board, 2000). It travels north where it is joined by the Assiniboine River at The Forks in downtown Winnipeg. The Assiniboine River flows east from southeastern Saskatchewan through southwestern Manitoba and eventually joins the Red River

(Red River Basin Board, 2000). The Red River forms the border of the RM of St. Andrews to the west, flowing through the Netley-Libau marsh and emptying into Lake Winnipeg (Red River Basin Board, 2000). It is along this most northerly reach of the Red River that our study area is located. Figure 2.1 indicates the location of the RM of St. Andrews and outlines the boundaries of the six wards in which it is divided. The Red River basin covers over 116,500 square kilometres and is one of the largest contributing sources of water to the Lake Winnipeg watershed. The Lake Winnipeg watershed drains an area of 984,200 km^2 (Welsted, et al., 1996). Figure 2.2 shows the extent and topography of the Red River basin. Within Manitoba, the width of the Red River channel ranges from 300 to 600 feet and its depth ranges from 25 to 45 feet (Red River Basin Board, 2000). The gradient of the river is 0.00004 from Emerson, at the Manitoba border, to Ste. Agathe and then increases slightly to 0.00007 from Ste. Agathe to the mouth of the river, at Lake Winnipeg (Red River Basin Board, 2000).

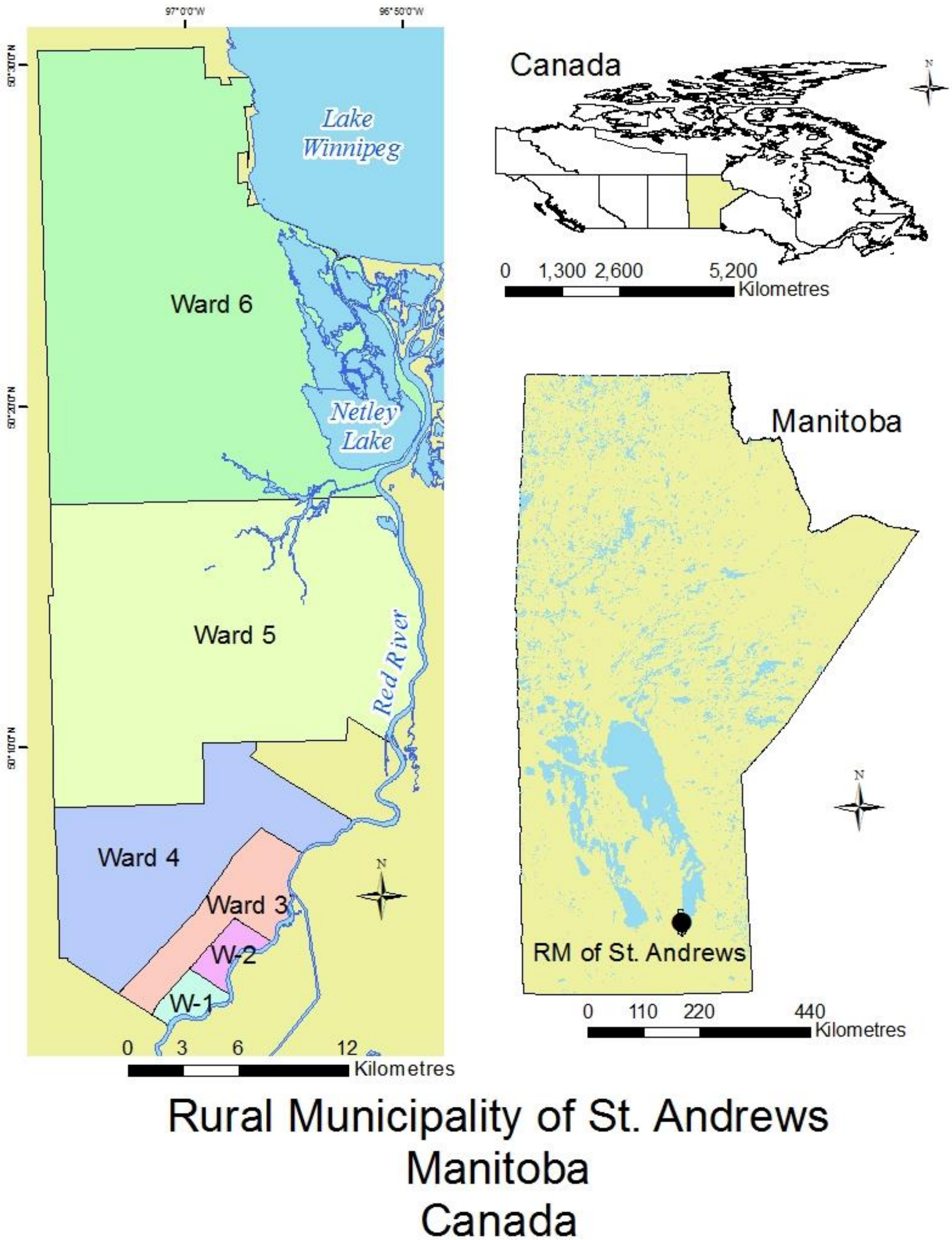

Figure 2.1 Study Area Location in the Rural Municipality of St. Andrews (MLI, 2009; 2011; Statistics Canada, 2011)

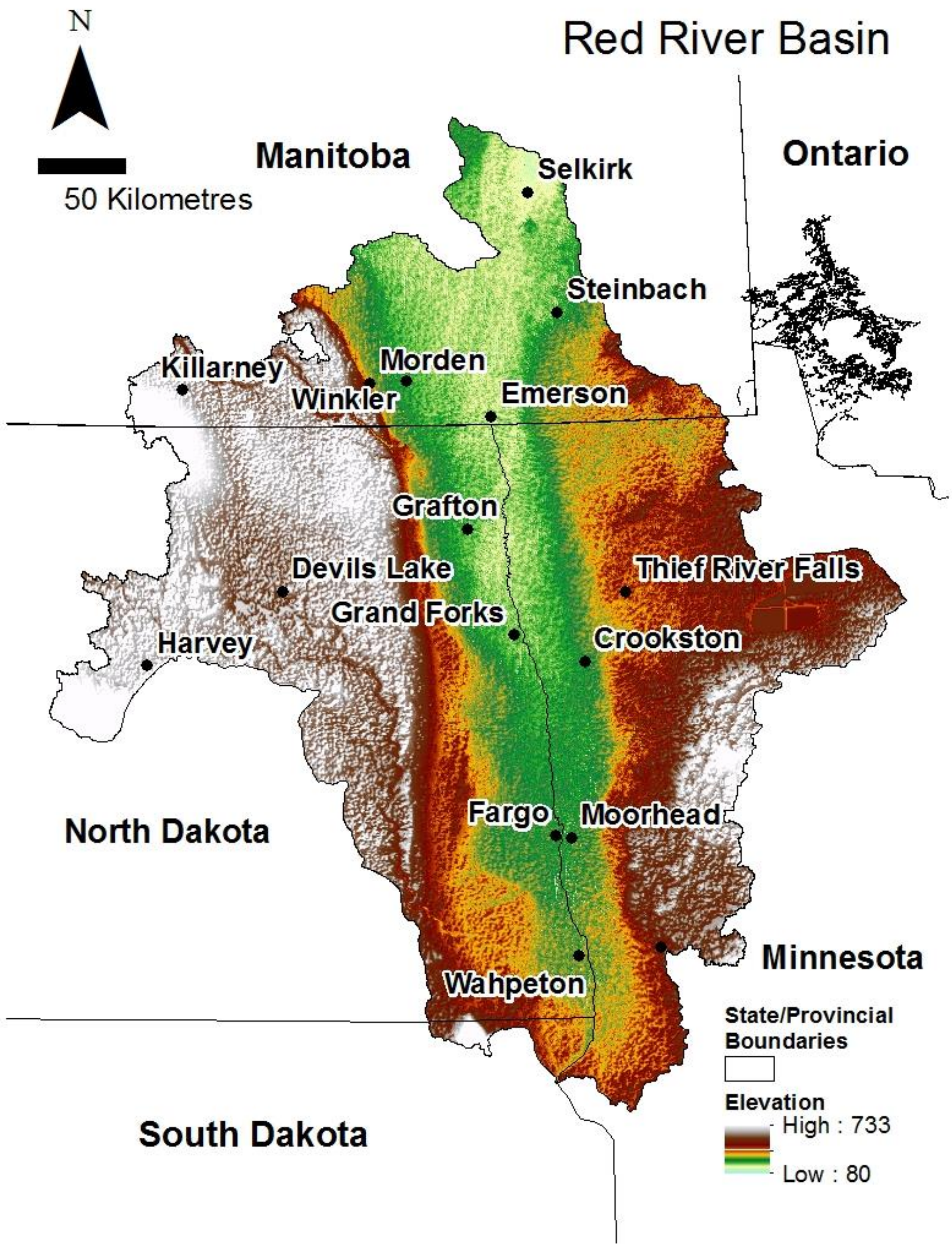

Figure 2.2 Topographic Relief in the Red River Valley (MLI, 2011; Statistics Canada, 2011)

2.4 Topography

Southern Manitoba is comprised of three of the four physiographic regions found in Manitoba, each with varying topographic conditions. The largest physiographic region is the Manitoba Lowlands region (Welsted, Everitt & Stadel, 1996). The Manitoba Lowlands region is characterized by a mostly flat topography with a very gradual downward slope north towards the Hudson's Bay. The RM of St. Andrews is located in this region. As demonstrated in Figure 2.3, there is a slope of less than 1% throughout the RM of St. Andrews. This flat topography causes water to move more slowly through the watershed, pooling on the landscape instead of draining off quickly into the surrounding waterways (Land Resource Unit, 1999).

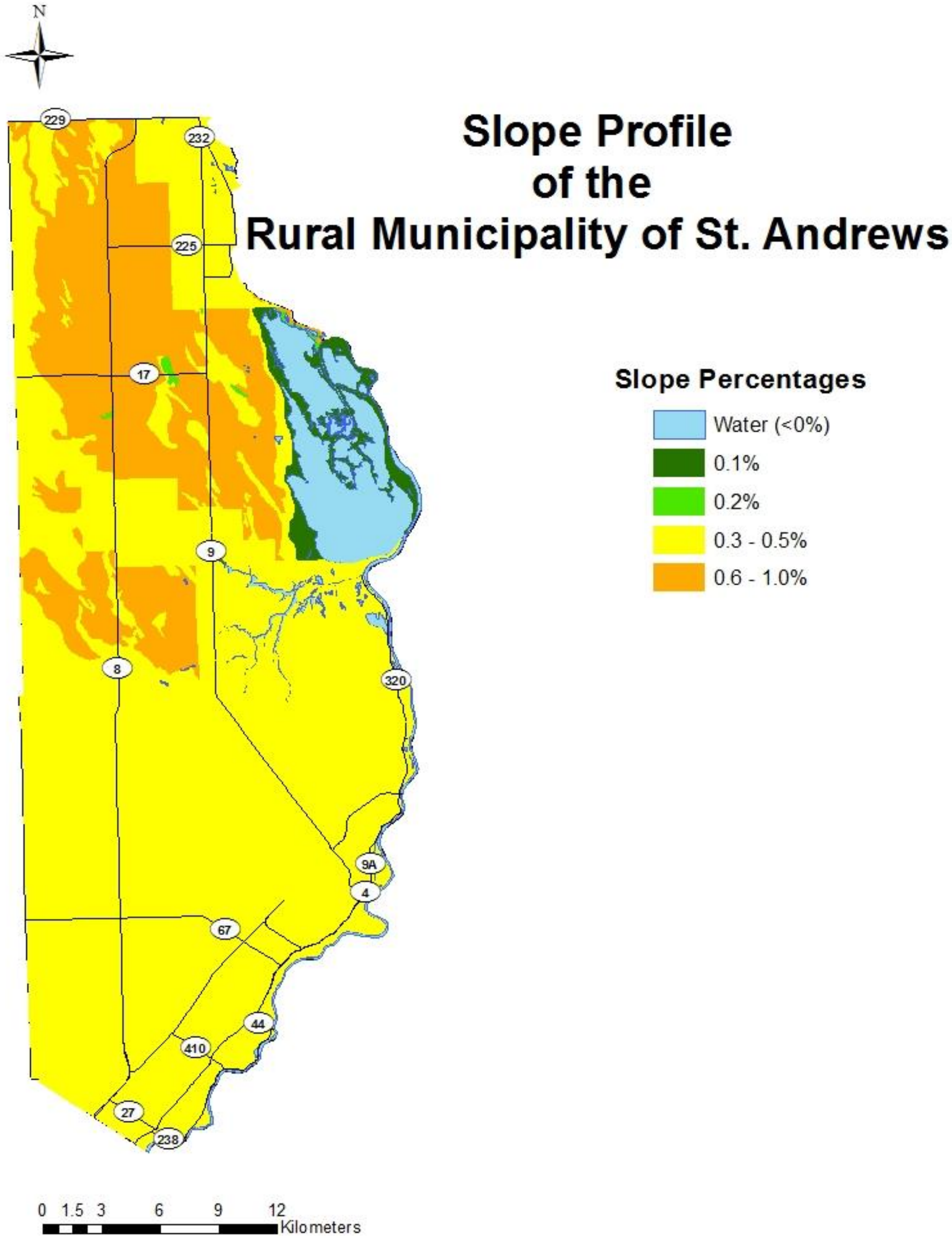

Figure 2.3 Slope Profile by Percentage in the Rural Municipality of St. Andrews (MLI, 2002)

2.5 Soils

The soils in St. Andrews were mostly formed from sediments that precipitated to the bottom of glacial Lake Agassiz as it retreated across the continent (Land Resource Unit, 1999). Figure 2.4 shows that the deposits left behind formed largely of Clayey Lacustrine soils which prevent drainage causing water to sit on the landscape. Medium texture soils are the most common soil type followed closely by fine textured soils with imperfect drainage (Land Resource Unit, 1999). The drainage characteristics of St. Andrews are shown in Figure 2.5. Fine textured soils such as those found in St. Andrews form a barrier preventing water from draining. These factors contribute to standing water and overland flooding presenting a hazard for the community.

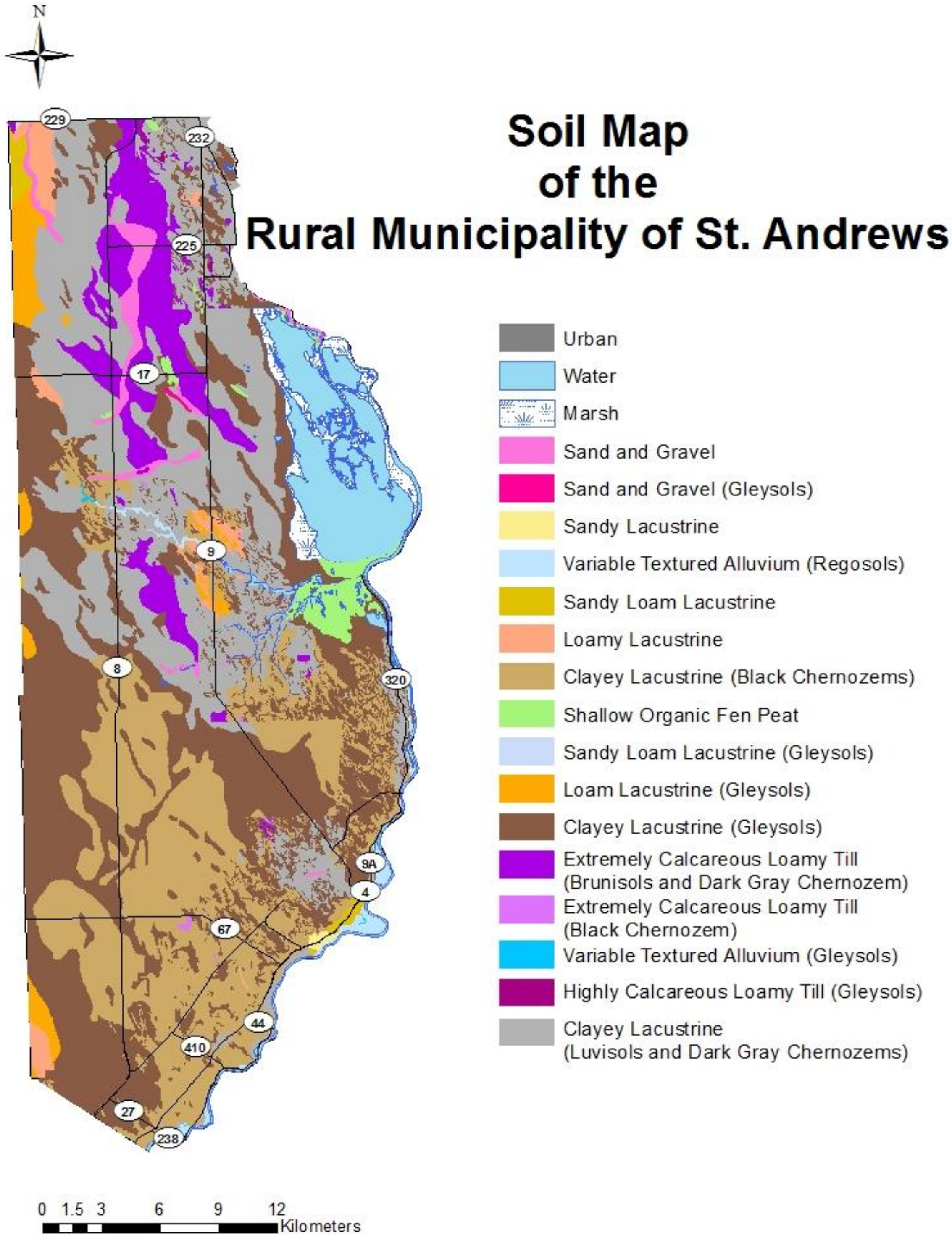

Figure 2.4 Soil Types in the Rural Municipality of St. Andrews (MLI, 2002)

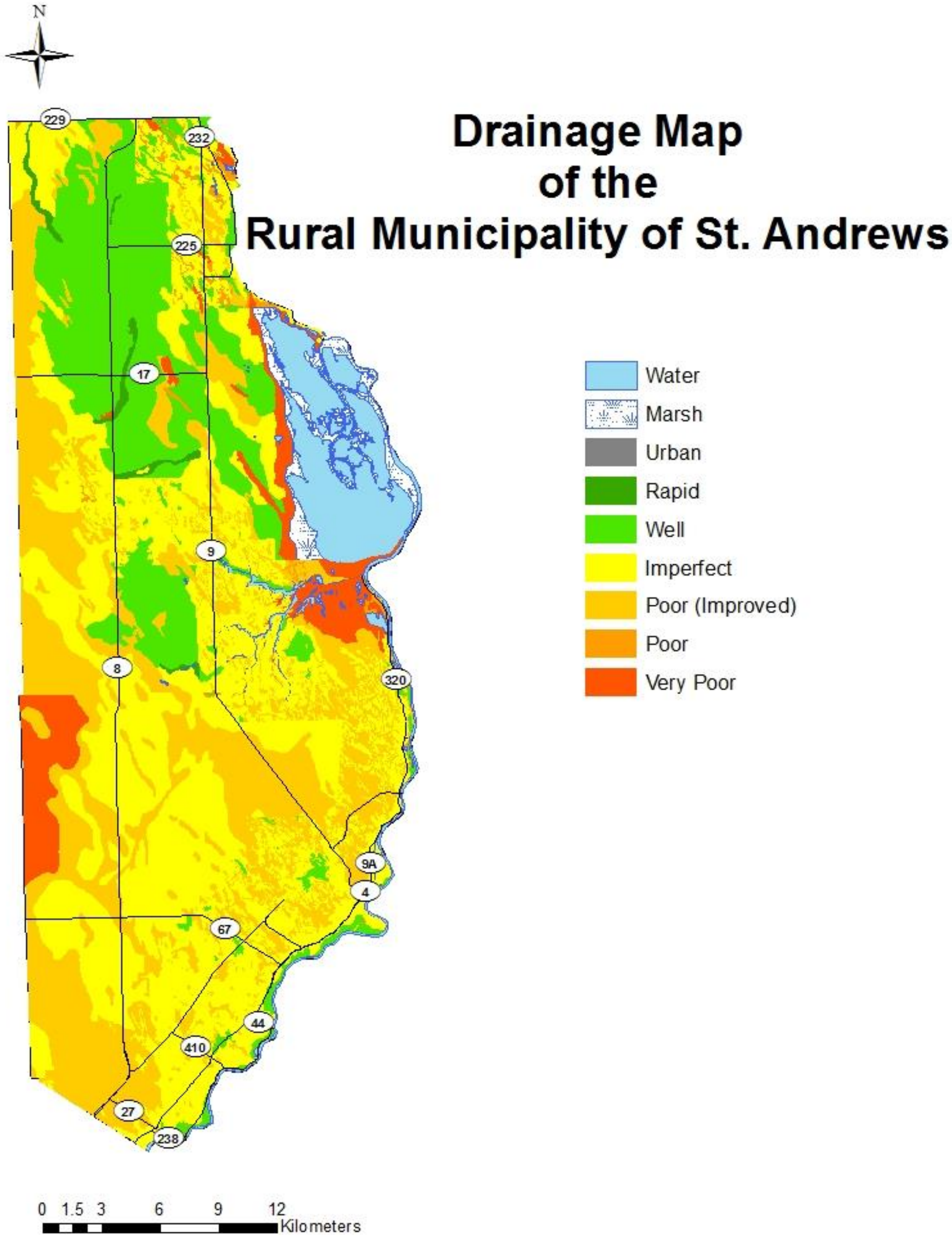

Figure 2.5 Drainage Ability in the Rural Municipality of St. Andrews (MLI, 2002)

2.6 Climate

Manitoba's climate is controlled by three factors, its high latitude, its continental position, and its flat topography (Welsted, Everitt & Stadel, 1996). The high latitude position of Manitoba means that it as a seasonal climate. Summers are short with long, hot days while winters are long with freezing temperatures and long nights. The continental location means there are no moderating effects from nearby oceans or mountains. The climate is fairly dry with wetter areas in the east receiving around 600 millimetres of precipitation annually (Welsted, Everitt & Stadel, 1996). Most locations receive approximately two-thirds of their yearly precipitation between May and September. The flat topography leaves the landscape exposed to the elements and vulnerable to extreme weather events. Manitoba has a highly variable climate experiencing nearly every type of extreme weather event (Welsted, Everitt & Stadel, 1996). Owing to the close proximity to the Red River, one of the most common extreme weather events experienced in the R.M. of St. Andrews is flooding (PSC, 2010). The R.M. of St. Andrews experiences frequent seasonal flooding in the populated areas along the river. There are a number of climatic factors which contribute to this flooding. In particular, spring melt occurs along southern reaches of the Red River earlier than along the northern portion and before ice melts on Lake Winnipeg (Welsted, 1996). This often results in free flowing ice and water impounding behind still-frozen stretches of river ice. This ice acts as a barrier impeding the northern movement of meltwater from the south and causing the river to spill over its banks, pooling on the surrounding floodplain. A second major source of flooding in St. Andrews is seiche tides, which occur in portions of Wards 5 & 6 that are situated on the Netley-Libau Marsh (the estuary of the Red River on Lake Winnipeg). Seiche tides can happen at any time during the year where the lake surface is unfrozen (Hamblin, 1976). This phenomenon results because the large surface area of the south basin presents a long ‘fetch’ (long lengths of surface over which wind can blow) and the shallow and constrained area of the estuary create conditions where the water can be literally ‘blown back’ along the River and tributaries in the Marsh. In some areas, strong August storms have resulted in water-level increases of over 1 m (Sutherland, pers. Comm.)

2.7 Land Use and Light

Southern Manitoba is characterized by dense clusters of population centered on a few cities and towns interspersed with large areas agricultural land. Figure 2.6 illustrates the large abundance of agricultural land present in the R. M. of St. Andrews. According to the MLI data, agriculture is the dominant land cover type occupying over 74% of the land surface (2004-2006). Population and built infrastructure is largely concentrated along the Red River and in Wards 1, 2, and 3. Homes are equipped with electricity and there is street lighting in urban areas which provide a source of night light in populated areas. Figure 2.7 illustrates the pattern of light intensity present in the R. M. of St. Andrews. If the intensity of light is stronger in more densely populated areas night lighting may be used as a proxy for population data where it is not available.

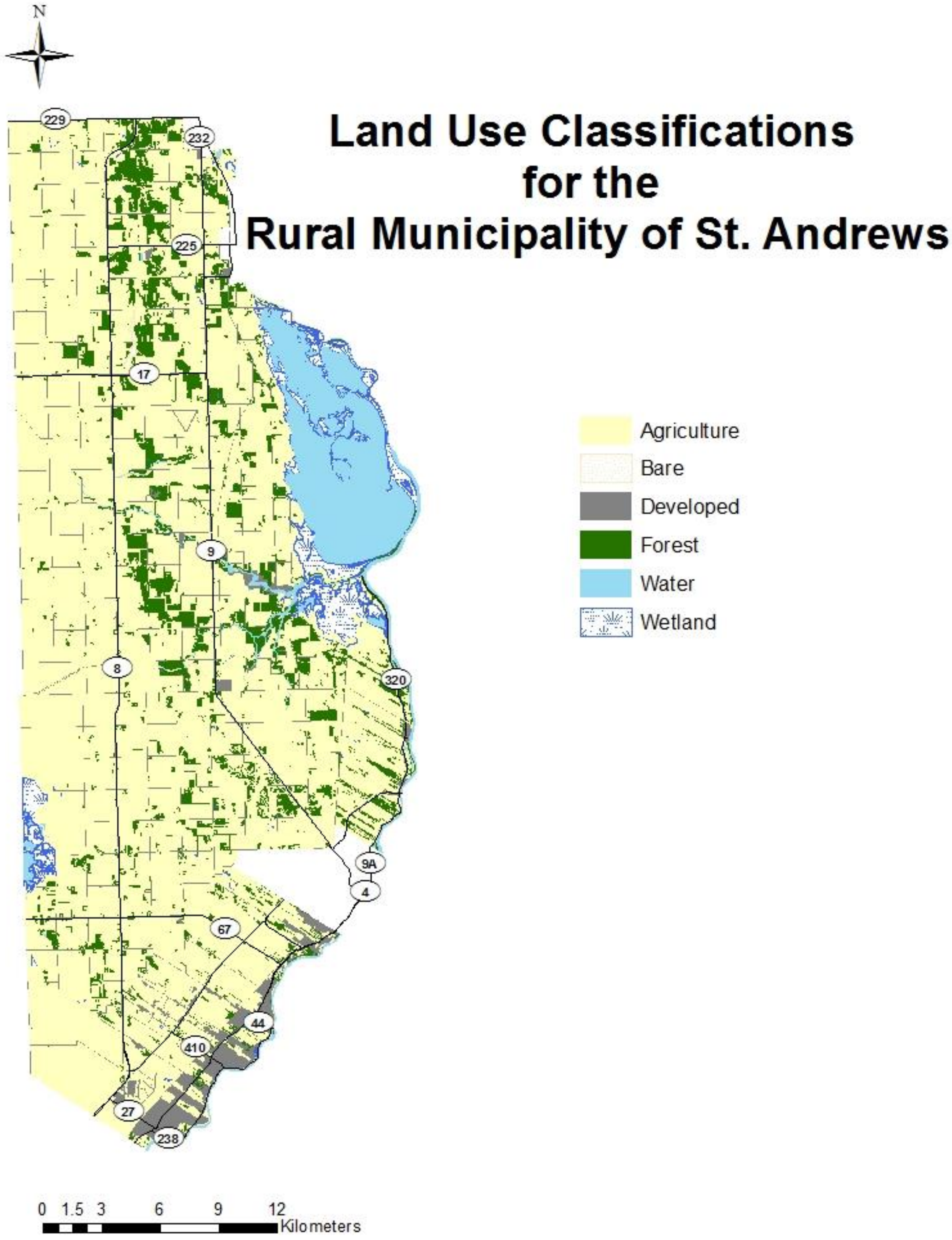

Figure 2.6 Land Use Classifications in the Rural Municipality of St. Andrews (MLI, 2004-2006)

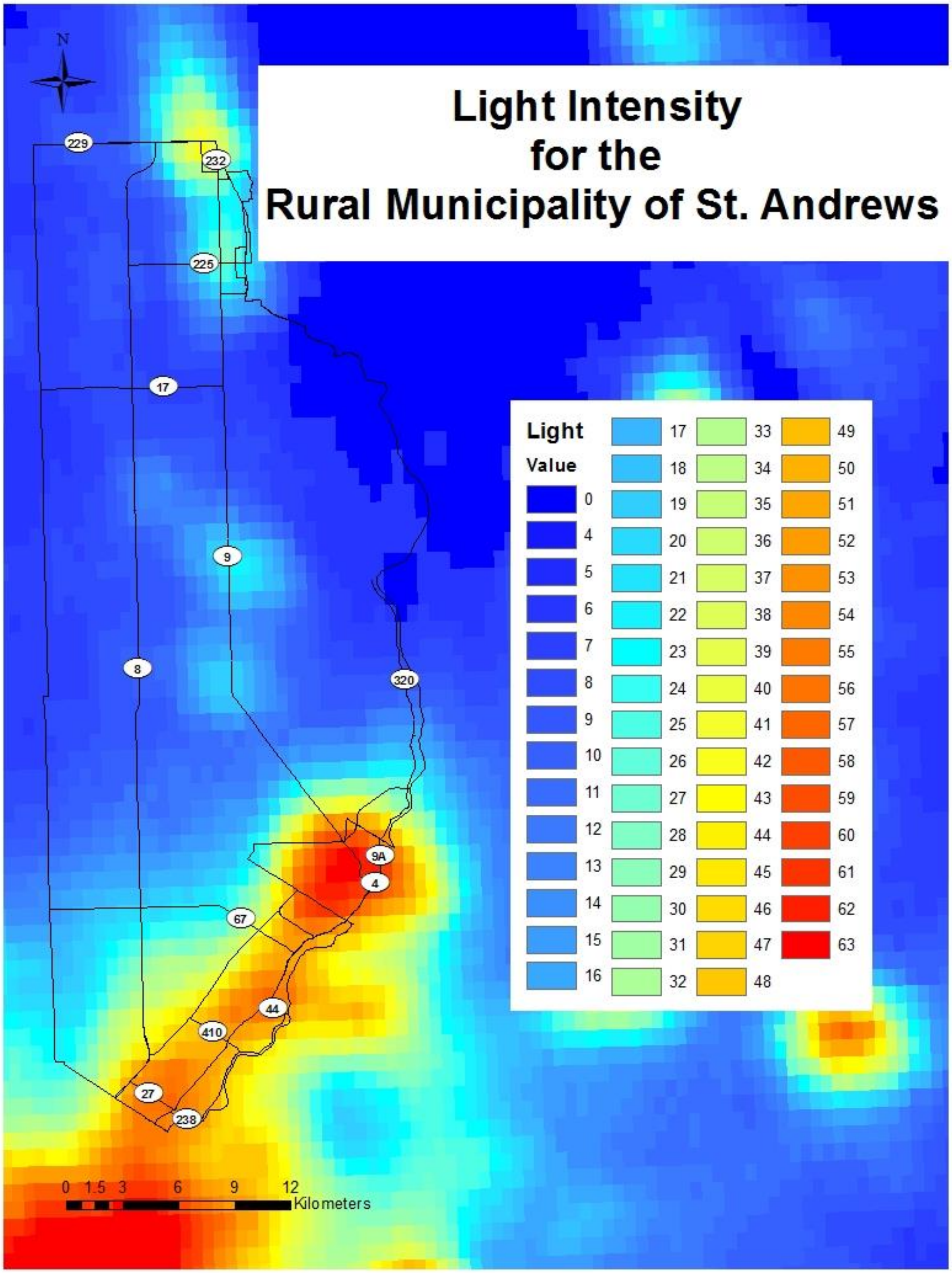

Figure 2.7 Nighttime Light in the Rural Municipality of St. Andrews (National Oceanic and Atmospheric Administration (NOAA), 2010)

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Chapter 3. HAZUS Database and Analysis

3.1 Abstract

Flooding is the most frequent and costly natural disaster in Canada (Public Safety Canada (PSC), 2010). Severe flooding events in recent decades have emphasized the need for jurisdictional co-operation in emergency management planning and disaster mitigation (Haque, 2000). An important part of effective emergency management planning is risk assessment (PSC, 2010). Hazards U.S. Multi-Hazard (HAZUS-MH) is a U.S. Federal Emergency Management Agency (FEMA) software program initially developed in 1997 that uses a Geographic Information System (GIS) to estimate losses due to natural hazards, including flooding (FEMA, 1997). This software package has been adapted to jurisdictions outside of the U.S. and is currently being evaluated in Canada. The objective of this study was to evaluate the use of the Canadian version of HAZUS for flood loss estimation in a selected Canadian community, the Rural Municipality (RM) of St. Andrews using aggregate and local assessment data. A data dictionary was developed to reclassify assessment data variables from the local codes used to the required HAZUS classes. The reclassified assessment database was used to create a building inventory on which analysis could be performed. The results of this study suggest that it is possible to use HAZUS for flood risk assessment in Manitoba however, there are challenges associated with running the Canadian HAZUS flood module.

3.2 Introduction

The Rural Municipality of St. Andrews is subject to severe periodic flooding along the Red River. In order to reduce the impacts of flooding for the residents of the community, the municipality has been exploring the use of quantitative risk assessment software to help support mitigation strategies. HAZUS is currently being investigated for its potential use in the Canadian context. In partnership with the municipality data-sharing agreements were developed which allowed the province to provide the data required to build an asset inventory database. The Manitoba tax assessment database was evaluated for its potential as a data source for creating a site-specific asset database for risk assessment. The asset inventory was combined with local hazard data to perform a building-by-building flood loss analysis using HAZUS. This information was compared with the results of analyses performed using the aggregated data supplied with the HAZUS software. Aggregate analysis was performed using the default Statistics Canada census boundaries supplied with the HAZUS program and using modified census boundaries created using a dasymetric approach. This approach combined the populated land use classifications into a layer which was used to exclude unpopulated areas of the census blocks. The results of this analysis suggest that HAZUS can be adopted for flood risk assessment in Manitoba. Recommendations for improvements to the software were made in addition to recommendations regarding the collection and storage of asset and hazard data in the province of Manitoba.

3.3 Study Area

The study area chosen for the HAZUS analysis was Ward 1 of the RM of St. Andrews. As the census boundaries did not conform to the boundaries of Ward 1, portions of census blocks straddling the boundary were included in the analysis (Figure 3.1). This area was chosen because St. Andrews experiences frequent flooding along the Red River which forms its eastern border. Flooding often occurs during the operation of the floodway and due to ice jams in early spring. For a more in depth description of the study area and factors contributing to the local flood regime see Chapter 2.

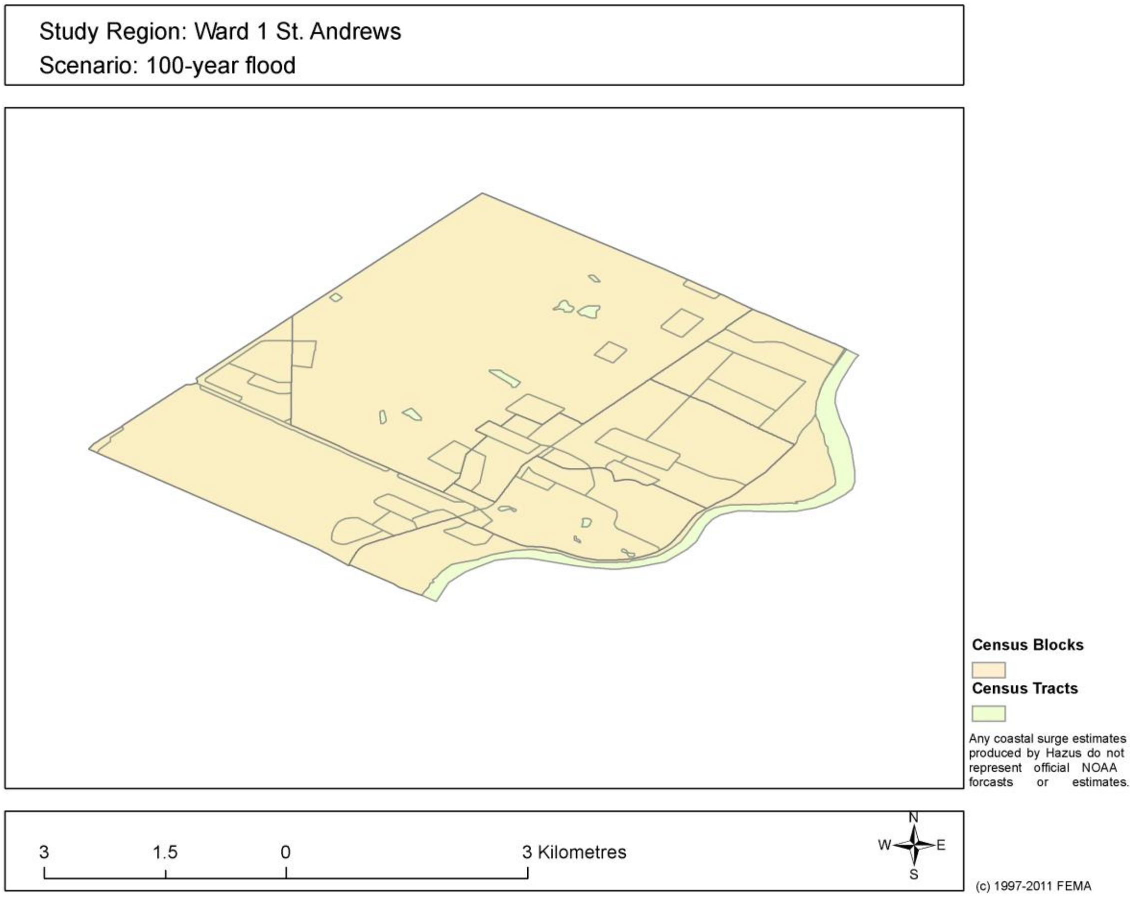

Figure 3.1 HAZUS Study Area in Ward 1 of the RM of St. Andrews

3.4 Methods

For this study the Canadian version of HAZUS-MH 2.1 was used. HAZUS is able to run scenarios using three flood hazard types; either riverine, coastal, or a combination of riverine and coastal. As this analysis does not involve any coastal areas, the riverine flood hazard type was selected. Limitations in the Canadian version of HAZUS mean that a flood depth grid must be supplied in order to perform a full analysis. To evaluate the potential of the HAZUS flood loss estimation software three types of analysis were performed. An analysis using the aggregate data supplied with the software program, analysis using census boundaries modified using a dasymetric approach, and a user-defined analysis using a user-supplied building inventory. In addition to the three types of analysis, two different flood scenarios were considered. A 100-year flood scenario and a worst-case scenario were analyzed.

3.4.1 Data Dictionary

The tax assessment database is managed by Manitoba Municipal Government (MMG) using the Manitoba Assessment Valuations Administration System (MAVAS). This database was used as the basis for the building inventory. However, the identifiers used in MAVAS for building stock characteristics did not match the required categories in HAZUS. In order to reclassify the database a data dictionary was developed. This dictionary was developed using a variety of sources including the HAZUS manual, a data dictionary developed for a HAZUS project in British Columbia and another dictionary developed in Washington in the U.S. (FEMA,2015; Hastings, 2015; FEMA, 2009). The data dictionary was used to create an Excel spreadsheet containing site-specific building stock variables.

In some instances the data required by HAZUS was not directly available from the assessment data or the format in which the data was provided was not directly compatible. For example, the assessment database allowed for buildings to have 1.5 or 1.75 storeys. HAZUS is only able to accommodate whole numbers, so these buildings were assumed to have two storeys.

Property tax roll number was the only common characteristic between the building locations and the assessment attributes and was used to link the two databases. The assessment database contained multiple entries for the same property parcel to account for improvements such as additions, garages, carports, and other items which may be considered in an assessment. These additional entries sometimes had conflicting information regarding the occupancy or foundation type. As HAZUS requires a single feature for each building, decisions had to be made regarding how to handle conflicts. These conflicts and the code chosen are summarized in Table 3.1.

Where buildings on a property were classified as both agricultural and residential, the residential code was used. Where properties were coded as having a foundation type of both basement and piles, basement was used. Where the foundation type was slab and piles, piles was used. In some instances the main building had a basement but an addition did not. In these cases the property was considered to have a basement. Once all properties with the required data had been reclassified there were properties remaining which were not assigned occupancy values. These entries were removed as it was determined that they were properties without buildings.

The assessment database also contained information regarding the foundation type. A data dictionary was also created for this information and the data reclassified. Where data gaps existed they were filled in with a default foundation type of basement.

Table 3.1 Summary of Conflicts Encountered Creating Data Dictionary and the Codes Chosen

Conflict	Code/Type Used
Occupancy type RES + AGR	RES
Foundation type Piles + Basement	Basement
Foundation type Basement + No Basement	Basement
Foundation type Piles + Slab	Piles
No foundation type	Basement

3.4.2 User-Defined Facility Inventory

The user-defined facilities inventory was created using a combination of Microsoft excel, Microsoft Access, and ArcGIS 10.0. Excel was the format in which the assessment database was provided, and was used to convert the data into the format used by HAZUS. ArcGIS was used to join the building footprint shapefile to the property parcel shapefile so that the building locations could be joined to the attribute data using the property parcel identifier as the common value. The final database, including the latitude and longitude coordinates of the buildings, were imported into Microsoft Access which was the format required to upload the database into HAZUS. The attribute information required to perform an analysis on user-defined facilities includes the building location, first floor height, number of storeys, building value, content value, foundation type, and occupancy type.

A shapefile of building footprints was provided through a data sharing agreement with the RM of St. Andrews. The centroids of the buildings were used to determine the latitude and longitude of the buildings. The excel spreadsheet containing the newly converted assessment database was joined to the building centroid layer to append the coordinates to the table. The table was then imported into Microsoft Access where the data fields were changed to the correct format for HAZUS. This database was imported into HAZUS and used as the asset inventory for the user-defined facilities analysis.

3.4.3 HAZUS Default Parameters

Some HAZUS risk assessment parameters were not present in the databases constructed in this project. The HAZUS manual provides many default values and tables that can be used to generate these data but some assumptions needed to be made to choose the appropriate surrogate values. For instance, the first floor heights were not provided in the assessment database so a default value based on the foundation type was used as a proxy. Table 3.2 shows the default first floor heights by foundation type as recommended by the HAZUS flood technical manual (FEMA, 2015). FEMA identifies a post-FIRM building as having been built or substantially improved since December 31, 1974 (FEMA, 2016). The two buildings in the dataset having post-FIRM and pre-FIRM values which differed were assigned the default post-FIRM values as they were constructed in 1974 or later.

Building content value was assigned as a percentage of the building value based on occupancy type. Table 3.3, taken from the HAZUS flood technical manual, demonstrates the percentages used to calculate the content values for this study (FEMA, 2015).

Table 3.2 Default first floor heights by foundation type

ID	Foundation Type	Pre-FIRM	Post-FIRM
1	Pile	7 ft	8 ft
2	Pier (or post and beam)	5 ft	6 ft
3	Solid Wall	7 ft	8 ft
4	Basement (or Garden Level)	4 ft	4 ft[1]
5	Crawlspace	3 ft	4 ft
6	Fill	2 ft	2 ft
7	Slab	1 ft	1 ft[1]

Reproduced from HAZUS Technical Manual Table 3.11. (FEMA, 2015)

Table 3.3 Default contents values by occupancy class

No.	Label	Occupancy Class	Contents Value (%)
		Residential	
1	RES1	Single Family Dwelling	50
2	RES2	Mobile Home	50
3	RES3	Multi Family Dwelling	50
4	RES4	Temporary Lodging	50
5	RES5	Institutional Dormitory	50
6	RES6	Nursing Home	50
		Commercial	
7	COM1	Retail Trade	100
8	COM2	Wholesale Trade	100
9	COM3	Personal and Repair Services	100
10	COM4	Professional/Technical/Business Services	100
11	COM5	Banks	100
12	COM6	Hospital	150
13	COM7	Medical Office/Clinic	150
14	COM8	Entertainment & Recreation	100
15	COM9	Theaters	100
16	COM10	Parking	50
		Industrial	
17	IND1	Heavy	150
18	IND2	Light	150
19	IND3	Food/Drugs/Chemicals	150
20	IND4	Metals/Minerals Processing	150
21	IND5	High Technology	150
22	IND6	Construction	100
		Agriculture	
23	AGR1	Agriculture	100
		Religion/Non-profit	
24	REL1	Church/Membership Organization	100
		Government	
25	GOV1	General Services	100
26	GOV2	Emergency Response	150
		Education	
27	EDU1	Schools/Libraries	100
28	EDU2	Colleges/Universities	150

Reproduced from HAZUS Technical Manual Table 14.6. (FEMA, 2016)

3.4.4 Flood Depth Grid

Creating a flood depth grid requires two kinds of information; the ground elevation and the flood surface elevation. The flood depth grid used for this analysis was created using the LiDAR digital elevation model (DEM) supplied by Atlis Geomatics and the high water mark data provided by Manitoba Infrastructure and Transportation (MIT). The LiDAR data was captured at a 1 metre horizontal resolution using the projected coordinate system Universal Transverse Mercator (UTM) North American Datum 1983 (NAD83). As HAZUS operates in an environment using the geographic coordinate system NAD83, the LiDAR data first had to be projected to NAD83 using ArcGIS 10.0. This software was chosen because of its availability and because this is the version of the software required to run HAZUS. The horizontal accuracy of the LiDAR data was 35-40 centimetres. Data points were collected at an average spacing of 1.2 points per square metre. The vertical resolution of the data was 0.01 metres and the datum used was the Canadian Geodetic Vertical Datum of 1928 (CGVD28) with the hybrid geoid model (HTv2.0). The vertical accuracy was 12.8 centimetres at 95% confidence.

The high water mark data identifies the design flood level which is roughly equivalent to the 100-year flood level. ArcGIS was used to create a flood level surface from which the DEM was subtracted to create the flood depth grid. The flood surface was interpolated using the high water marks and an inverse distance weighting method. The resulting flood depth grid was a raster file with resolution of approximately one metre. An alternate worst-case scenario flood was created by adding two metres to the 100-year flood surface.

The flood extent polygon produced during the creation of the 100-year flood depth grid matched very closely with the flood extent polygon provided by MIT which suggests that this is a reasonably accurate method for creating a depth grid. The DEM and flood depth grid used for this analysis can be seen in Figure 3.2. The worst-case scenario flood depth grid was created by adding two metres on to the 100-year flood service. The DEM and flood depth grid for the worst-case scenario flood are illustrated in Figure 3.3.

3.4.5 Aggregate General Building Stock

The aggregated general building stock provided with the HAZUS Canada software uses the 2011 Census data from Statistics Canada. These data are aggregated at the census block level which is an area roughly equivalent to a city block bounded on all sides by city streets (Statistics Canada, 2015). Building occupancy types are classified as residential, commercial, agricultural, industrial, religion, government, or education. The building construction types are classified as wood, concrete, steel, masonry or manufactured housing (FEMA, 2015).

There are features available in the U.S. version of HAZUS which are not available in the Canadian version. When performing an analysis, the user has the option of choosing the analyses to perform. Analyses were performed on the general building stock, indirect economic losses, shelter requirements, and debris generation. Essential facilities were not present in this study area and were therefore not analyzed. Analyses of utility systems, agricultural products, transportation systems and vehicles can be performed only if this information is supplied by the user (Nastev & Torodov, 2013). Some utility system data are present in the Provincial assessment database (e.g. electrical substations) where those facilities are tied to a land parcel. Other infrastructure data (e.g. transmission lines) are not part of that database and must be obtained directly from the appropriate utility organizations. These kinds of infrastructure were not used in the analysis

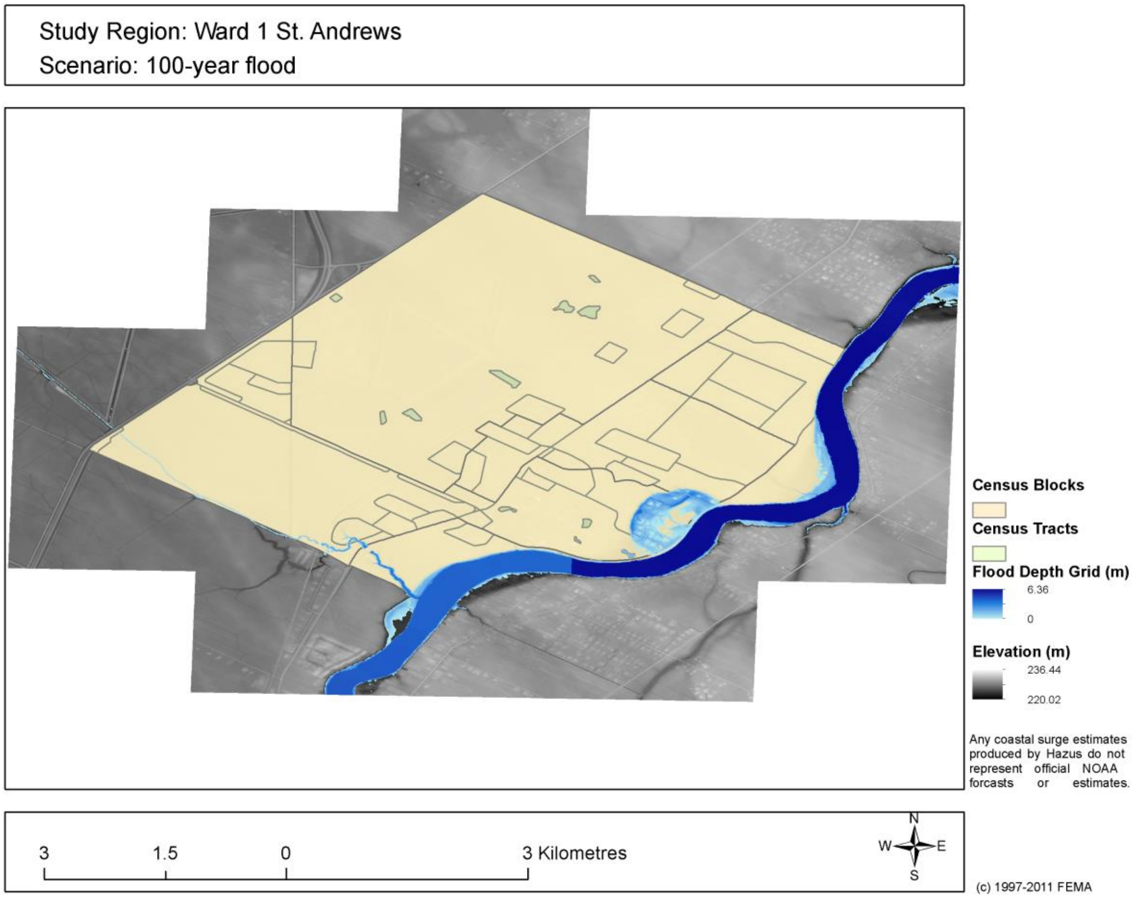

Figure 3.2 Map of HAZUS study area including 100-year flood depth grid and DEM

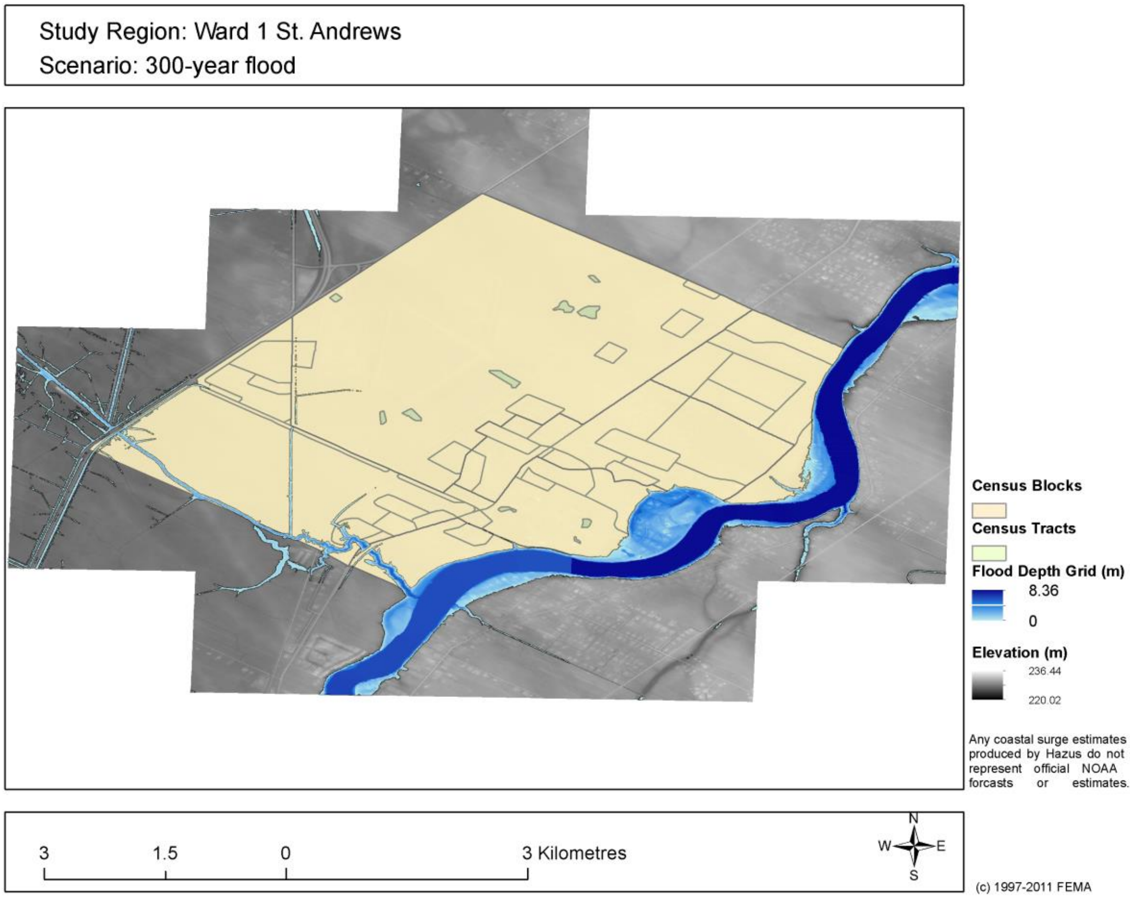

Figure 3.3 Map of HAZUS study area including worst-case scenario flood depth grid and DEM

presented here. Analysis of casualties, available in the US version, has not been incorporated into HAZUS Canada and is necessarily not included in this study.

In order to evaluate the capability of using a dasymetric approach modified census boundaries were created. When incorporating modified census boundaries HAZUS requires that one-to-one cardinality of the census blocks be maintained. This means no census blocks may be added or subtracted, and no data may be added or removed from the attribute table. These restrictions prevent a true stratification of the population information based on proportion of population. Rather ancillary data such and land use classification can be used to exclude areas where we are certain no population exists.

As the night light imagery used did not indicate any unpopulated regions within the study area, this information could not be used in the dasymetric approach. Land use classification data did suggest unpopulated regions, so this information was used to modify census block boundaries for the dasymetric approach. The populated land use classifications were determined to be the developed and agriculture classifications. These areas were combined used to clip the census block boundaries supplied by HAZUS. These modified boundaries were then imported into the appropriate geodatabase within HAZUS to replace the existing census boundaries.

3.4.6 Damage Curves

Damage curves are used by HAZUS to determine the level of damage based on the depth of flooding. These curves are based on the United States Army Corp of Engineers (USACE) Flood Impact Analysis (FIA) depth-damage curves developed for the United States. Figure 3.4 shows some of the damage curves available for buildings with one floor. There are different damage curves for buildings with different combinations of occupancy, foundation, and number of

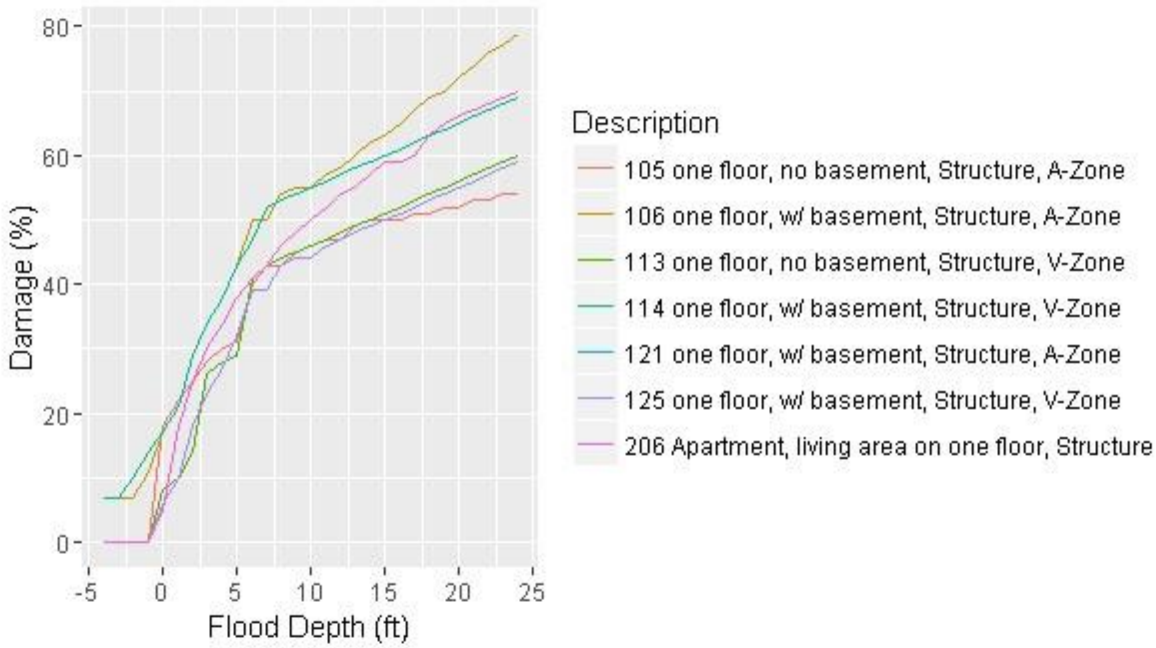

Figure 3.4 Default HAZUS damage curves for building types with one floor (FEMA, 2015)

storeys. Depth-damage curves may need to be modified to better represent the Canadian context. Depth-damage functions were developed for Manitoba in 2000 by KGS Group and the International Joint Commission however, they may need to be updated.

Figure 3.5 shows a depth-damage function developed by KGS for a single-story residence. It is interesting to note that this curve estimates damages before the flood reaches the first floor height. These functions may be an appropriate substitute for the default damage curves provided with HAZUS, but have not been included in this study. A Canada-wide, or province-wide, calibration is necessary to ensure a set of robust curves, and is outside the scope of this project.

3.5 Results

The data dictionary created to convert the MAVAS database codes to HAZUS codes is included in Appendix A. This data dictionary can be used in future HAZUS studies conducted in Manitoba.

3.5.1 Building Damage Costs

The study area attributes of each analysis are listed in Table 3.4. As the study areas were the same, the size of the study area was reported as 7 square miles for all three analyses. HAZUS reported that according to both sets of aggregate data, 899 buildings were within the study area with a total aggregate replacement value of $164 million dollars. Of those buildings 92.1% were classified as residential, 6.9% were commercial, 0.9% were industrial and 0.1% were religious facilities. In the user-defined scenario there were also 899 buildings with a total replacement value of $186 million dollars. Of the user-defined facilities 92.9% were residential, 6.9% were commercial, and 0.2% were agriculture. Figure 3.6 shows the user-defined facilities by occupancy type within the study region. Figure 3.7 shows the user-defined buildings with the damaged buildings colored in red.

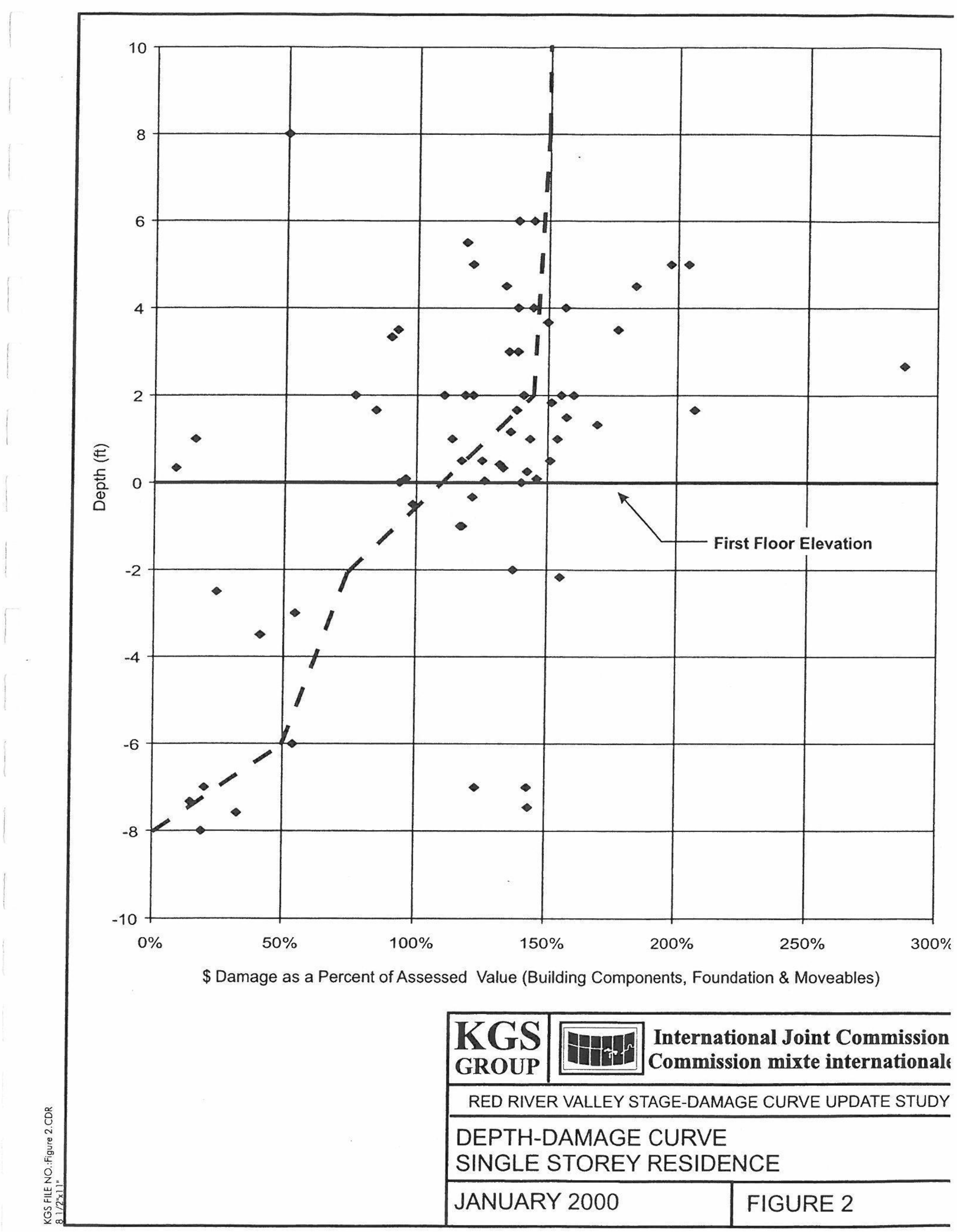

Figure 3.5 Depth-damage curve developed by KGS for a single storey residence (IJC, 2000)

Table 3.4 HAZUS Analysis Results for 100-year and worst-case flood scenarios using default aggregate, modified aggregate, and user-defined building data

	Analysis	**Building Count**	**Total Building Value ($)**	**Area (square miles)**	**Damage Costs ($)**	**Damaged Building Count**
100-Year Flood	Aggregate (default)	899	164,000,000	7	3,900,000	15
	Aggregate (modified)	899	164,000,000	7	3,180,000	16
	User-defined	899	186,985,400	7	374,690	15
Worst-Case Scenario	Aggregate (default)	899	164,000,000	7	8,580,000	36
	Aggregate (modified)	899	164,000,000	7	7,910,000	33
	User-defined	899	186,985,400	7	2,698,359	38

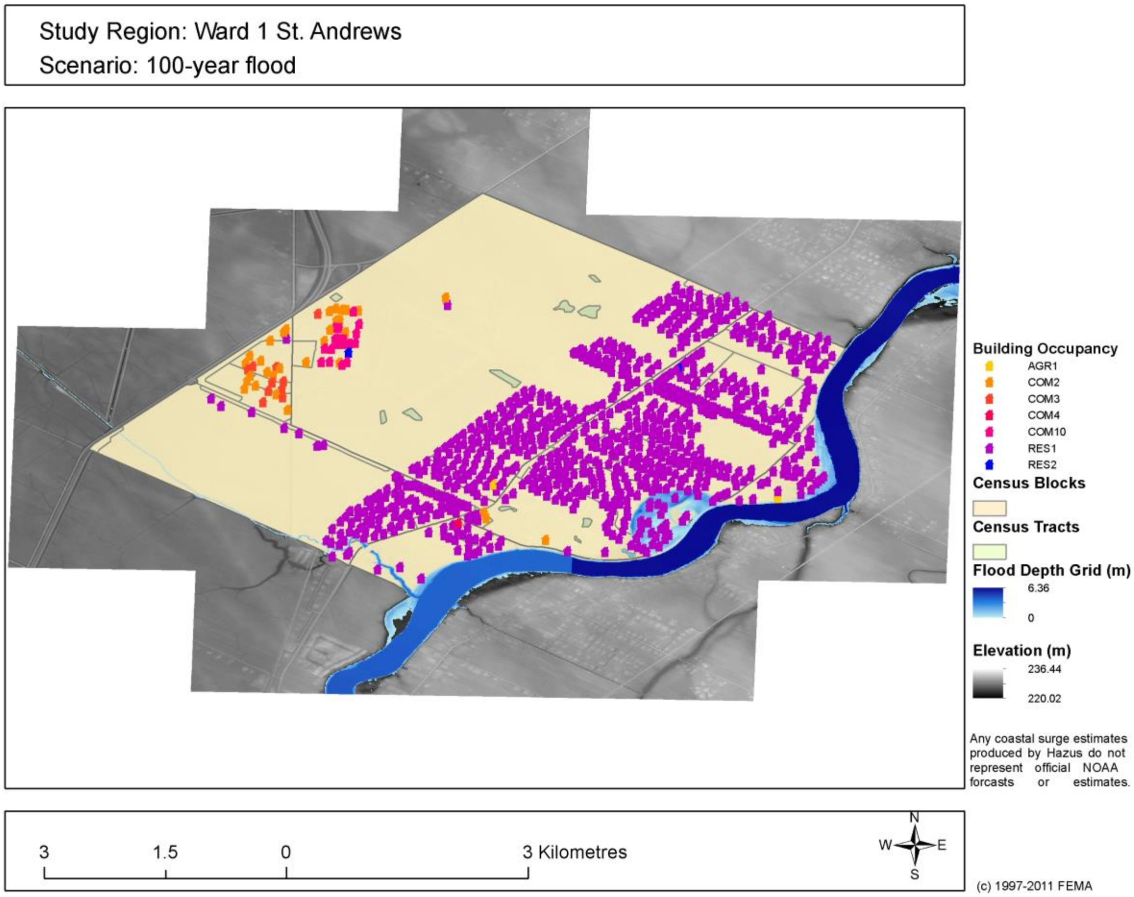

Figure 3.6 Map of user-defined facilities by occupancy type

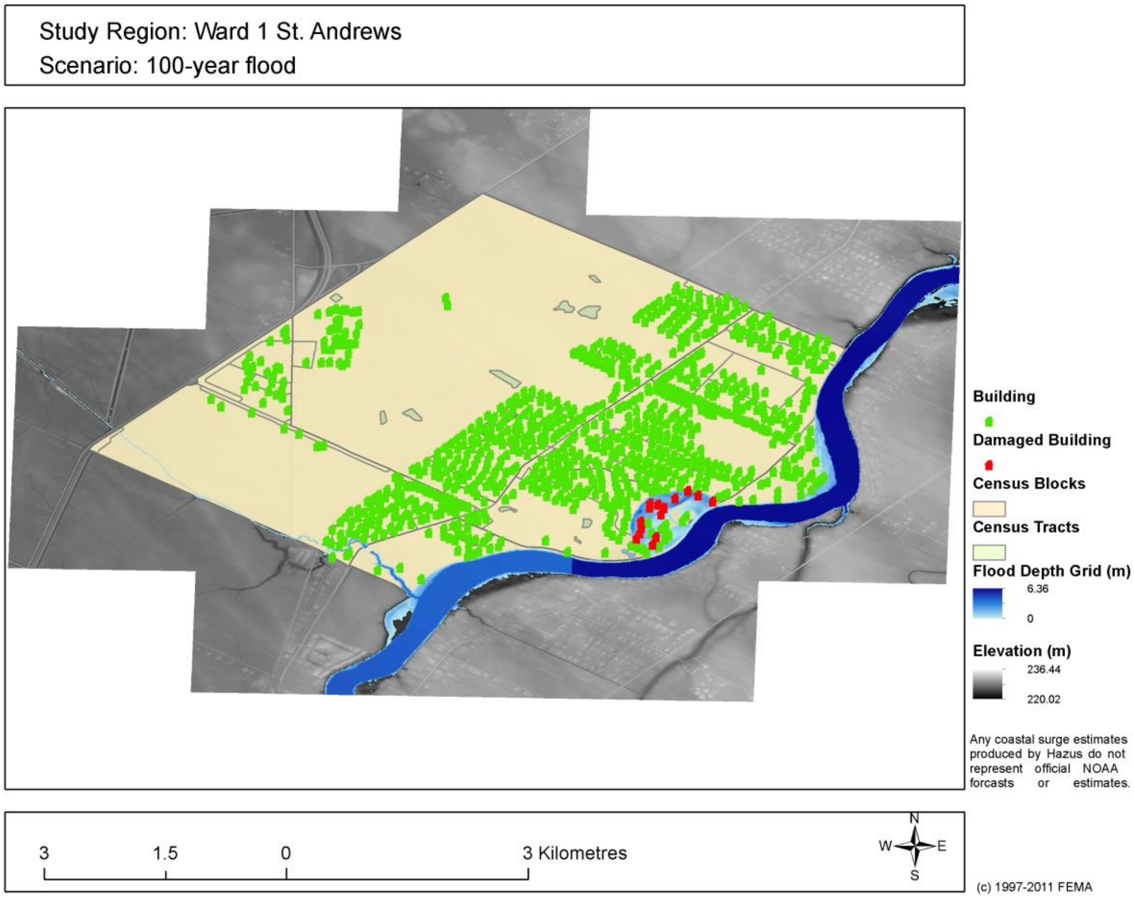

Figure 3.7 Map of damaged and undamaged user-defined facilities

The damage estimations generated for both the aggregated data and the user-defined facilities are compared in Table 3.4. In the 100-year flood scenario the default aggregate analysis estimated that 15 buildings would be damaged with a total cost of $3.4 million. The aggregate analysis using the modified census boundaries estimated that 16 buildings would be damaged with a total cost of $3.18 million. The analysis of the user-defined facilities also determined 15 buildings would be damaged but the total loss estimate was much smaller at $374,690. The analysis yielded a null result for one of the facilities in the flooded area. The reason for this was not determined. This may have impacted the totals provided. It is possible this result was null because it was in the flooded area but was not flooded enough to cause any damage. In either case, the total costs predicted using the user-defined analysis were much lower than the costs predicted during the aggregated analyses.

Modifying the census boundaries for the aggregate analysis caused the predicted number of buildings damaged to increase slightly however, the predicted total costs decreased. HAZUS has the capability to map various characteristics at the census block level in order to visually analyze damage distribution patterns. Figure 3.8 illustrates the total RES1 buildings damaged using both the default and modified census boundaries. This map also shows that a portion of the lowest section of the oxbow area was removed with the modified boundaries which concentrated the buildings in the remaining area of the census block. As this area was the most prone to flooding, an additional building was damaged, but it was damaged to a lesser degree. Figure 3.9 shows the number of RES1 buildings damaged between 41 to 50 percent using both sets of census boundaries. It shows that there was an increase in the number of buildings damaged to this degree in the oxbow area. This is the reason for the increase in the number of buildings damaged. The total losses experienced in each census block are illustrated in Figure 3.10. It shows there

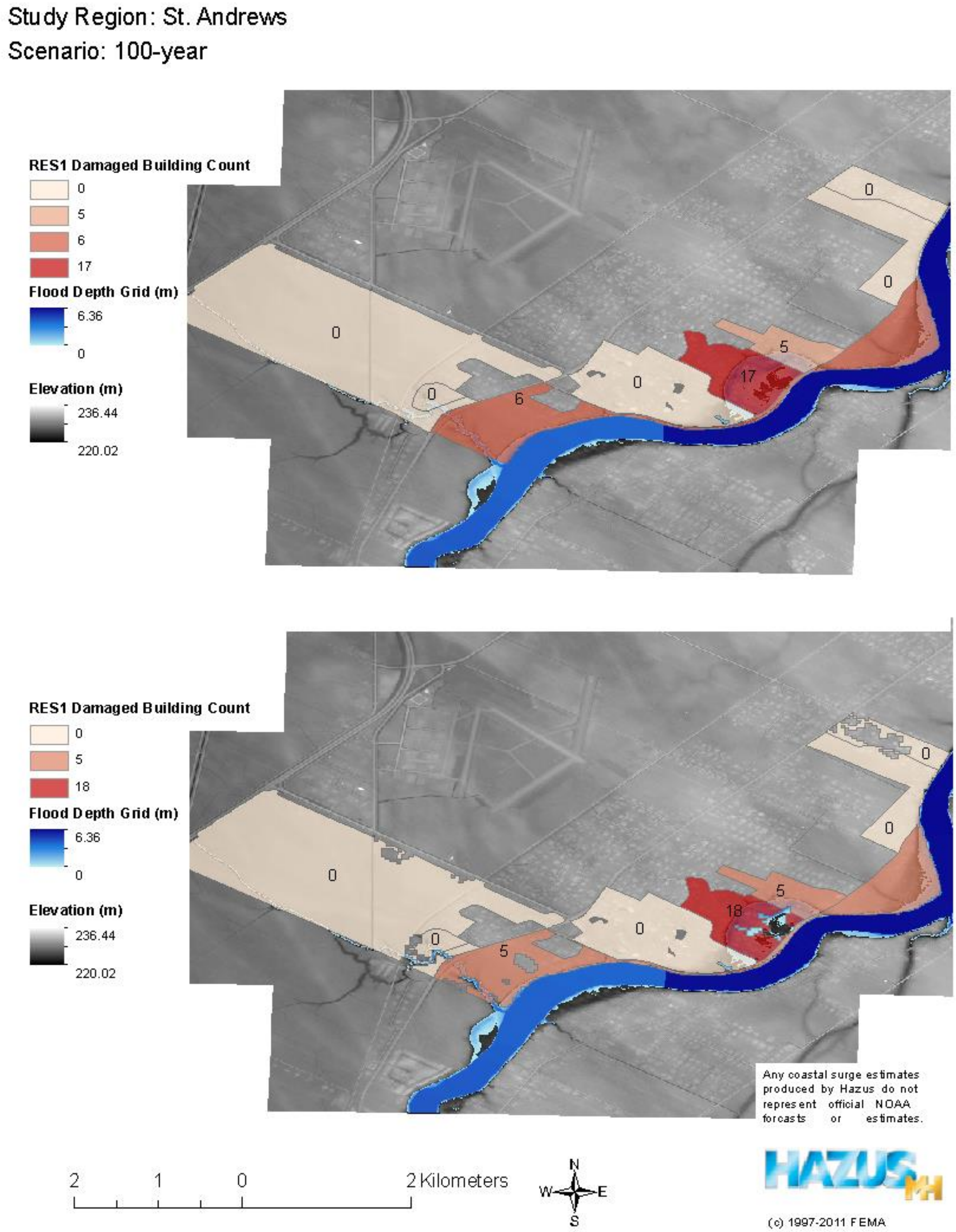

Figure 3.8 Total number of RES1 buildings damaged aggregated by default and modified census block for 100-year flood

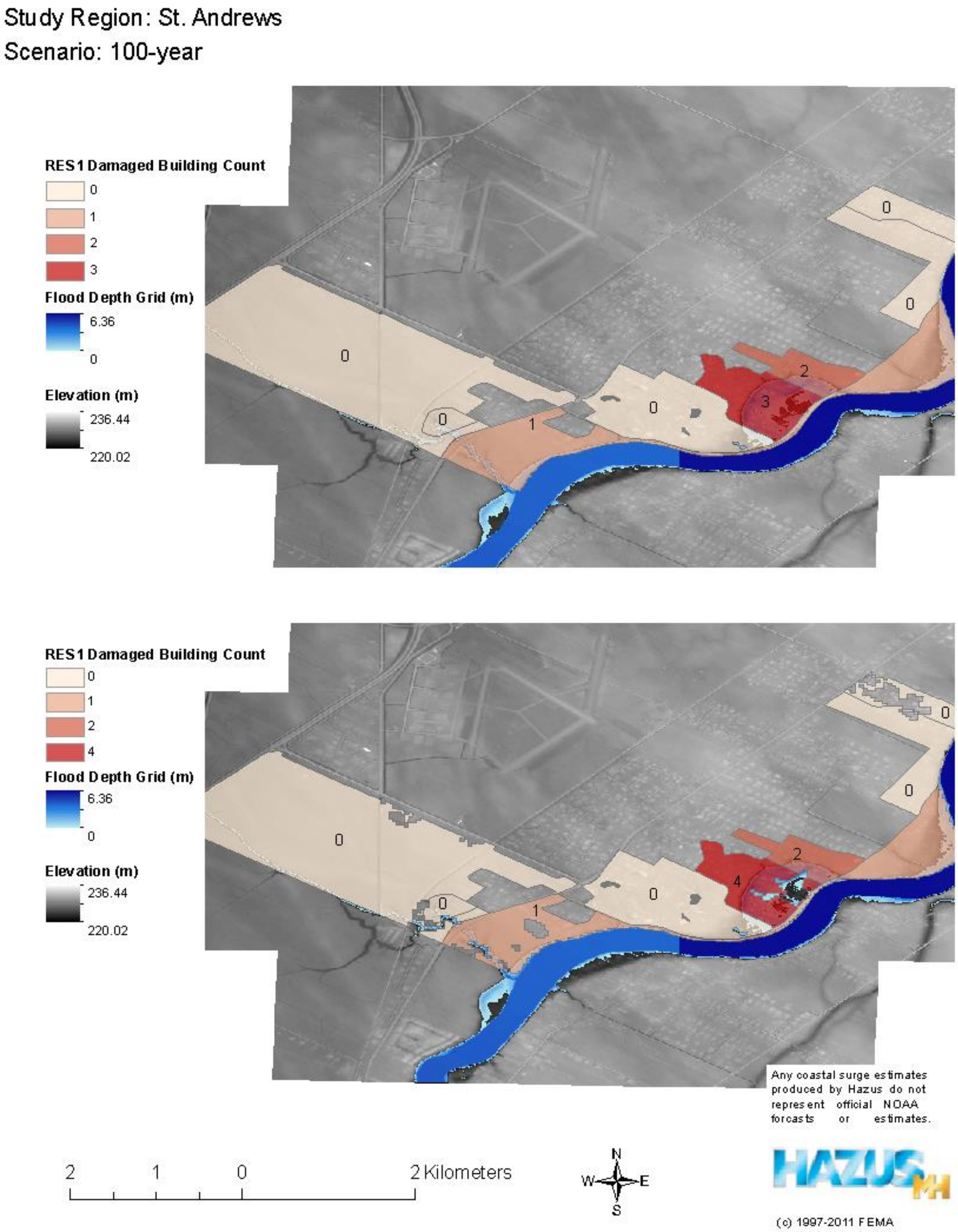

Figure 3.9 Number of RES1 buildings damaged between 41 to 50 percent aggregated by default and modified census block for 100-year flood

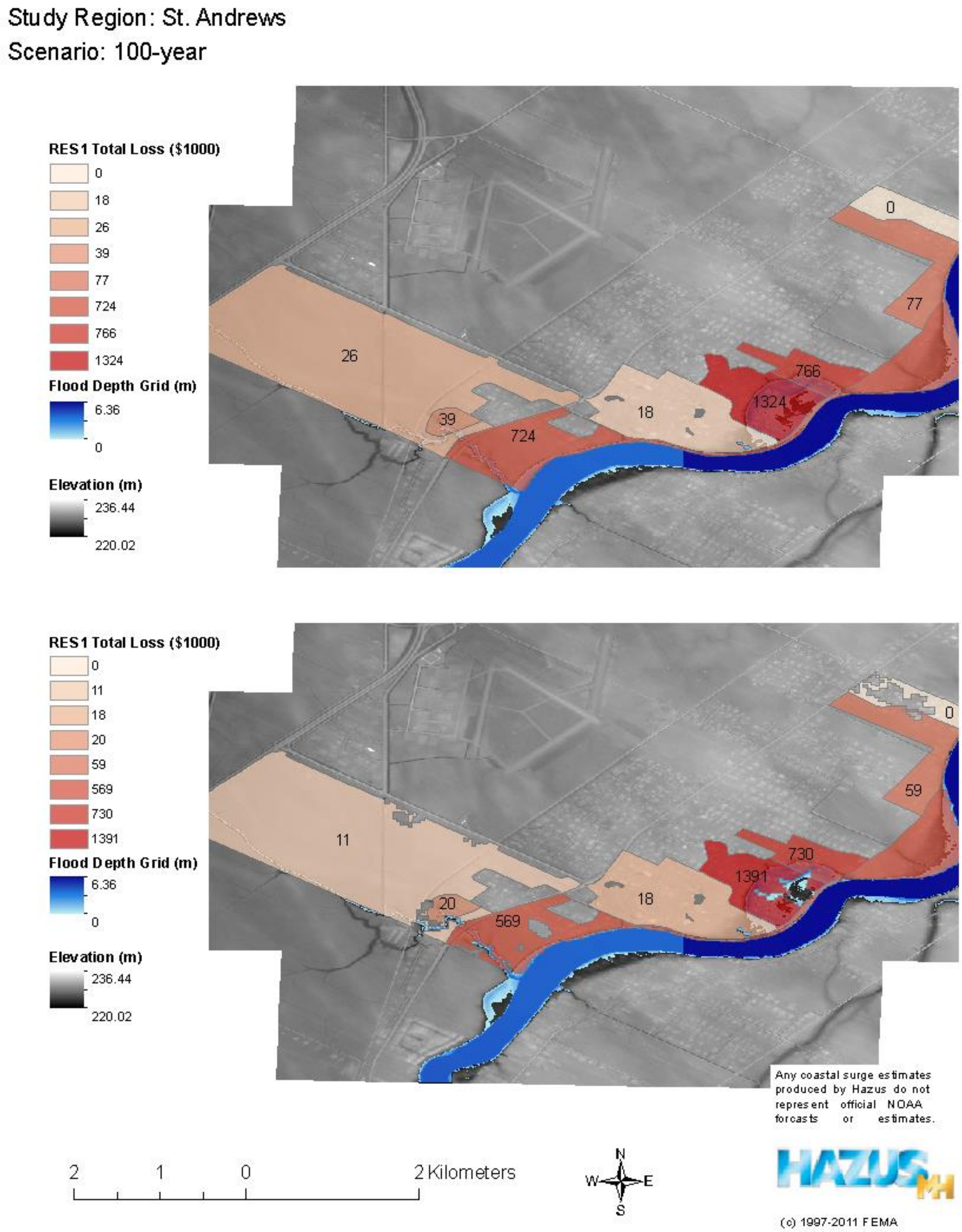

Figure 3.10 Total loss in ($1000) at full replacement value aggregated by default and modified census block for 100-year flood

was a reduction in losses in all census blocks with the exception of the census block in the oxbow area. This reduction in losses outweighed the any potential additional losses from the presence of more buildings. A larger number of buildings were damaged but they were farther away from the river so were damaged to a lower degree, resulting in lower total costs.

During the worst-case flood scenario the default aggregate census boundaries estimated 36 buildings would be damaged with a total cost of $8.58 million. The modified census boundaries resulted in an estimated 33 buildings damaged with a total cost of $7.91 million. The user-defined analysis resulted in 38 buildings being damaged with a total cost of $2.70 million. This suggests that as the area of flooding increases the differences between the results of the analyses become more pronounced. The user-defined facilities analysis found the highest number of buildings damaged but the lowest total costs.

Figure 3.11 shows the differences between the total numbers of residential buildings damaged using the default and modified census boundaries during a worst-case scenario flood. Unlike the 100-year flood, there are a smaller number of buildings damaged using the modified boundaries during the worst-case flood scenario. The map shows the most buildings were damaged in the census blocks around the oxbow area. Maps can be generated for any of the general occupancy types, residential, commercial, agriculture, etc. They can also be generated by specific occupancy type, for example RES1, RES2, etc. There are also several different attributes which can be mapped. Damages can also be presented by damage state percentage. For example Figure 3.12 shows the number of buildings damaged between 41 and 50 percent during a worst-case flood. The total predicted losses for default and modified census boundaries is demonstrated in Figure 3.13. Losses were lower across all census blocks using the modified census boundaries which is likely why overall losses were lower.

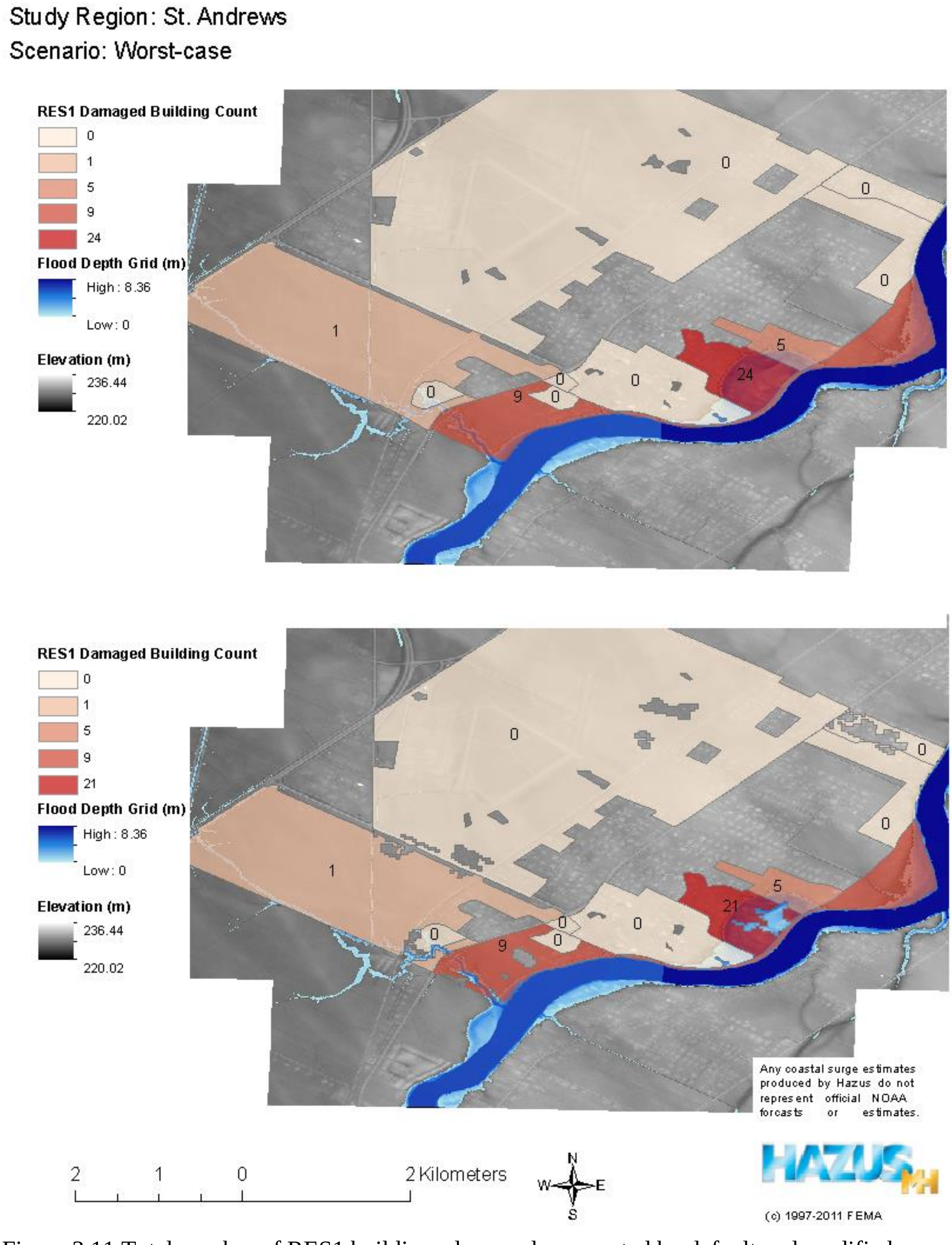

Figure 3.11 Total number of RES1 buildings damaged aggregated by default and modified census block for worst-case scenario flood

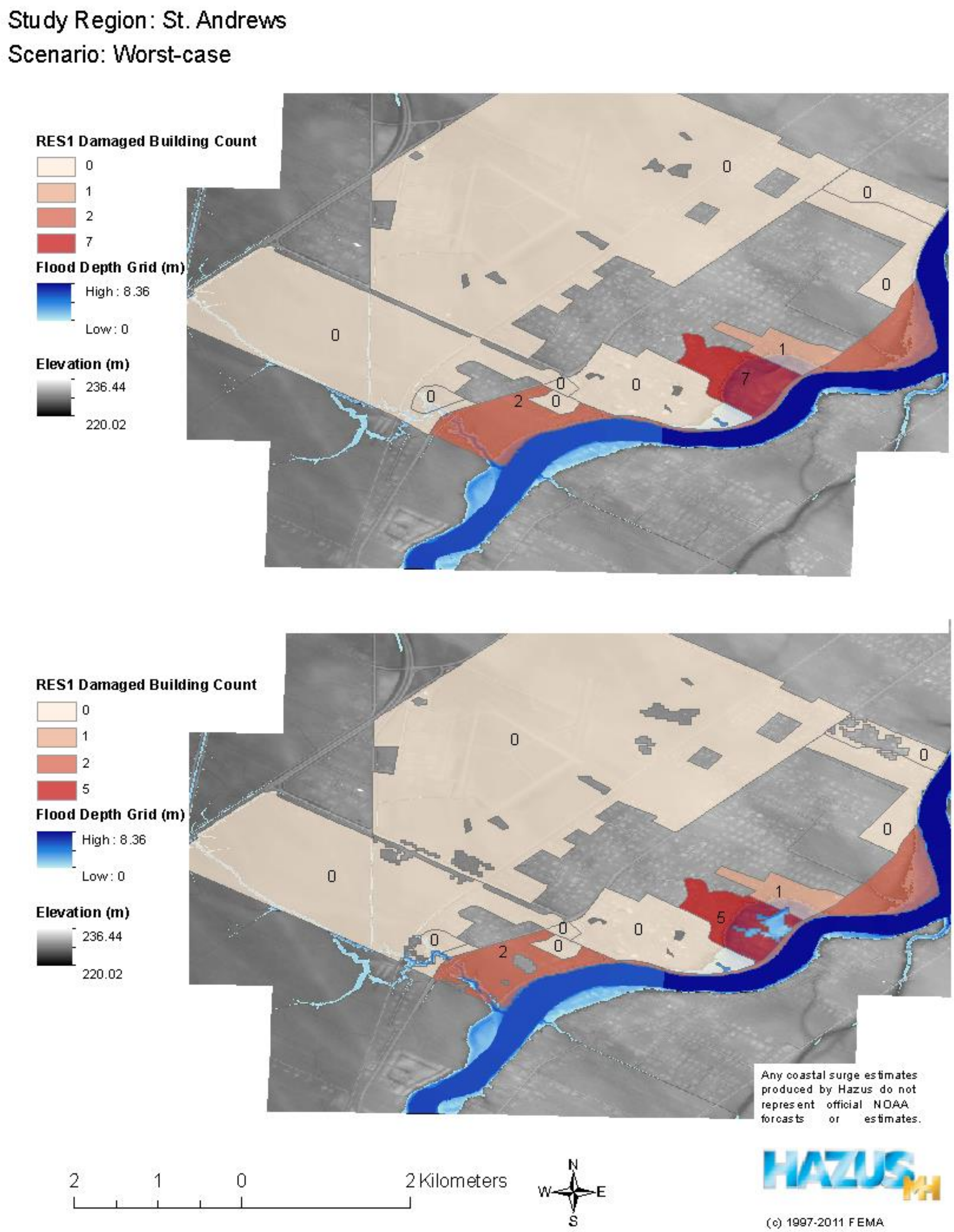

Figure 3.12 Number of RES1 buildings damaged between 41 to 50 percent aggregated by default and modified census block for worst-case scenario flood

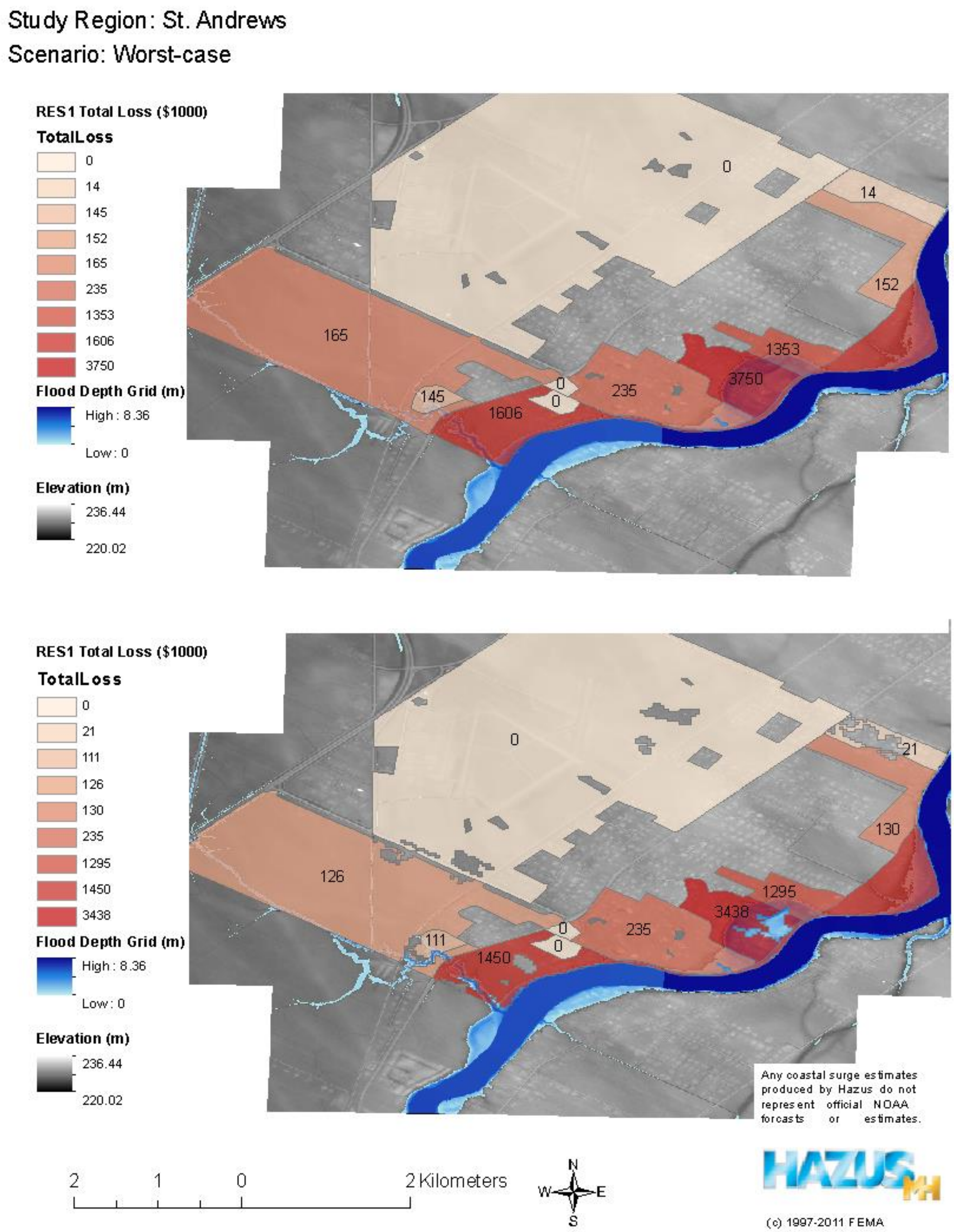

Figure 3.13 Total loss in ($1000) at full replacement value aggregated by default and modified census block for worst-case scenario flood

It is important to note that some estimations generated in the reports for the aggregate analysis were not generated during the user-defined analysis. While a summary report is available for the aggregate analysis, no such reports can be generated for the user-defined analysis. The summary reports generated during this study are included in Appendix B. Due to the lack of reporting capabilities for user-defined analyses, results were exported to a new shapefile and analyzed separately to determine the total cost. This is a limitation of the HAZUS software.

3.5.2 Indirect Economic Costs, Debris Generation, and Shelter Requirements

A limitation of the HAZUS software is that it computes factors using the aggregated data which cannot be calculated during a user-defined analysis such as losses due to business interruption, shelter requirements, and debris generation. This information can be reported separately or as part of the global summary report. HAZUS estimates 467 tons of debris will be generated using the default census boundaries during the 100-year flood scenario. Of the total, 58% will be from material classified as finishes, such as dry wall and insulation. Structural components such as wood and brick will form 27% of the debris. It is estimated it will take 19 truckloads to remove the debris at 25 tons per truck. Using the modified census boundaries the model estimates 403 tons of debris will be generated with 64% from finishes and 20% from structural components. It was estimated that only 16 truckloads would be required to remove the debris when the modified boundaries were used. Figure 3.14 shows the distribution of debris across the study area for the 100-year flood.

The worst-case scenario flood using the modified boundaries saw 2,178 tons of debris generated with 28% comprised of finishes and 42% structural components. The distribution of the debris for the worst-case scenario flood is shown in Figure 3.15.

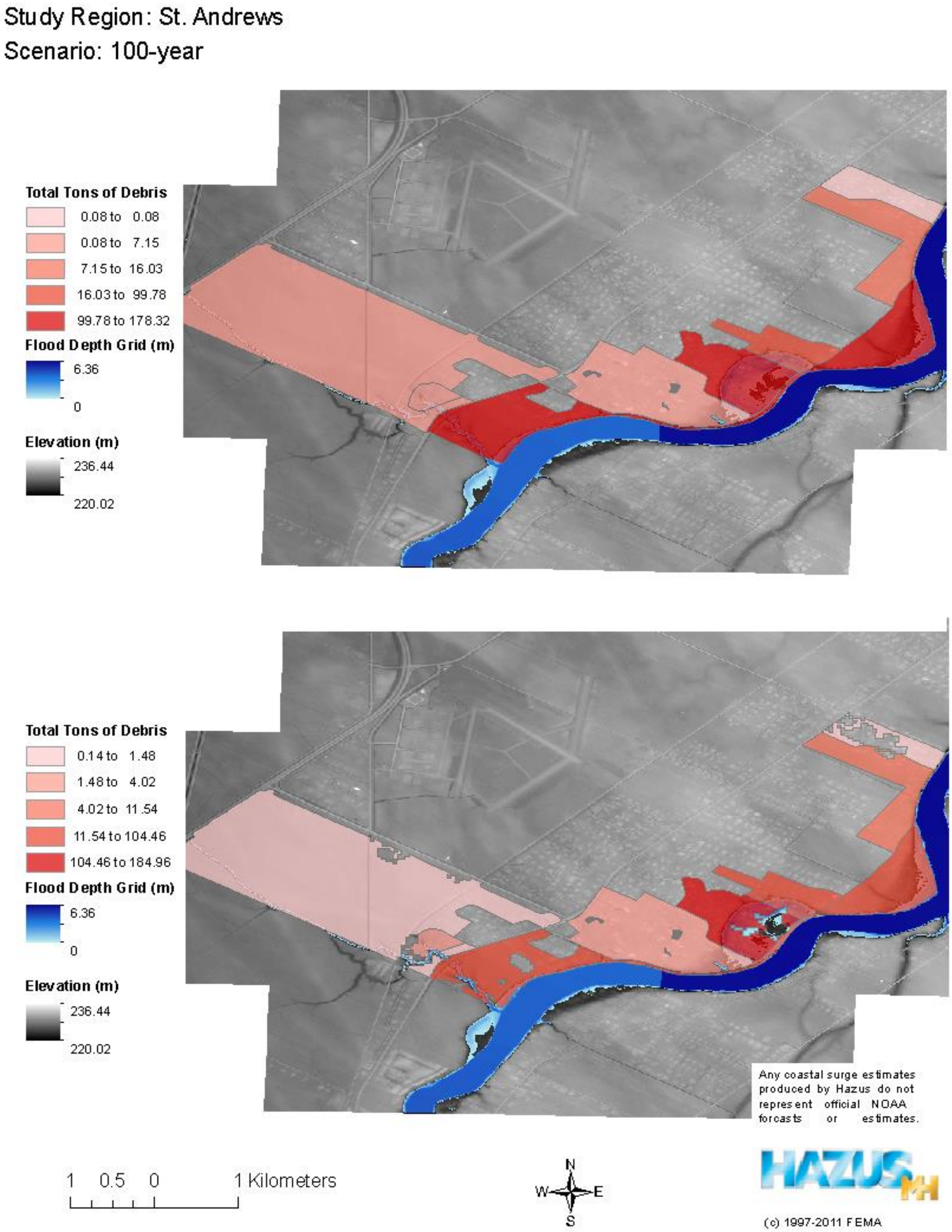

Figure 3.14 Total tons of debris generated aggregated by census block for 100-year flood scenario

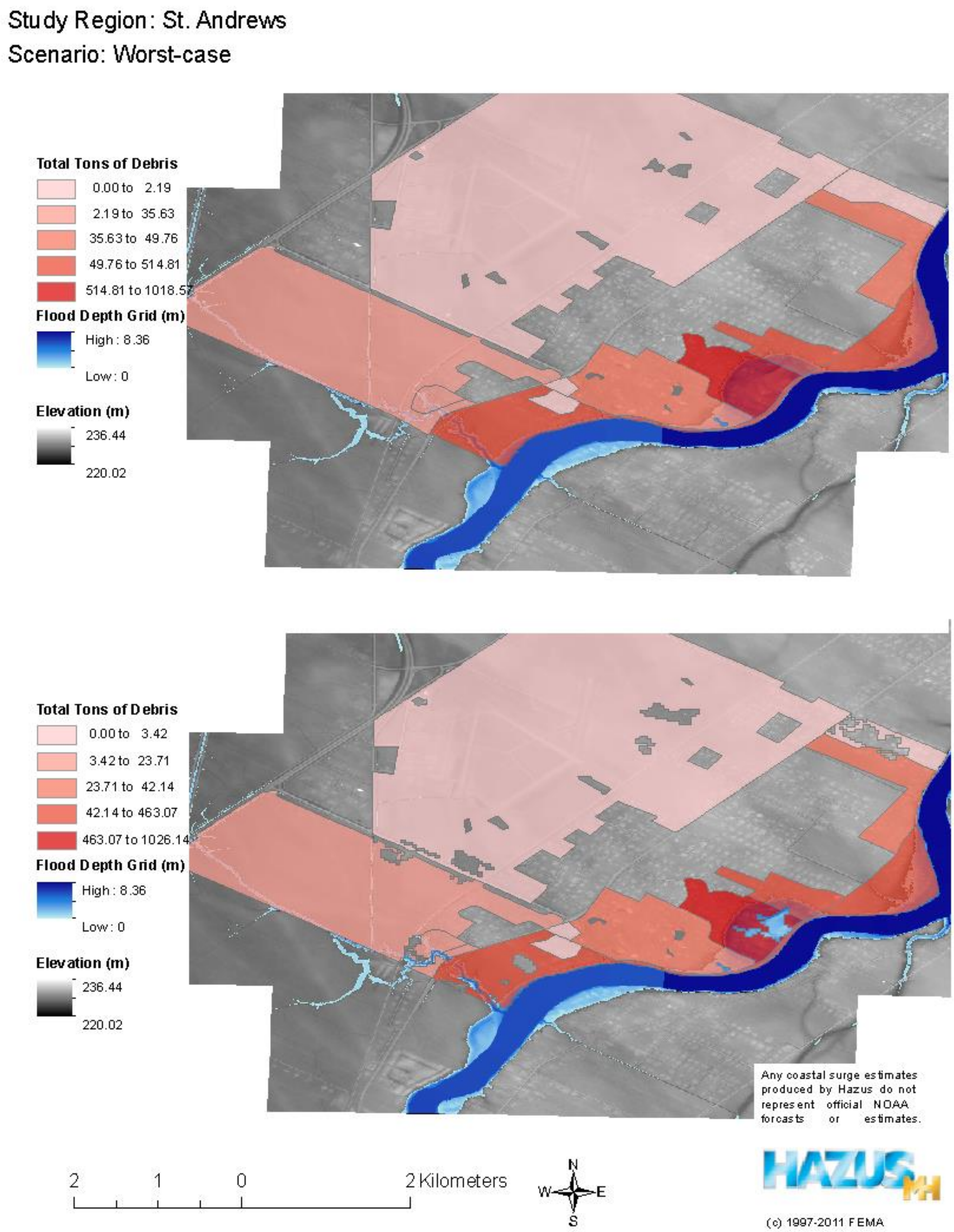

Figure 3.15 Total tons of debris generated aggregated by census block for worst-case flood scenario

Within the default census boundaries, it is estimated that it will require an estimated 87 truckloads to remove the debris generated by the worst-case scenario flood.

Using the modified census boundaries the same scenario estimates a total of 2,054 tons of debris will be generated with finishes comprising 27% of the total and structural components 42% of the total. It is estimated that it will require 82 truckloads to remove the debris.

Displaced populations and shelter requirements can also be estimated during an aggregate analysis. Figure 3.16 shows the distribution of displaced households during the 100-year flood event within the study area. HAZUS estimates that using the default census boundaries 45 households will be displaced due to the flood and of these households 97 people will seek temporary shelter. During the same flood scenario the model estimates only 43 households will be displaced due to the flood using the modified census boundaries. Of these, 92 people will require the use of public shelters.

During the worst-case flood scenario using the default census boundaries the model estimates 63 households will be displaced with 151 people seeking temporary shelter. Using the modified census boundaries, HAZUS estimates 58 households will be displaced due to the flood with 137 people seeking shelter. The distribution of the displaced households for the worst-case scenario is demonstrated in Figure 3.17.

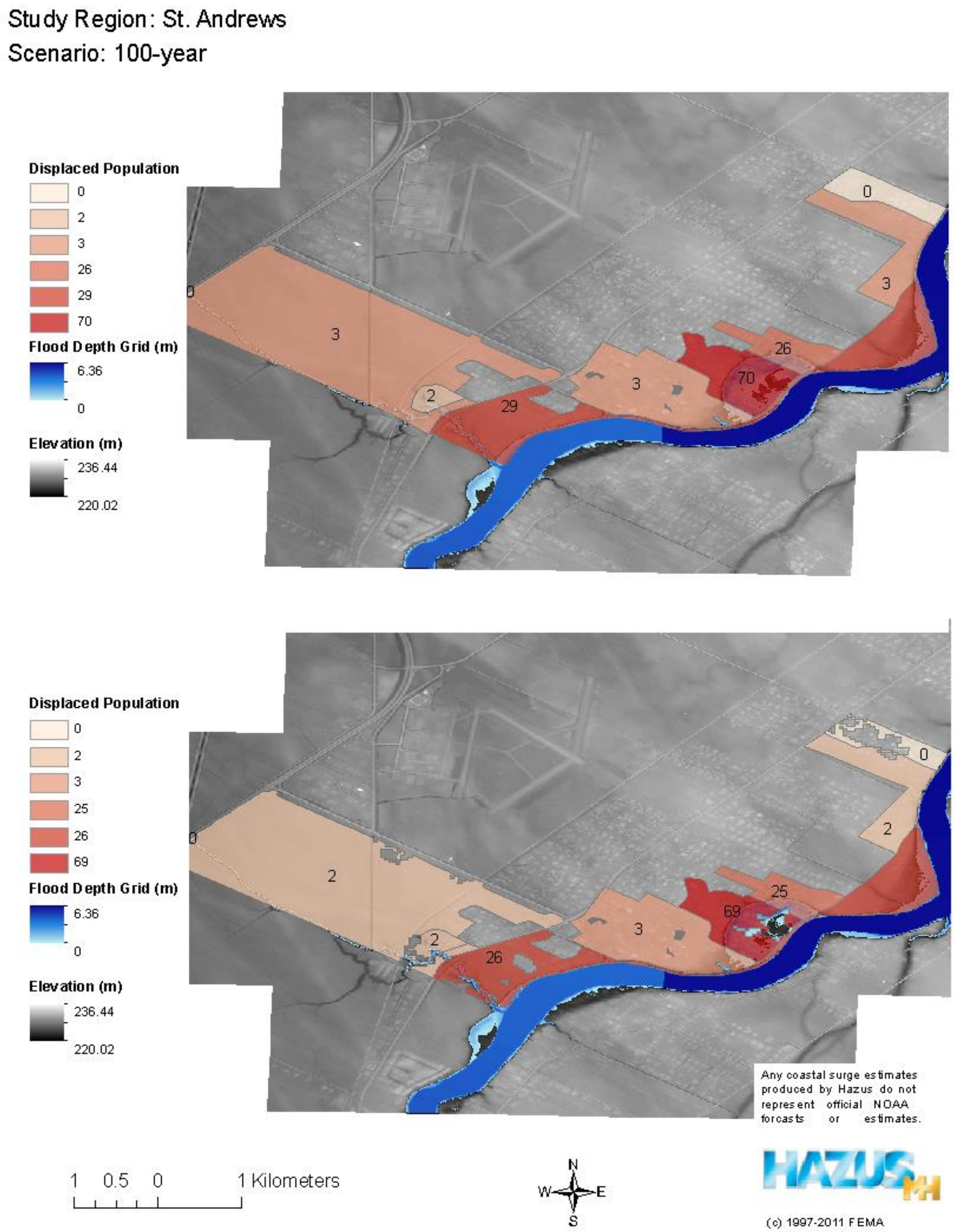

Figure 3.16 Displaced population aggregated by default and modified census boundaries during 100-year flood

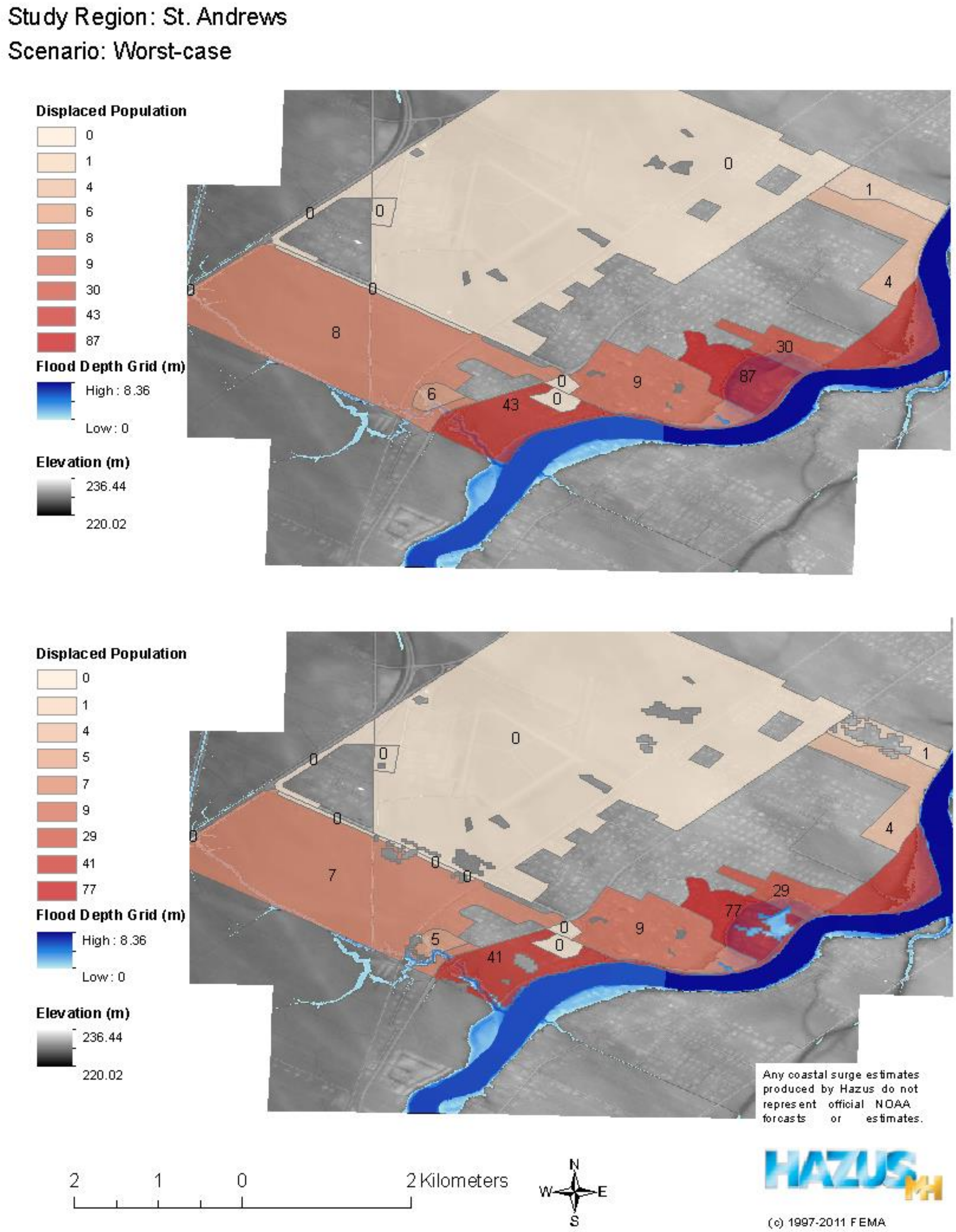

Figure 3.17 Displaced population aggregated by default and modified census boundaries during worst-case scenario flood

3.6 Discussion

It is interesting to note that the number of buildings damaged in the flood scenario were the same between the two datasets analyzed, yet the damage costs differed slightly. There are many possible explanations for this discrepancy. As noted, one of the buildings damaged returned null values for the analysis. If this building was flooded at a height which would cause damage, the damages incurred were not included in the total, meaning the results were underestimated. While this is a possible explanation, it is doubtful that this is the actual cause. Even if the building were completely destroyed it would not be likely to make up the discrepancy in damage values.

Another possible explanation for the discrepancy is that there is an issue with the depth-damage functions provided with HAZUS. These curves are based on data from the United States and may not be accurate for use in a Canadian context. That being said, the same damage curves are used for both the aggregate and user-defined analyses so if there was an issue with the curves it should affect the results of the user-defined analysis as well.

The most likely explanation for the difference in damage cost estimates is that there is uneven spatial distribution of building values across the census block as found with projects in the U. S. Rozelle et al. (2011) found that the aggregate analysis predicted higher losses than user-defined scenarios across two different flood events in North Dakota. While the user-defined analysis is an alternate option for a site-specific analysis, as mentioned by the Association of State Floodplain Managers (ASFPM) in their 2010 study, there is no way to export the user-defined analysis into a report. For this reason, the dasymetric approach has been explored.

Torodov (2012) conducted a study in Rhode Island which found, as we did, that the dasymetric approach reduced the overall losses. As no studies have been conducted using the dasymetric approach in Canada, this is the first time this trend has been found in the Canadian context.

MacDonald (2016) conducted a study in North Dakota which examined the use of the dasymetric approach using census boundaries modified based on the National Land Cover Database (NLCD) in HAZUS. The results found that the loss estimations were lower using the dasymetric approach than when using the default census boundaries. If the buildings with the lowest values are located within the flooded area, and buildings with higher values are situated away from the flood hazard, the aggregation of data would result in an overestimation of the value of the inventory at risk. This issue could be addressed through the use of the dasymetric approach.

As HAZUS recognizes estimates are made at a coarse scale it is encouraging that the results obtained were so close between the two types of analysis. As HAZUS was adapted from the U. S., figures are reported in measurements such as square miles and U.S. dollars. This should be fairly simple to resolve but can cause confusion with the interpretation of reports generated by HAZUS.

Another problem encountered with the HAZUS software is that users are unable to upload a DEM if it does not cover the extent required by HAZUS. The extent required by HAZUS is determined for the purpose of using the stream network model to create a flood depth grid (FEMA, 2015). Since HAZUS does not have the ability to create a stream network in Canada as it does in the U.S., there is no real need for the DEM to cover a specific area. While an incomplete DEM can simply be added to the map document, it cannot be used for the Quick Look or Enhanced Quick Look analyses unless it covers the entire area required by HAZUS. This can be a frustration for some users who pay for high quality DEMs to be created for their community only to find they cannot be used inside the HAZUS environment because they do not contain data for the surrounding watershed. Especially when these areas are not subject is flooding and therefore are of a low priority for mapping.

The software returned null values for some buildings during the user-defined analysis. Other HAZUS Canada users have suggested this may occur due to a building value of zero, although other buildings had zero value and did not return null values (HAZUS Canada, 2014). No reason could be determined for this. This issue reduces the reliability of estimations made using the user-defined analysis. This demonstrates another problem with using this method as an alternative to the aggregate analysis.

During the analysis there were many problems experienced when generating reports. Sometimes certain analyses would not run, generating an empty output. For example, periodically the debris analysis would not run even though it was selected. There were some discrepancies in the figures provided in the global summary report. For example instead of giving the true percentage, HAZUS reported that a number of buildings damaged represented over 0% of the buildings in the analysis. While this is technically correct, re-running the analysis resulted in a more accurate percentage being populated. Other HAZUS Canada users have also found discrepancies when running additional analyses. Some users have found corruption with the study region when adding data to a scenario or running an analysis more than once in the same study region (HAZUS Canada, 2015). In order to ensure results are reported properly, it is recommended to load all data into HAZUS prior to performing analysis. Once analysis is performed, results should be analyzed right away. If additional analyses are required it is best to use a new study region (HAZUS Canada, 2015).

The best source of information for creating an asset database is the assessment database, MAVAS managed by Manitoba Municipal Government. With a few changes to the way assessment data is collected this database could be a powerful tool for flood risk assessment using HAZUS or any other comparable software. Collecting first floor heights and geographic coordinate information for all buildings would essentially make the assessment database a complete asset database that could easily be reclassified and imported into HAZUS.

Some other modifications can also be suggested; the MAVAS assessment data is organized by property roll numbers which are not unique for each building but could be added. Conversely, current building footprint data available and used in this study does not contain an identifier which can be used to associate it with the assessment data for that particular building. The buildings were spatially joined to the property parcel shapefile provided by the RM of St. Andrews. Any results with the duplicate property numbers were reduced to one entry. This means we are unable to account for properties with multiple buildings. This could be resolved by incorporating the collection of building footprint data or spatial coordinates in the MAVAS database.

3.7 Conclusion

The objective of this study was to evaluate the use of HAZUS software for floss loss estimation in Manitoba. The results determined that HAZUS can be used to model flood loss in Manitoba however, the implementation of this software as a standardized quantitative risk assessment tool relies on the development of a standardized central asset database. In both flood scenarios the aggregate analysis provided the highest loss estimations with the dasymetric approach being slightly lower and the user-defined analysis producing the lowest loss estimations. These results show that there is a large amount of variation in the results obtained depending on the data used. The software itself also requires more development to eliminate stability issues and standardize measurements for the Canadian context. However, the current version has substantial reporting available only for aggregate data. This includes reporting industrial facilities and infrastructure, service interruption and other indirect effects, debris and recovery estimations. A more refined stratification of the aggregate data could prove very useful if it could be incorporated into the software.

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Chapter 4. Dasymetric Approach

4.1 Abstract

Population data has become increasingly accessible however, the data is often aggregated in such a way that it is difficult to pinpoint specific populations on the landscape. A need exists to be able to stratify population data in such a way that populated areas can be identified at a finer scale. A dasymetric approach can be used to produce a more spatially accurate population model. In order to evaluate the possibility of using land cover classification and nighttime light as ancillary data for this approach we must first determine whether significant relationships exists. Population variables were compared with night light intensity and land use classification using correlation, regression, and principal component analyses. The results of this analysis suggest presence of a relationship between these variables and population which can be used to refine flood loss estimations made using HAZUS software.

4.2 Introduction

HAZUS-MH (Hazards U. S.-Multi-Hazard) is a quantitative risk assessment tool which is capable of predicting damages associated with flooding. The default asset inventory included with the software is aggregated at the census block level. As the census blocks in Manitoba are relatively large compared to those found in the United States, where the software was developed, there have been some concerns raised over the accuracy of the loss estimations. Several studies have found loss estimations to be inflated when using the aggregate data (ASFPM, 2010; Rozelle, 2011; McDonald, 2016). Providing site-specific data allows the user to perform a building-by-building analysis however, it is not possible to generate reports using this method. Data must be gathered manually through the analysis of the shapefile generated (ASFPM, 2010).

In order to generate more accurate estimations without sacrificing the capability of generating reports, the dasymetric approach has been suggested.

The availability of remotely sensed data has allowed for the observation and analysis of properties and phenomenon which could not previously be examined or at least not without considerable cost and effort (Piwowar & LeDrew, 1995). Now, with the availability of satellite imagery we can see the world in a way that was not previously possible. The accessibility of such information has provided researchers with an opportunity to take advantage of a powerful tool for quantifying information on a landscape scale. Varying spectral properties of different types of land cover can allow experts to map uses on the ground without ever visiting the location. Land use classifications have been developed for Manitoba using available satellite imagery.

In addition to the regular daytime imagery collected, the Defense Meteorological Satellite Program – Operational Linescan System (DMSP-OLS) collects imagery taken at night. The anthropogenic light produced in populated areas is collected through these nighttime images. Researchers have hypothesized that these images can be used to refine estimates of population with a dasymetric approach (Mennis, 2003; 2009, Liu, Sutton, & Elvidge, 2011; Amaral, Monteiro, Camara & Quintanilha, 2006.). A dasymetric approach uses ancillary data, such as land cover, to redistribute data boundaries within a landscape (Mennis, 2009). For example population data aggregated at the census block level can be more precisely located on the landscape by determining the proportional relationship of population with each land cover type. In order to evaluate the dasymetric approach we needed to determine whether a relationship exists between the variables being examined. In this case, we examined the relationship between population and dwelling density and two ancillary variables, the level of nighttime light and land use classification (LUC).

In addition to the land use classifications developed from MLI, the proximity to a river was analyzed as a potential classification which could inform the use of a dasymetric approach to population mapping. Gaughan et al. (2016) hypothesized that due to population growth along the eastern seaboard of mainland China, distance to water may be an important variable for mapping population growth. If populations settle along waterbodies such as oceans, lakes, and rivers, this increases physically vulnerable to flooding. In Manitoba in particular, distance to water can be used as an added piece of information to land cover classification. Agriculture or forest classifications may be more likely to be populated if they are adjacent to water than if they are not. If a relationship exists, it may be used to refine aggregated damage estimations produced by HAZUS.

4.3 Study Area

The study area chosen to test the dasymetric approach is much of Southern Manitoba from the US border to the south, to a latitude that includes the south basin of Lake Winnipeg to the north (approximately 52°N), and to the border of Saskatchewan to the west and Ontario to the east. The study boundaries were chosen to match the census dissemination areas for which complete land use cover and night light data were available and reflects, at regional scale, a broad range of those characteristics. The study area contains a mix of sparsely and densely populated areas, urban and rural areas, distributed across various land use classifications and with varying levels of night light intensity. For a more thorough description of the study area see Chapter 2.

4.4 Methods

4.4.1 Night Light Imagery

The night light imagery used for this study was taken from the DMSP-OLS and is shown in Figure 4.1. The image used was taken with satellite number F18 in 2010. The spatial resolution of the image is 30 arc-seconds (approximately 1 km at the equator) (DMSP-OLS) (NOAA, 2010). The digital number (DN) values of the pixels range from 0-63 with 0 being the darkest and 63 being the brightest (Sutton et al., 1997). The file was downloaded in WGS 1984. After the imagery was converted to a point file it was projected to NAD 1983 UTM zone 14 to match the coordinate system used for the land use and population data. These data were chosen as they contained the coverage required for this study and were freely available.

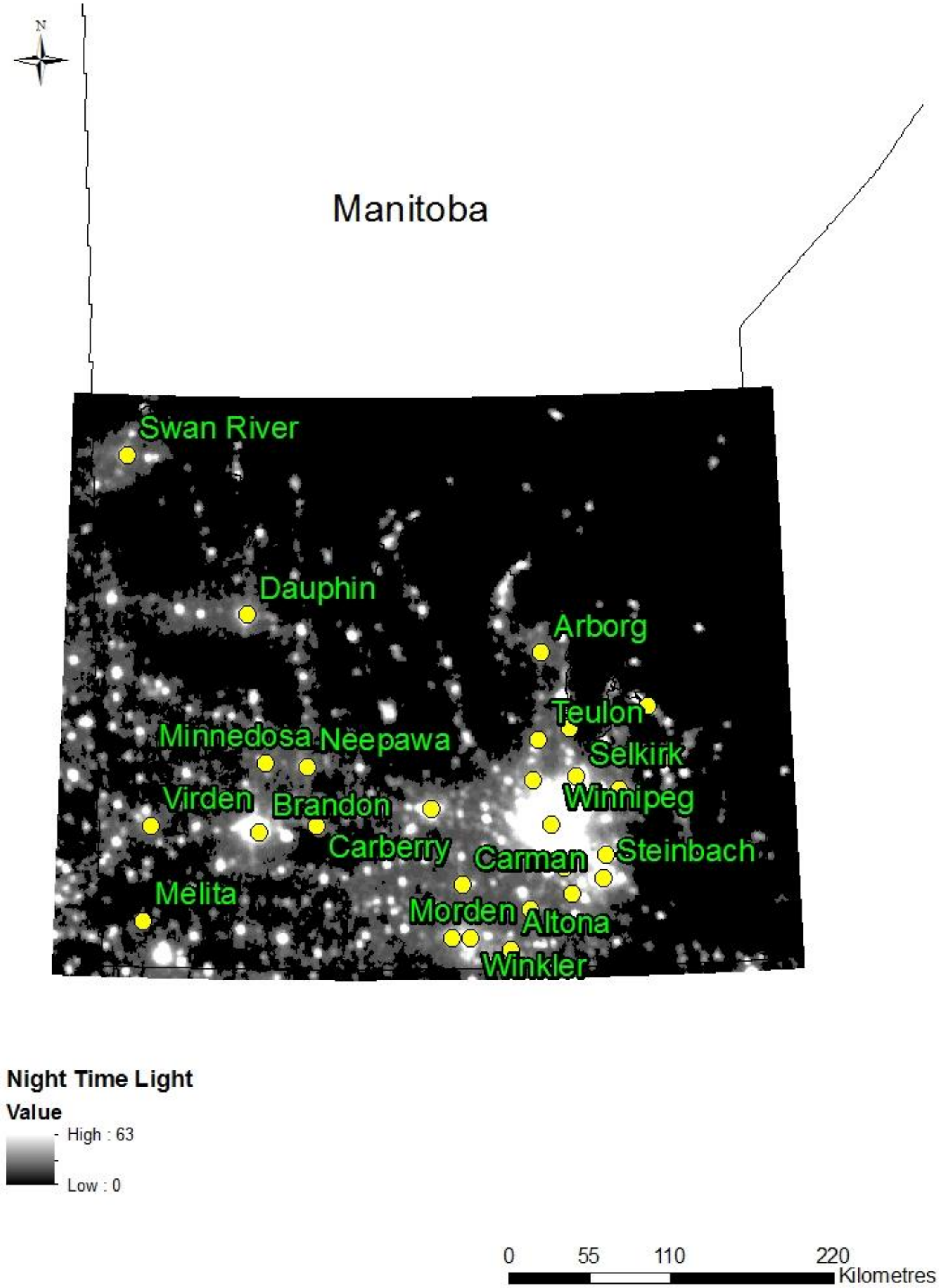

Figure 4.1 Nighttime light image of southern Manitoba (DMSP-OLS, 2010; Manitoba Land Initiative, 2001; 2015)

4.4.2 Land Use Classification

The land use classification data used for this study was obtained from the Manitoba Land Initiative (MLI) website and is shown in Figure 4.2. The land use classification shapefiles were created by the province of Manitoba using Landsat TM images taken between 2004 and 2006. The pixel resolution of this data is 30 meters. In the original classification shapefile, 17 land classes are used. These classes were further aggregated into six classifications, water, forest, agriculture, developed, wetland, and bare. These aggregate classes were developed because they represented the natural grouping of the original categories (e.g. rock outcrops and bare) and were shown to have statistically similar properties during preliminary statistical analyses. The proximity to the Red River was also analyzed as a type of ancillary information which could be used to inform a dasymetric approach.

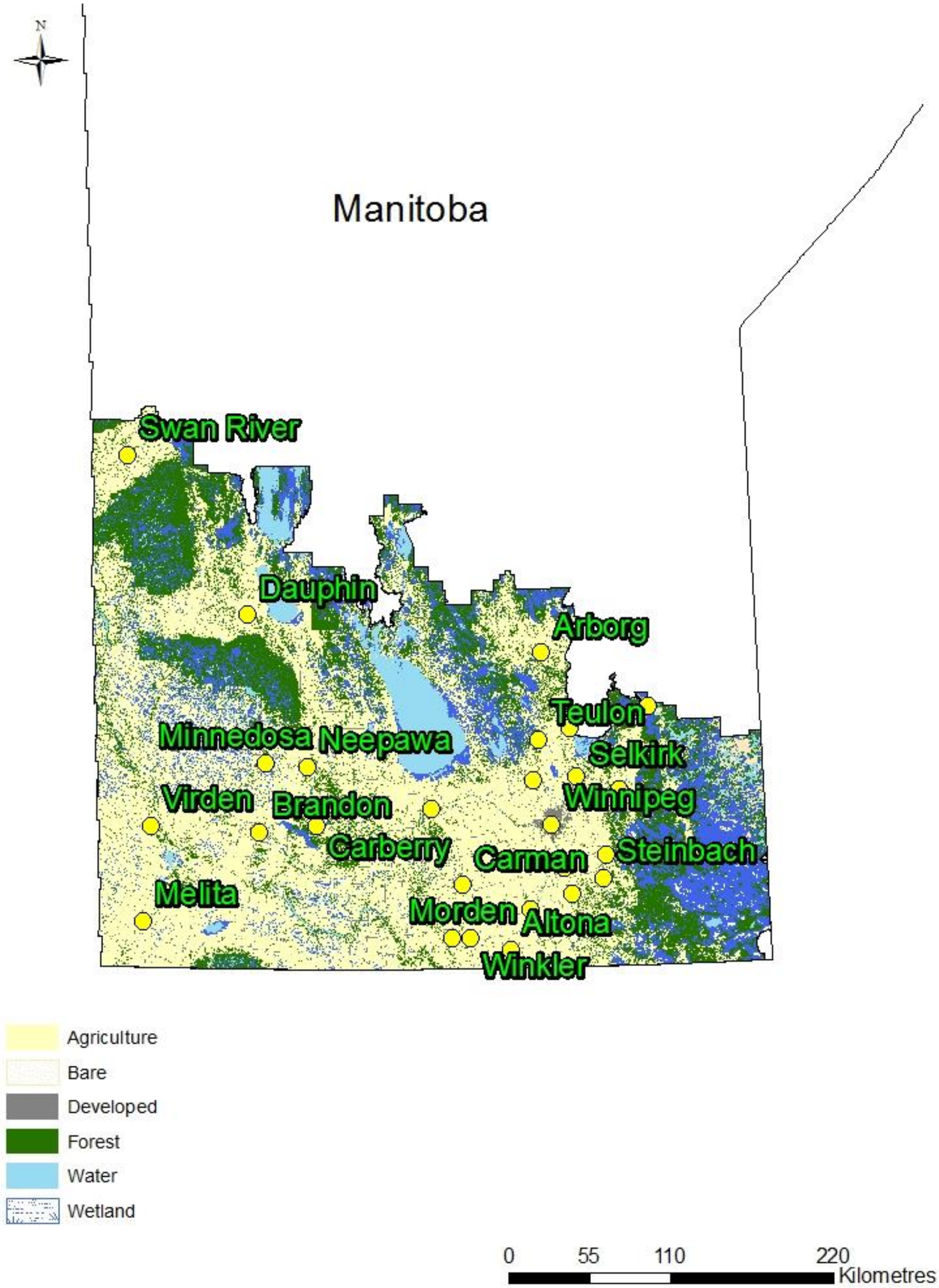

Figure 4.2 Land Use Classification (LUC) of southern Manitoba (MLI, 2004-2006; Manitoba Land Initiative, 2001; 2015)

4.4.3 Population

The population data were obtained from the 2011 Census and consisted of a boundary shapefile and a separate file with the attributes. The boundaries and statistics aggregated at the dissemination area level were obtained from the Statistics Canada website. The attribute data is not available for direct download at the dissemination area level therefore, it was extracted from the Beyond 20/20 files available. The data was brought into excel as a .csv file and the relevant variables were selected. These variables included population, number of dwellings, and area in square kilometers. These variables were used to calculate population and dwelling density which were compared with the attributes of interest. Figure 4.3 and Figure 4.4 show the population and dwelling density by census dissemination area for the study area.

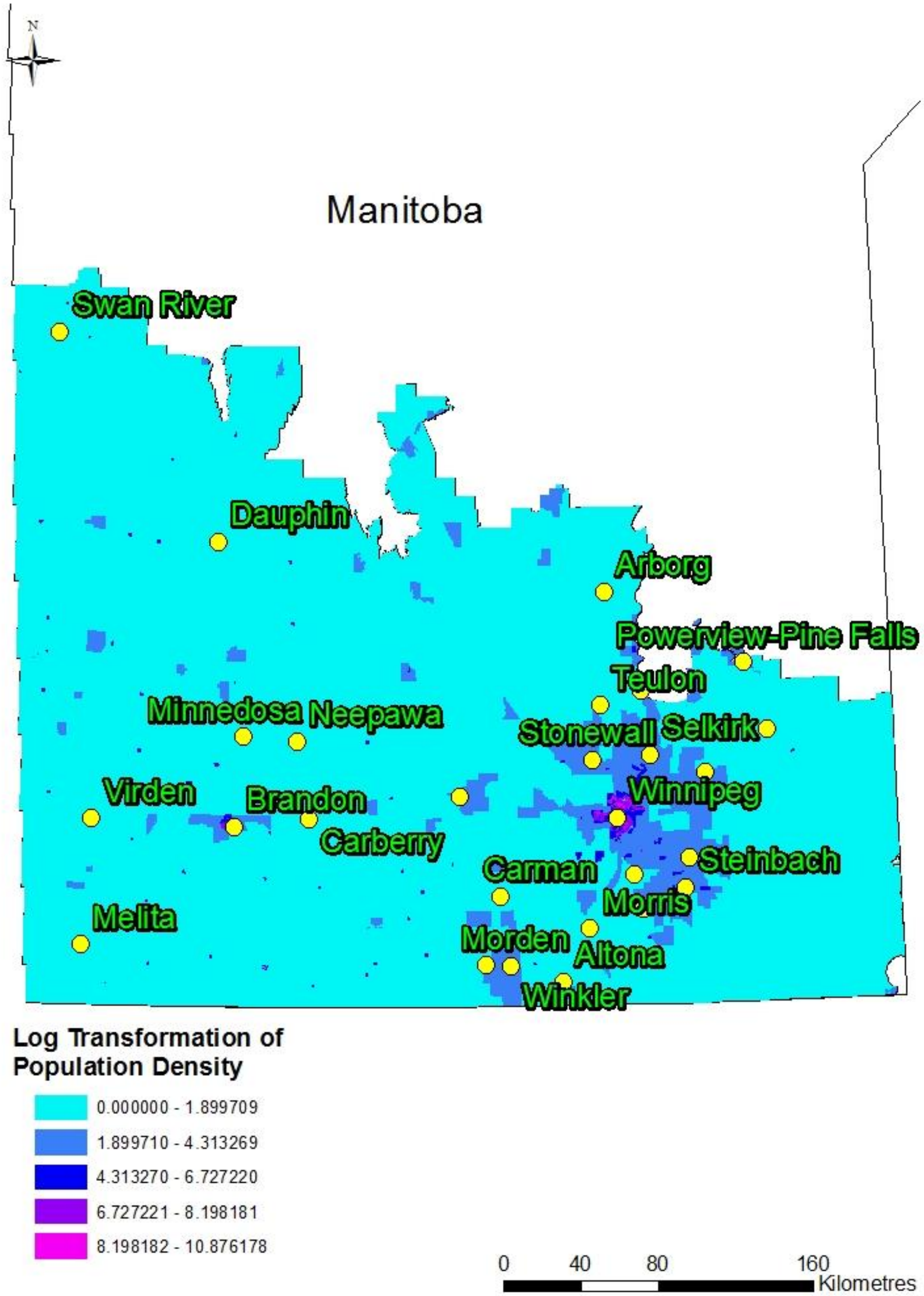

Figure 4.3 Log transformation of population density by census dissemination area (Statistics Canada, 2011; Manitoba Land Initiative, 2001; 2015)

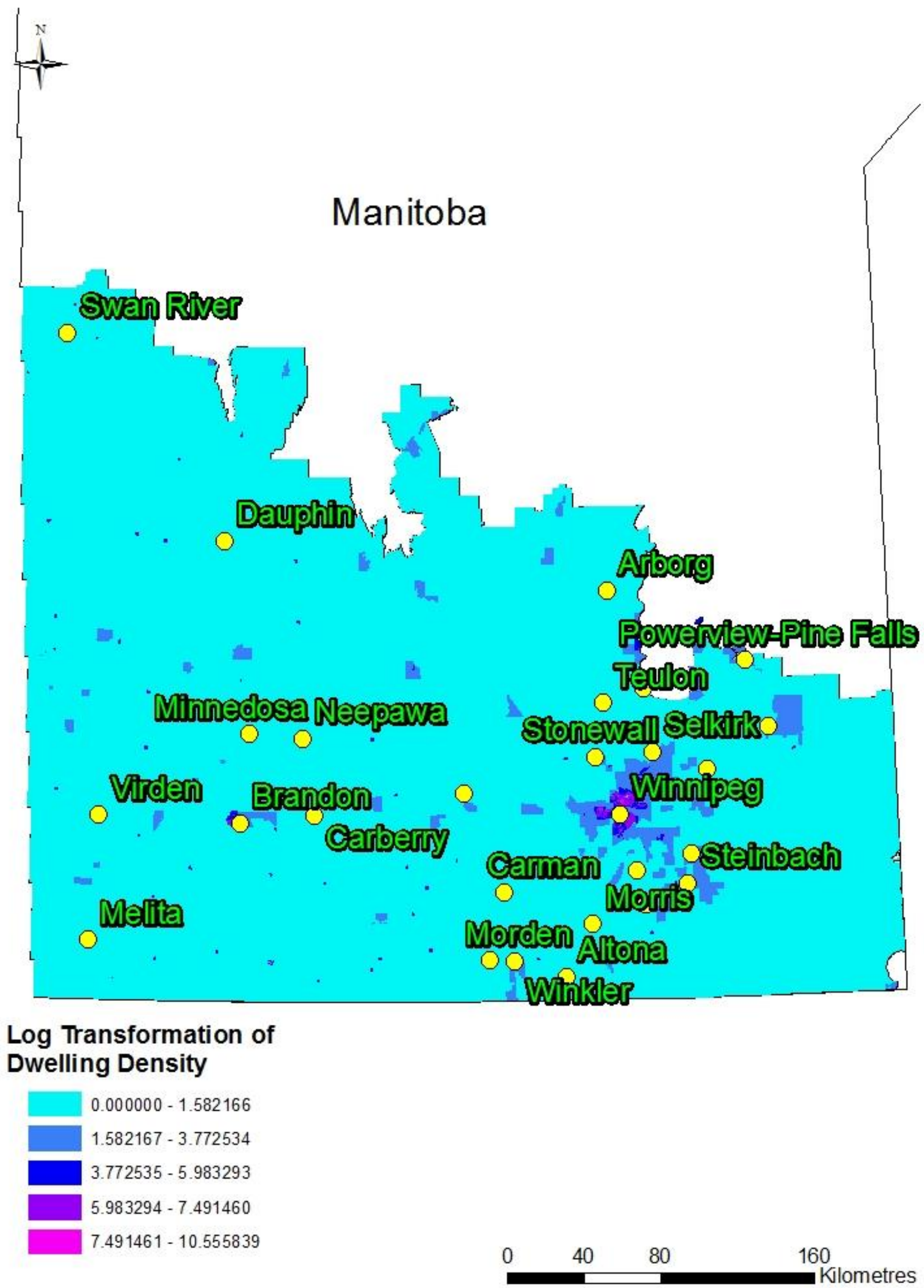

Figure 4.4 Log transformation of dwelling density by census dissemination area (Statistics Canada, 2011; Manitoba Land Initiative, 2001; 2015)

4.4.4 Sample Grid Creation

ArcGIS 10 was used to convert the night light image into a point shapefile, where the points were the centroids of the pixels, resulting in a grid of points spaced apart. The resulting file contained the sample points for this study. The point file was spatially joined to the population and LUC files so that each point contained a value for night light intensity, population density, dwellings and land use classification. The total number of sample points was 203338, much of which occurred in relatively unpopulated agricultural or undeveloped areas.

To reduce the dataset for analysis, and because the overall dataset included thousands of replicates of unpopulated landscape, sub-sample quadrats were created around populated centers such as cities, towns, and rural municipalities using the Province's communities database. This database includes all named settlements including those that are of a 'historical' nature (i.e. abandoned or depopulated). In order to filter out these abandoned sites only sites classified as cities, towns, villages or rural municipalities were used in to create the sub-sample quadrats. Multiple quadrat samples were included for the City of Winnipeg, due to its high population density and large area. These quadrats were used to extract points from named areas to create a sub-sample database with information for only those areas and the landscapes surrounding them. This provides samples that do include low-density human occupancy and depopulated areas without biasing analyses by the large unpopulated Manitoba landscape. The points included in the sub-sample database were removed from the larger database to create two separate datasets without any overlapping features. A similar approach using buffers around rivers was done to isolate a sub-sample points adjacent to potential flood-prone areas. This data was analyzed separately to determine if there was a difference in population distributions between homes 1 kilometre or more from the river and those within 1 kilometre of the river.

4.4.5 Statistical Analysis

The statistical software package R was used to analyze the relationships between the variables. A principal component analysis was performed to examine the relationships among the three variables. A series of biplots were created to examine the distribution of the quantitative data. Separate biplots were compared for the full landscape and for the named settlements sub-sample dataset. In order to better visually represent the distribution of these variables, biplots were produced using the log transformed root of the variables for population density, dwelling density, and the log transformation of light. Histograms showing the distribution of the values for each of the variables were created. The histograms for population density and dwelling density were log transformed to better represent their distributions. A regression analysis was performed to determine the relationship between light, population density, and dwelling density. Boxplots were created to compare the distribution of the three variables within the six different land use classes. Boxplots were also used to compare the distribution of the three variables in sample points near and far from a river.

4.5 Results

4.5.1 Data Summary Statistics

The summary statistics calculated for the quantitative variables for the full landscape of the study area, and sub-sample datasets around the named settlements, are compared in Table 4.1. The summary shows that overall, the mean values were low for all of the variables considered. Confining the analysis to known populated areas eliminated the areas with zero values for most of the variables, with the exception of light intensity. This suggests that in very low population areas light levels may be too low to be detected. The distributions of the datasets supports this

Table 4.1 Summary statistics for population density, dwelling density, and light

	Population Density		Dwelling Density		Light	
	Landscape	Named Settlements	Landscape	Named Settlements	Landscape	Named Settlements
Min.	0	0.189	0	0.126	0	0
1st Quantile	0.563	0.968	0.311	0.423	0	6
Median	0.974	2.044	0.464	0.87	0	9
Mean	5.99	140.1	2.545	59.14	4.827	18.73
3rd Quantile	1.725	7.739	0.789	3.132	7	30
Max.	16050	25600	8225	12630	63	63
Standard Deviation	107.7213	707.6005	47.09905	322.1237	7.665168	20.07557

observation as shown in Figure 4.5. Biplots are compared between the two datasets for the three quantitative variables in Figure 4.6. These plots show the distribution of the variables with their mean and range. The distributions of all of the variables are strongly skewed to the right as they have a high frequency of low values.

Boxplots were created to show the distribution of light, population and dwelling density, categorized by the LUC in which they are found. Figure 4.7 shows that mean values in the Developed LUC are much higher than for any of the other land use types. This indicates that populations are higher in this LUC than others.

The quantitative variables were also examined in relation to their proximity to a river. Figure 4.8 compares the mean and range of the variables as Boxplots categorized as either near or far from a river. The means for the sample points near the river were higher for all three variables. This indicates that there are more people living near rivers than far from rivers.

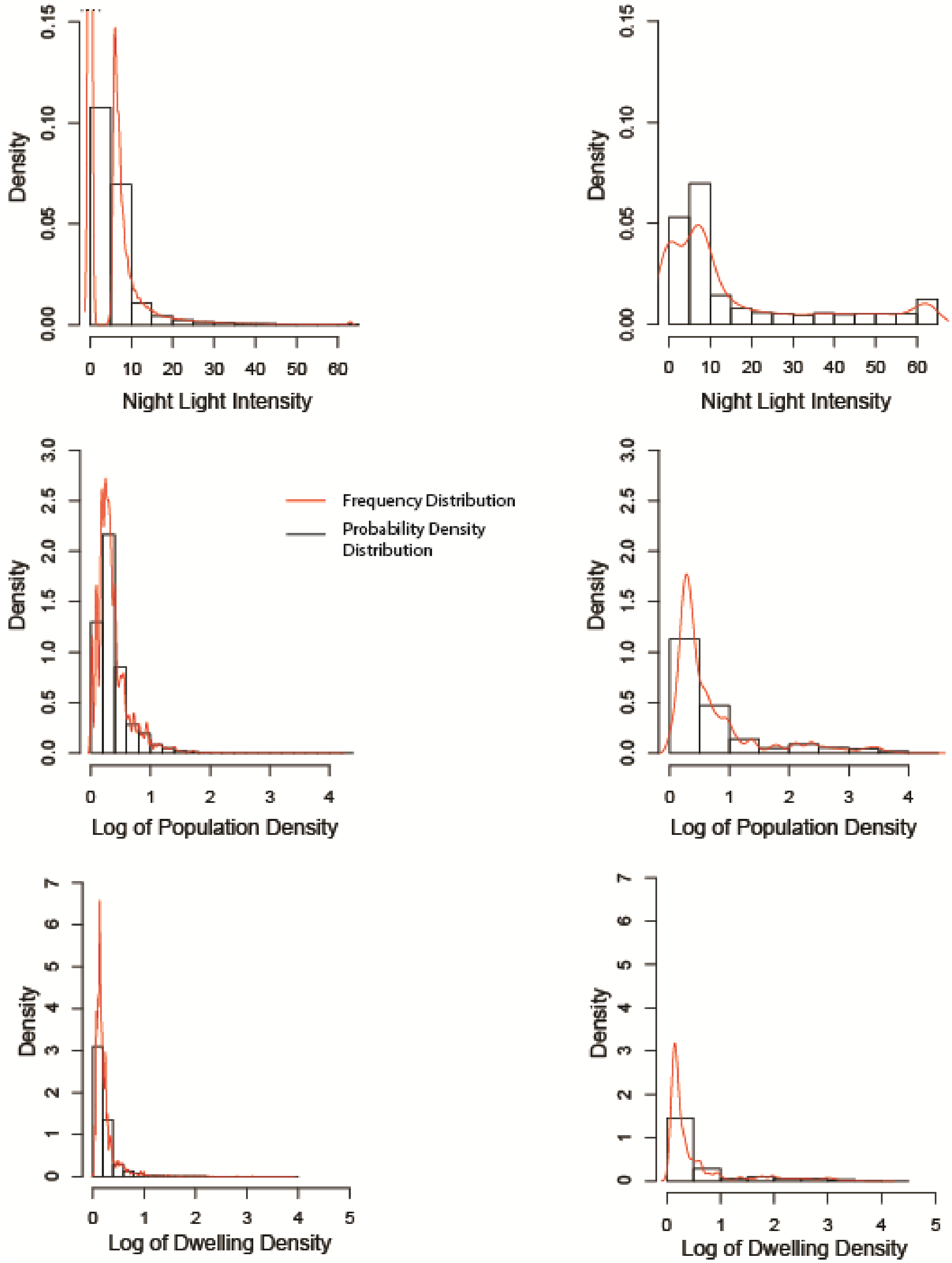

Figure 4.5 Histograms of night time light (top row), the log of population density (middle row) and the log of dwelling density (bottom row) for the entire study area (left column) and the named settlements only (right column).

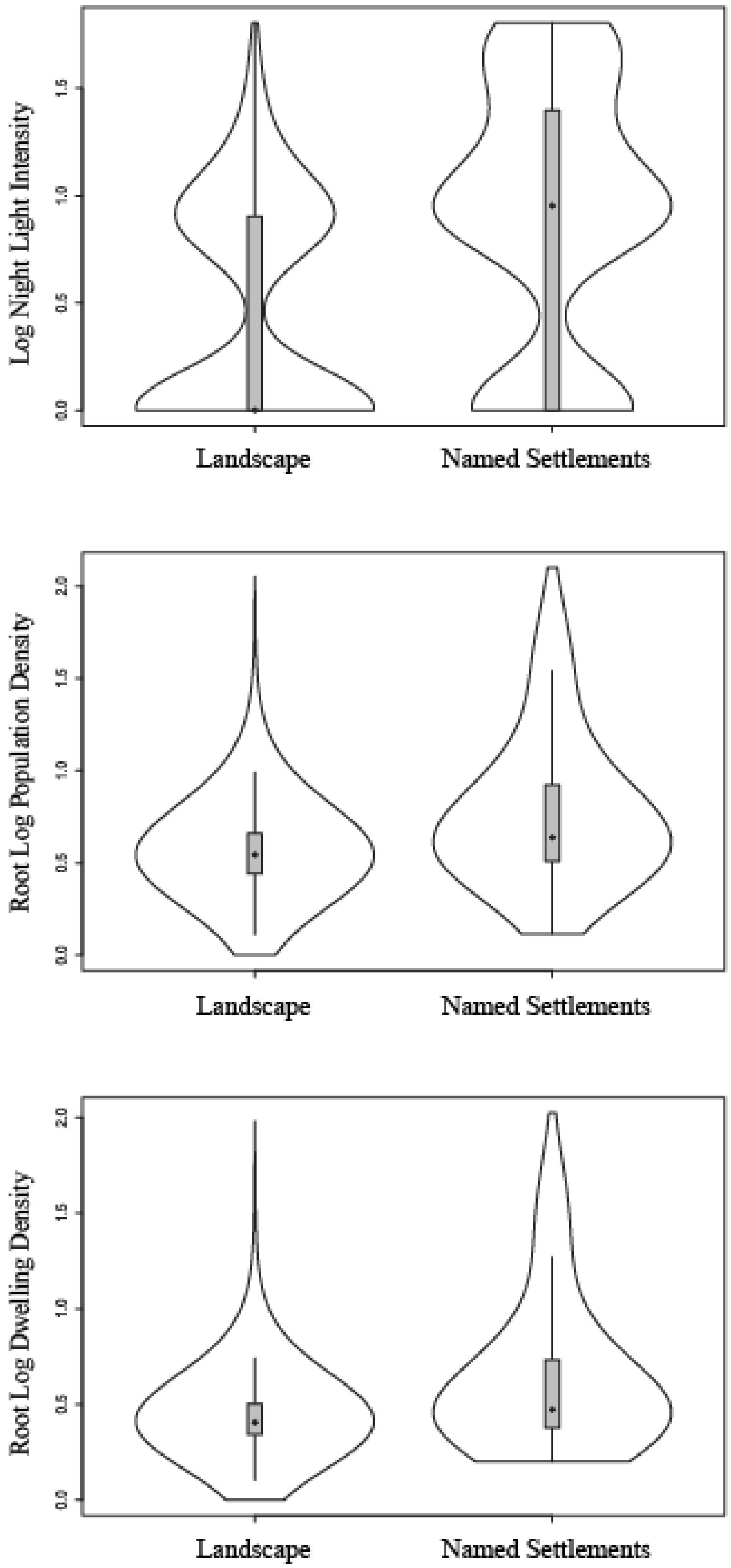

Figure 4.6 Biplots of night time light (top), population dwelling (middle), and dwelling density (bottom).

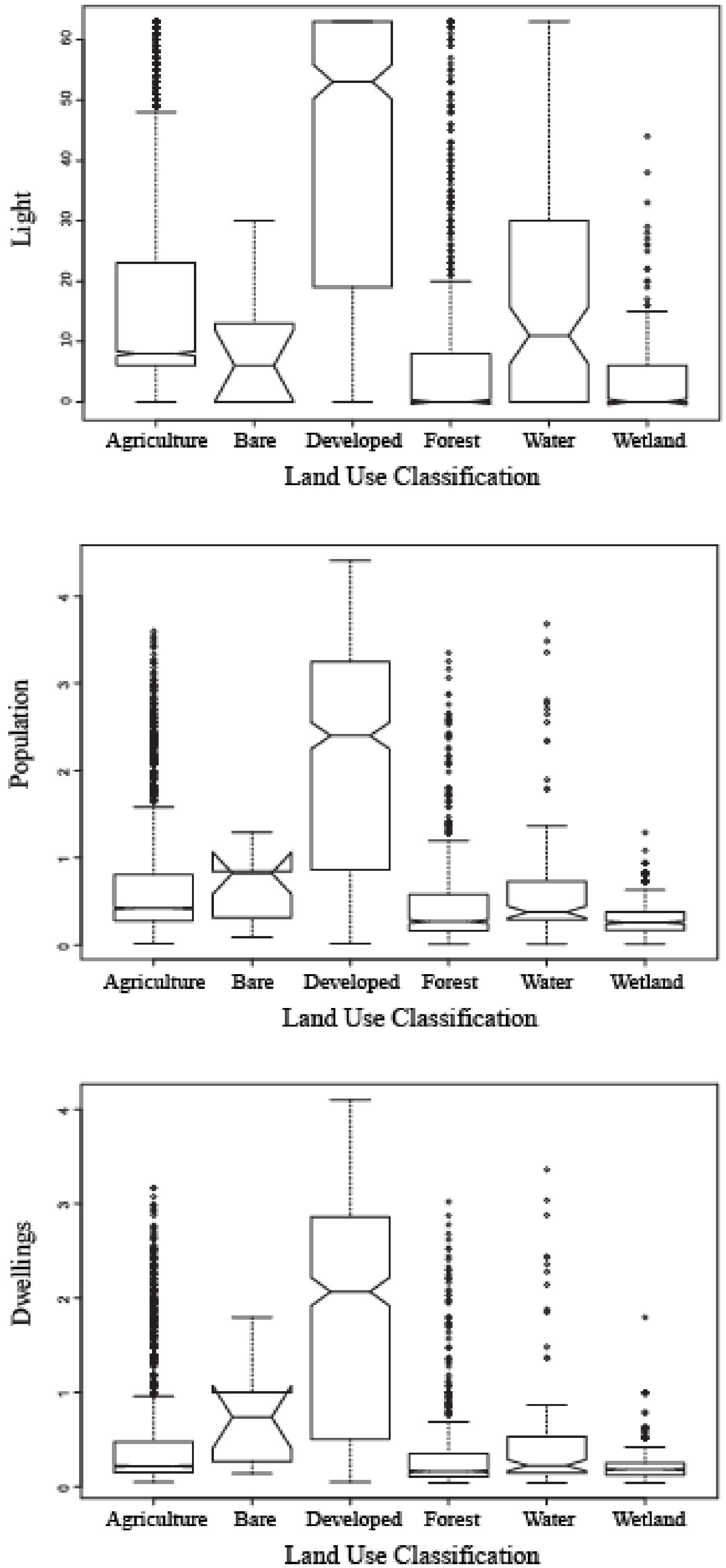

Figure 4.7 Boxplots showing the distribution of values for night time light (top), population density (middle), and dwelling density (bottom) categorized by Land Use Classification (LUC).

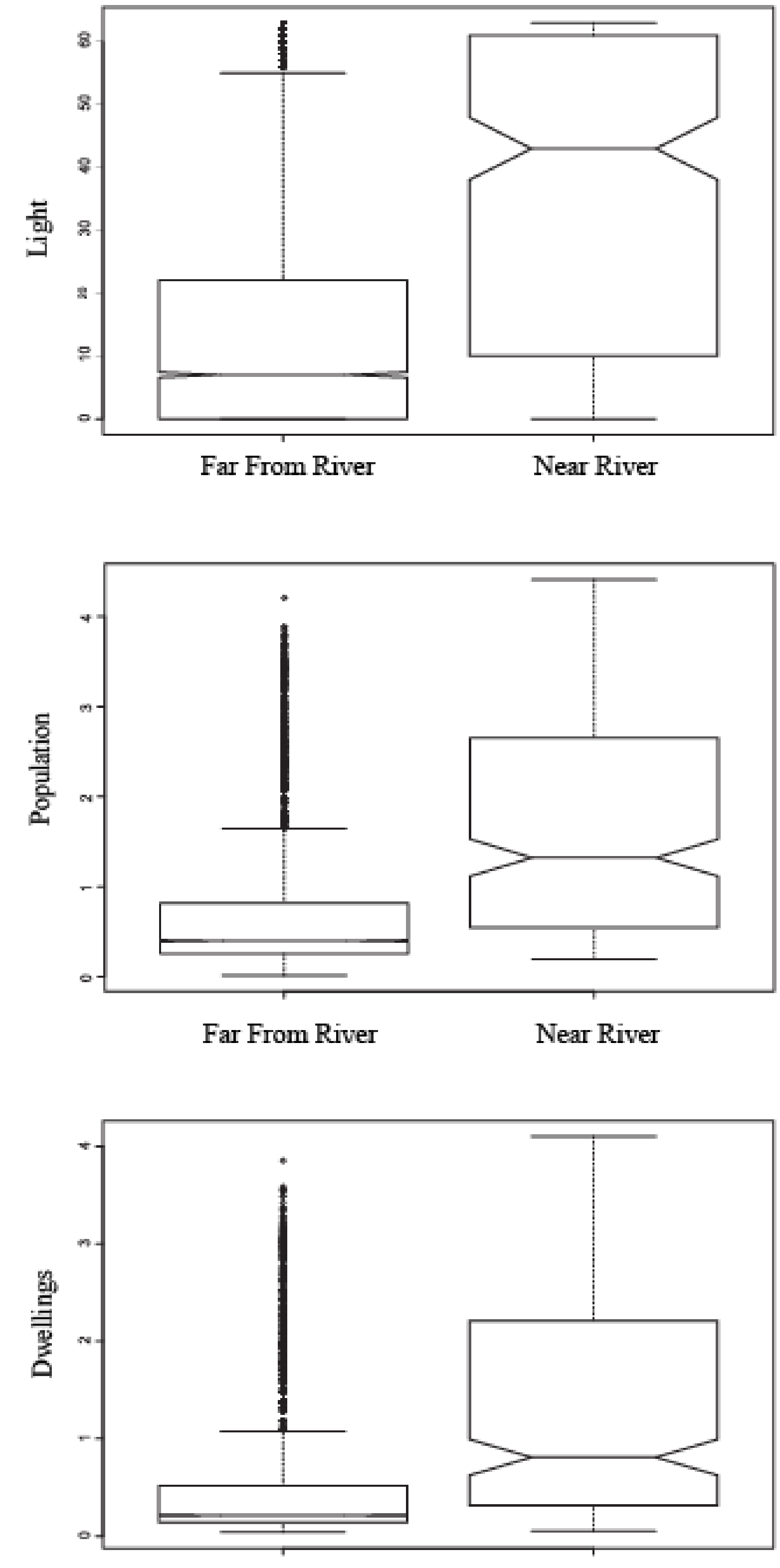

Figure 4.8 Boxplots showing the distribution of values for night time light (top), population density (middle), and dwelling density (bottom) categorized by sample points near the river and far from the river.

4.5.2 Correlation and Regression Analysis

The regression analysis revealed a significant relationship between all of the variables examined. Figure 4.9 compares the correlation plots showing the relationship between population and dwelling density and light. The regression line is included to demonstrate the direction of the relationship. Table 4.2 shows there is a positive correlation between all of the variables examined. As expected, population and dwelling density were strongly correlated. There was also a positive correlation between light and the other two variables for both datasets however, the correlation was stronger for the named settlements than the rest of the landscape.

The low p-values for all relationships obtained during the regression analysis suggest that we can reject the null hypothesis and that a relationship between the variables does exist. Table 4.3 lists the results of the regression analysis.

The correlation coefficient for each relationship tested was fairly high. All relationships were positive with the strongest being between population and dwellings. The relationships were stronger when only the named settlements were analyzed than when the entire landscape was analyzed. The relationship between population and light is stronger than the relationship between dwellings and light.

The residuals in Table 4.3 indicate that the date were not normally distributed for either dataset analyzed. If the data were normally distributed the median would be close to zero with the other values roughly equally spaces around the median. The values listed indicate the dataset is skewed to the left. This is supported by the shape of the distributions in Figure 4.5.

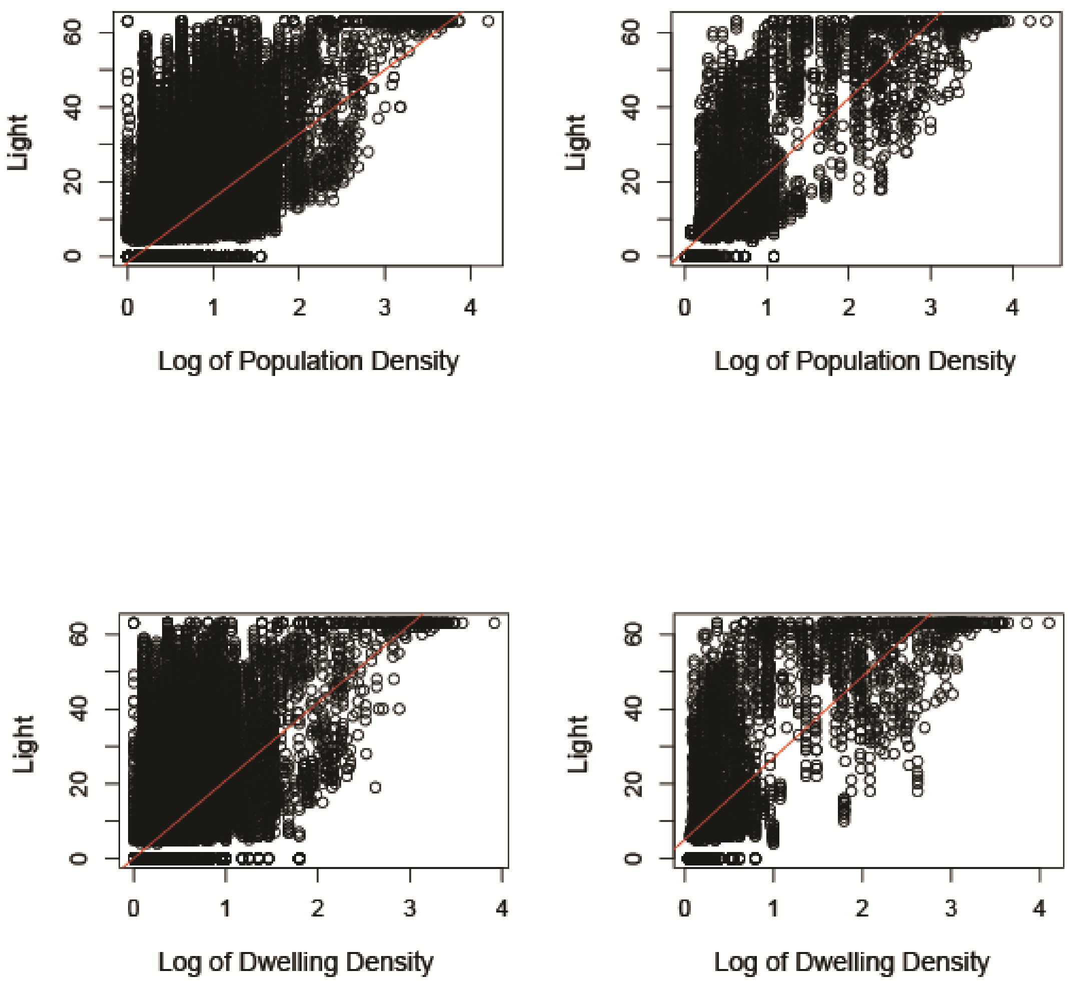

Figure 4.9 Correlation plots with regression lines showing the relationship between night time light and population density (top) and night time light and dwelling density (bottom) for the entire landscape (left column) and for the named settlements only (right column). All correlations presented are significant with $p<<0.0001$.

Table 4.2 Correlation matrices for full landscape and named settlements datasets

Landscape			
	Light	Population	Dwellings
Light	1	0.6879401	0.6137769
Population	0.6879401	1	0.9141971
Dwellings	0.6137769	0.9141971	1

Named Settlements			
	Light	Population	Dwellings
Light	1	0.8051368	0.767326
Population	0.8051368	1	0.9868454
Dwellings	0.767326	0.9868454	1

Table 4.3 Multiple linear regression results

Landscape

Residuals:

Min	1Q	Median	3Q	Max
-24.614	-3.06	-0.981	1.697	64.577

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-1.5768	0.01973	-79.92	<2e-16
log10(pop_dens + 1)	19.2806	0.10051	191.83	<2e-16
log10(DwellDens + 1)	-3.1299	0.13672	-22.89	<2e-16

Residual standard error: 5.556 on 197389 degrees of freedom
Multiple R-squared: 0.4747, Adjusted R-squared: 0.4747
F-statistic: 8.917e+04 on 2 and 197389 DF, p-value: < 2.2e-16

Named Settlements

Residuals:

Min	1Q	Median	3Q	Max
-29.556	-6.538	-2.708	3.871	52.121

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-1.5187	0.2749	-5.525	3.43E-08
log10(pop_dens + 1)	45.3255	1.1284	40.168	< 2e-16
log10(DwellDens + 1)	-28.6008	1.2531	-22.824	< 2e-16

Residual standard error: 11.42 on 5943 degrees of freedom
Multiple R-squared: 0.6766, Adjusted R-squared: 0.6765
F-statistic: 6217 on 2 and 5943 DF, p-value: < 2.2e-16

Table 4.3 also shows that F = 6217 ($p < 2.2e-16$) which indicates that we should clearly reject the null hypothesis that the variables population density and dwelling density collectively have no effect on nighttime light. The results also show that population density is significantly controlling for dwelling density (p = 2.2e-16), as is dwelling density controlling for population density (p=2.2e-16). In addition, the output also shows that the proportion of the variance in the data that is explained by the model is $R^2 = 0.6766$. The proportion of the variance explained by the model when correcting for the number of variables is R^2 adjusted = 0.6765.

The values located in the t-value column indicate the value for testing whether the correlation coefficient is different from zero. The values in the p-value column indicate the probability of obtaining a t-value of at least that magnitude if the correlation coefficient were zero. In the case of both the named settlements and landscape data the p-values indicated the probability of obtaining the t-values indicated is extremely small. This suggests that it is very unlikely that the correlation coefficient is zero. All correlations were significant at $p<0.0001$.

The estimates column indicates the values of the regression equation which can be used to predict the dependent variable using the independent variables. For the named settlements database the regression equation would be as follows:

Light = (-1.5187) + 45.3255 (log10(population density + 1)) + (-28.6008) (log10(dwelling density + 1)

This relationship can be reversed in order to use the nighttime light level to predict the population density or dwelling density.

4.5.3 Principal Component Analysis

The principal component analysis suggests that the first principal component varies strongly with population and dwelling density with both increasing as the other increases. The second principal varies strongly with nighttime light also in positive direction. In terms of the relationships between the various land use classifications, Figure 4.10 shows that as population increases, the likelihood of being in a developed LUC increased as well. The other land use classifications varied in a negative direction suggesting they were more closely associated with low population and dwelling densities. Table 4.4 shows the numeric results of the PCA. The standard deviation is the square root of the eigenvalues and represents the standard deviation associated with each principal component. The second row of the table lists the proportion of the variance in the data explained by each of the components. The third row describes the cumulative proportion of the variance explained by each component. We can see there that the first two principal components account for more than 99% of the variance of the data for the named settlements and 97% for the rest of the landscape.

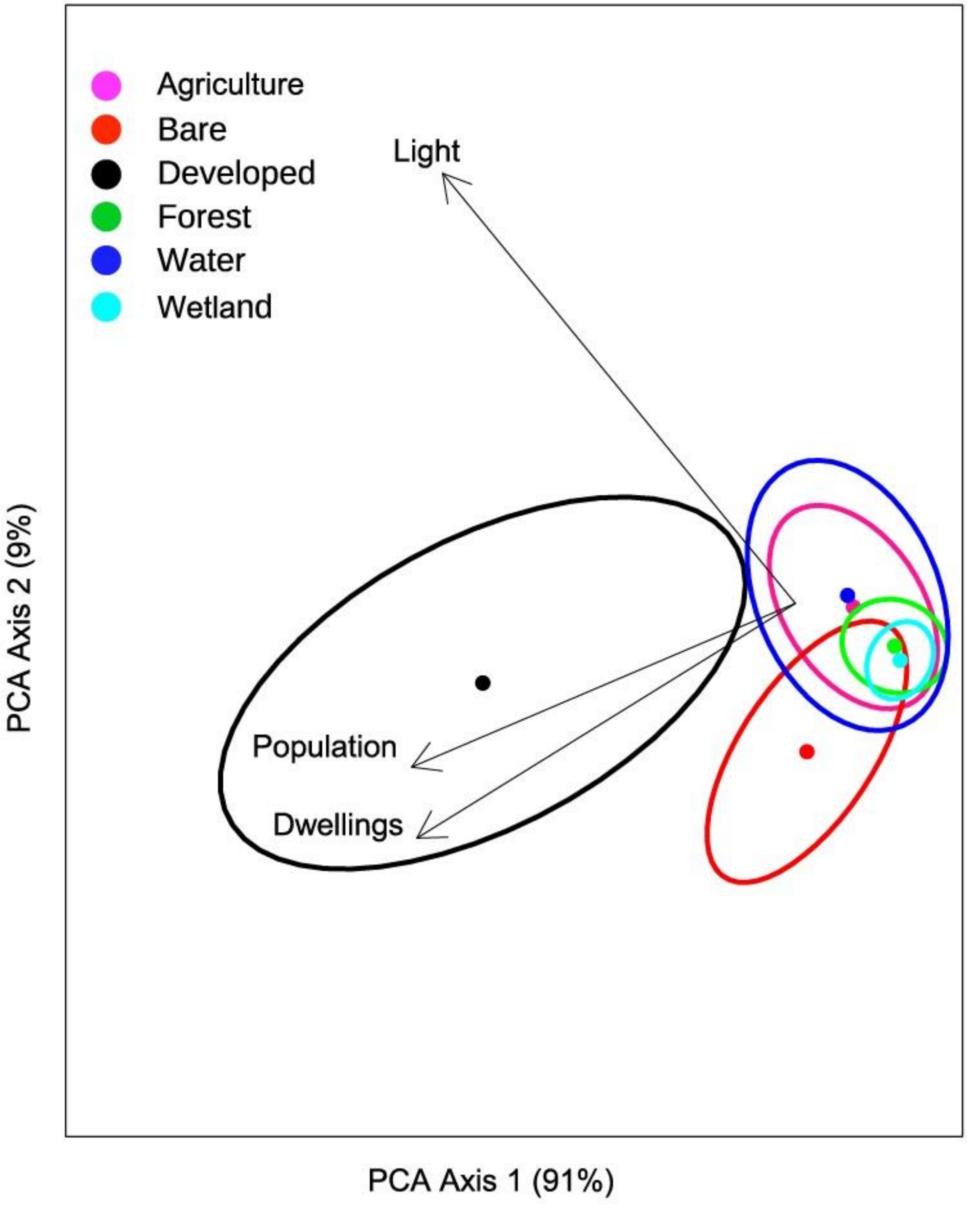

Figure 4.10 Principal Component Analysis (PCA) for night time light, population density, and dwelling density categorized by Land Use Classification (LUC) for the Named Settlements

Table 4.4 Principal Component Analysis (PCA) results

Landscape			
	PC1	PC2	PC3
Standard deviation	1.5764	0.6596	0.2825
Proportion Variance	0.8284	0.1450	0.00431
Cumulative Proportion	0.8284	0.9734	1

Settlements			
	PC1	PC2	PC3
Standard deviation	1.6462	0.52806	0.10576
Proportion of Variance	0.9033	0.09295	0.00373
Cumulative Proportion	0.9033	0.99627	1

4.6 Discussion

A relationship was found between land use classification and population and dwelling density. Developed lands were more often associated with high population and dwelling density while the other land use classifications were more often associated with low population and dwelling density. Using this information land use classification data can be used to spatially constrain the asset inventory to only the developed area. If asset data is confined to the populated area it could increase the accuracy of estimations in one of two ways. If the population is concentrated along a waterway aggregated estimates may be undervalued as the program would determine that a smaller percentage of the population is at risk. On the other hand, if the population is largely outside of the flood zone, aggregated estimates may be too high as the program assumes a larger percentage of the population are exposed to the hazard.

While a strong positive relationship exists between light and population, the threshold effect encountered at the maximum and minimum values make the development of a robust predictive model unlikely. That said, night light can still be a useful tool for differentiating populated areas from unpopulated areas. Higher resolution night time light imagery is now available for purchase which may further increase the utility of this data for the dasymetric approach.

Both variables were studied over a large area meaning that while the relationships are valid at the landscape level, they may be less reliable at a more localized, community level. Levin et al. (2014) states that relationships between population and night time imagery have yet to be validated at a localized scale. They suggest that finer resolution imagery would be required for applications at the municipal or city level.

4.7 Conclusion

The objective of this research was to determine whether a relationship exists between population and dwelling density, night time light, and land use classification. The results of this study suggest that a relationship does exists which could be used as part of a dasymetric approach to refine HAZUS flood loss estimates. Further research is needed to determine if this approach is feasible on a more localized scale.

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Chapter 5. Conclusion and Recommendations

5.1 Summary

There were two primary goals which were achieved during this study. The first goal was to evaluate the role of HAZUS as a Quantitative Risk Assessment (QRA) tool in Manitoba. In Chapter 3 we examined a flood loss scenario using HAZUS-MH as a quantitative risk assessment tool and found that HAZUS-MH has the potential to be adapted for use in a Manitoba context. The results of the analysis quantified structural damage and loss and allowed the user to spatially map these losses. This tool has the capability to inform decision-makers within government of potential losses due to flooding so that they may make decisions regarding mitigation and response strategies. The ability to simulate a flood event and view the potential damages before they occur can help with land use planning in flood prone areas to reduce the cost of flood recovery in Manitoba.

The second goal of this study was to evaluate the use of nighttime light and land use classification information to increase the accuracy of HAZUS estimations. Chapter 4 compared the relationship between variables such as land use and night time light with population and dwelling density. This relationship was explored to determine the feasibility of using land use classification or night time light to refine population data in a dasymetric approach. A strong relationship was found between these variables which suggests they may be used to disaggregate loss estimations produced by HAZUS beyond the census block level to produce more accurate results.

5.2 Major Findings

Manitoba has historically been subject to periodic severe flooding events and there is no indication that the frequency and magnitude of these events will decrease in the future. In fact, some scientists suggest that due to factors such as climate change and isostatic rebound, the frequency of these types of events will only increase with time (Brooks, Thorleifson & Lewis, 2005; Ashmore & Church, 2001).

Quantitative risk assessment allows government agencies to determine the likelihood of a flood event and the potential losses it can cause. This allows emergency planners to develop an appropriate response strategy. It can also be useful for making decisions regarding structural and non-structural mitigation measures.

HAZUS Canada can be used as an effective quantitative risk assessment tool in the Manitoba context however, some refinements are required in order to address potential issues with building damage cost estimates. Estimations obtained using HAZUS are only as accurate as the data on which they are based. In order to ensure predictions made using HAZUS are reasonable, it is important that the most accurate data be used. In addition, it is important that this data be as current as possible.

This project has identified the need for a centralized asset database. Data is available in pieces through various government agencies but the completeness and standardization of these data varies from agency to agency. MAVAS, the assessment database managed by MMG, is a good starting point for this database but lacks the spatial awareness required to make it a truly powerful tool for risk assessment. In addition, first floor heights are sparsely available and not standardized in the way they would need to be for use with HAZUS.

While this study did not find an issue with the building count estimations for the aggregate data when compared with the user-defined data, the dasymetric approach could nevertheless be useful for refining the spatial extent of the mapping component of HAZUS. Night time light and land use classification are both strongly correlated with population and dwelling density. This suggests that both variables are viable options for use in a dasymetric approach to mapping flood loss estimations.

5.3 Contributions of the Research

There are several important contributions this research makes to the field. This project piloted the use of assessment data for populating the HAZUS building stock in Manitoba. A data dictionary was created which can be used by other HAZUS users to incorporate MAVAS data into HAZUS. This research contributed to the field by piloting the use of the dasymetric approach for HAZUS Canada. This research also examined the relationship between light and land cover in Manitoba. The information regarding this relationship can have implications for modelling population data for applications beyond the use of HAZUS.

5.4 Limitations of the Research

- The study area consisted of mostly residential buildings. This means there was very little opportunity to test the ability of the program to perform estimations in areas with a high percentage of commercial or industrial buildings. There was also very little flooding experienced by the buildings present which means the ability of the model to predict losses in areas with a large number of assets on flood-prone land could not be evaluated. It is recommended that future studies focus on larger study areas with more at risk assets and variation in occupancy type.
- The area selected had very little variety in the land use classifications present. For this reason, the evaluation of using land use classification data in the dasymetric approach showed very little difference in predicted losses. A larger study area with more variation

in land use classification should be undertaken to further evaluate the potential of this data for a dasymetric approach.

- The resolution of the night light images freely available is too coarse. The pixels in the study area were larger than many of the census blocks. Night time light levels were high throughout the study area which means there were no areas without population. For this reason the data cannot be used for the dasymetric approach in HAZUS to refine census boundaries.
- Default values were used for first floor elevations as actual elevation data was not available. As HAZUS uses the first floor elevation to calculate the percentage of damage, it is important that this value be accurate. It is recommended that future studies attempt to determine first floor elevations. If this is not possible it may be useful to try to develop a set of default first floor elevations based on foundation type which are customized for Manitoba. There may be existing construction regulations which may be used to inform the development of defaults.
- This study was unable to validate the results of the HAZUS predictions. In order to accurately compare the results loss data would be required for a similar flood event in the same area. The closest approximation of this data would be government assistance claims data. This data is not available for a 100-year flood with 2011 building stock in the study area as a flood of this level did not occur at this time. In addition, even if the data were available, government assistance claims are often not representative of actual losses as there are restrictions as to what is covered and variation in the completeness and accuracy of claims filed.

5.5 Recommendations

Based on the results of this research the following recommendations are made:

- Incorporate depth-damage functions which are specific to Canada, or even Manitoba. A series of depth-damage functions were developed for southern Manitoba by KGS in 2000 (International Joint Commission, 2000). These functions may be suitable for producing more accurate building damage cost estimations or they may need to be updated.
- Update outputs and displays for metric units instead of empirical. Many outputs report figures in USD or square miles. These figures should be updated to CAD and square kilometers.
- Adoption of this software should be done in coordination with local governments to ensure access to the required data. It is recommended that the basis for the asset database be the MMG MAVAS database. This appears to be the most complete resource for the data required to populate the HAZUS database. With a few simple changes to the way this data is collected and stored, it could be a powerful tool for all types of hazard risk assessment.
- It is recommended that MMG begin including spatial location data such as building footprint or latitude and longitude coordinates. This would facilitate the integration of data into a geographic information system. The inclusion of first floor heights measured using a standard unit and datum is also recommended.
- Development and maintenance of a more complete Lidar database would provide a source of up-to-date, high-resolution elevation data which is integral for accurate flood risk assessment.

- A spatial database of high water marks for various flood return periods should be developed to allow for multi-scenario analysis comparing damages from floods of varying magnitudes.
- Higher resolution night time light imagery is currently available for purchase. Higher resolution images should be used where possible to increase accuracy.
- The large amount of agricultural area within Manitoba could mean that using land use classification to disaggregate population data may lead to underestimations in rural areas. For this reason further study is recommended to determine if using land use classification for the dasymetric approach to refine HAZUS estimations is effective in agricultural areas with sparse population density.

5.6 Conclusion

The high cost of flooding makes effective risk management an important priority for the Canadian government (Public Safety Canada (PSC), 2010). In order to develop effective strategies accurate risk assessment is essential. Flood risk assessment requires a complete characterization of the hazard as well as the assets at risk.

There are several kinds of data which are required to perform a flood risk assessment, regardless of the tool used. The two main categories of data required by HAZUS are the asset inventory and the hazard inventory. The data required to compile an asset inventory for a flood risk assessment are as follows:

- Building Location
- First floor height
- Number of storeys

- Building value
- Content value
- Commercial Inventory Value
- Foundation type
- Occupancy type
- Building Area

The hazard inventory for flood analysis in HAZUS is the flood depth grid. Creating a flood depth grid requires two pieces of information:

- High water marks for the flood scenario (or flood cross-sections)
- Elevation data (DEM)

While most data required for flood risk assessment are available in Manitoba, they are spread across several different databases, managed by different organizations, with varying levels of completeness and standardization. This makes the information time consuming to gather and it requires a large amount of processing to be useful. The amalgamation of data from various sources also makes it difficult to validate and leads to uncertainty in how the data was collected. A standardized central database for hazard and asset data, managed by one specific branch of the provincial government is vital for the adaptation of a standardized risk assessment tool in Manitoba. HAZUS has the potential to become this tool, provided the required data is available.

Although HAZUS can be used with the default aggregate data, the validity of damage costs is questionable. In addition to a standardized database, the development of depth-damage functions suitable for use in the Canadian context should be undertaken.

While this study did not determine that the use of a dasymetric approach would increase the accuracy of damage cost estimations, it was found that it could be useful for refining the spatial extent of the populated area which could increase the accuracy of loss maps produced using HAZUS.

In order to properly evaluate the use of HAZUS as an effective risk assessment tool in Manitoba the loss estimation results should be compared with the losses calculated during the flood scenario being examined. While this project examined the 100-year flood scenario from 1997, exhaustive flood loss data for this flood was not readily available. While the data may exist in some form, the scope of this project did not allow for the compilation of this data into a useable format which could be compared to the HAZUS results. In order to more thoroughly evaluate the accuracy of the loss estimations produced by HAZUS, the project must be coordinated by a particular government agency which is able to establish a centralized hazard and asset database and put resources toward compiling past flood loss records. Funding should be directed towards the fulfilment of these objectives as it is difficult for government officials to commit the required time to these projects when it is not part of a government-lead initiative.

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Appendix I. MAVAS to HAZUS Data Dictionary

PROP_CD	PROP_TYP	PROP_TYP_DESC	HAZUS Occupancy Category (name)	HAZUS Occupancy Category (code)
10	10	GUEST HOUSE	Single family dwelling	RES1
10	12	COTTAGE LOW QUALITY	Single family dwelling	RES1
10	14	COTTAGE AVG QUALITY	Single family dwelling	RES1
10	16	COTTAGE GOOD QUALITY	Single family dwelling	RES1
10	20	1 STY LOG SHACK	Single family dwelling	RES1
10	21	1 STY RES POOR QUALITY	Single family dwelling	RES1
10	22	1 STY RES LOW COST	Single family dwelling	RES1
10	23	1 STY RES FAIR QUAL	Single family dwelling	RES1
10	33	BI LEVEL RES FAIR QUALITY	Single family dwelling	RES1
10	50	1 1/2 STY LOG SHACK LINED	Single family dwelling	RES1
10	51	1 1/2 STY RES POOR QUAL	Single family dwelling	RES1
10	52	1 1/2 STY RES LOW QUAL	Single family dwelling	RES1
10	53	1 1/2 STY RES FAIR QUAL	Single family dwelling	RES1
10	60	1 3/4 STY LOG SHACK LINED	Single family dwelling	RES1
10	61	1 3/4 STY RES POOR QUAL	Single family dwelling	RES1
10	62	1 3/4 STY RES LOW QUAL	Single family dwelling	RES1
10	63	1 3/4 STY RES FAIR QUAL	Single family dwelling	RES1
10	71	2 STY RES POOR QUALITY	Single family dwelling	RES1
10	72	2 STY RES LOW QUALITY	Single family dwelling	RES1
10	73	2 STY RES FAIR QUALITY	Single family dwelling	RES1
10	04A	3 LEVEL RES AVG QUALITY	Single family dwelling	RES1
10	04B	3 LEVEL RES AVG	Single family dwelling	RES1

		QUAL 2X6		
10	04C	3 LEVEL AVG QUAL-SUPER EE	Single family dwelling	RES1
10	05A	3 LEVEL RES AVG GD QUAL	Single family dwelling	RES1
10	05B	3 LEVEL RES AVG GD 2X6	Single family dwelling	RES1
10	05C	3 LEVEL AVG GD-SUPER EE	Single family dwelling	RES1
10	05E	3 LEVEL RES AVG GD LOG	Single family dwelling	RES1
10	06A	3 LEVEL RES GOOD QUALITY	Single family dwelling	RES1
10	06B	3 LEVEL RES GOOD QUAL 2X6	Single family dwelling	RES1
10	06C	3 LEVEL RES GOOD-SUPER EE	Single family dwelling	RES1
10	102B	2 STY GUEST HOUSE 2X6	Single family dwelling	RES1
10	102S	2 STY GUEST HOUSE	Single family dwelling	RES1
10	10B	GUEST HOUSE 2X6	Single family dwelling	RES1
10	10HB	1 1/2 STY GUEST HOUSE 2X6	Single family dwelling	RES1
10	10HS	1 1/2 STY GUEST HOUSE	Single family dwelling	RES1
10	122B	2 STY COTTAGE LO QUAL 2X6	Single family dwelling	RES1
10	122S	2 STY COTTAGE LOW QUALITY	Single family dwelling	RES1
10	12B	COTTAGE LOW QUALITY 2X6	Single family dwelling	RES1
10	12HB	1 1/2 STY COT LOW QUA 2X6	Single family dwelling	RES1
10	12HS	1 1/2 STY COTTAGE LOW QUA	Single family dwelling	RES1
10	142B	2 STY COTTAGE AVG QUAL2X6	Single family dwelling	RES1
10	142S	2 STY COTTAGE AVG QUALITY	Single family dwelling	RES1
10	14B	COTTAGE AVG QUAL 2X6	Single family dwelling	RES1
10	14HB	1 1/2 STY COT AVG QUA 2X6	Single family dwelling	RES1
10	14HS	1 1/2 STY COT AVG QUALITY	Single family dwelling	RES1
10	162B	2 STY COTTAGE GD	Single family dwelling	RES1

		QUAL 2X6		
10	162S	2 STY COTTAGE GD QUALITY	Single family dwelling	RES1
10	16B	COTTAGE GOOD QUAL 2X6	Single family dwelling	RES1
10	16HB	1 1/2 STY COT GD QUAL 2X6	Single family dwelling	RES1
10	16HS	1 1/2 STY COT GOOD QUAL	Single family dwelling	RES1
10	20UL	1 STY LOG SHACK UNLINED	Single family dwelling	RES1
10	23B	1 STY RES FAIR QUAL 2X6	Single family dwelling	RES1
10	23E	1 STY RES FAIR QUAL LOG	Single family dwelling	RES1
10	24A	1 STY RES AVG QUALITY	Single family dwelling	RES1
10	24A2	1 STY/2 STY RES AVG QUAL	Single family dwelling	RES1
10	24AB	1 STY RES AVG Q OLD BRICK	Single family dwelling	RES1
10	24AH	1 STY RES AVG QUAL HISTOR	Single family dwelling	RES1
10	24B	1 STY RES AVG QUALITY 2X6	Single family dwelling	RES1
10	24B2	1STY/2STY AVG QUAL 2X6	Single family dwelling	RES1
10	24C	1 STY RES AVG Q-SUPER EE	Single family dwelling	RES1
10	24E	1 STY RES AVG QUALITY LOG	Single family dwelling	RES1
10	24PB	1 STY RES AVG Q POST/BEAM	Single family dwelling	RES1
10	25A	1 STY RES AVG GD QUALITY	Single family dwelling	RES1
10	25A2	1STY/2STY AVG GDQUAL	Single family dwelling	RES1
10	25AB	1 STY AVG GD Q OLD BRICK	Single family dwelling	RES1
10	25AH	1 STY RES AVG QU HISTORIC	Single family dwelling	RES1
10	25B	1 STY RES AVG GD QUAL 2X6	Single family dwelling	RES1
10	25B2	1STY/2STY AVG GD QUAL 2X6	Single family dwelling	RES1
10	25C	1 STY RES AVG GD-	Single family dwelling	RES1

		SUPER EE		
10	25E	1 STY RES AVG GD QUAL LOG	Single family dwelling	RES1
10	25PB	1STY AVG GD Q POST/BEAM	Single family dwelling	RES1
10	26A	1 STY RES GOOD QUAL	Single family dwelling	RES1
10	26A2	1STY/2STY RES GOOD QUAL	Single family dwelling	RES1
10	26AB	1 STY RES GD Q OLD BRICK	Single family dwelling	RES1
10	26AH	1 STY RES GD QU HISTOR	Single family dwelling	RES1
10	26B	1 STY RES GOOD QUAL 2X6	Single family dwelling	RES1
10	26B2	1STY/2STY GOOD QUAL 2X6	Single family dwelling	RES1
10	26C	1 STY RES GOOD-SUPER EE	Single family dwelling	RES1
10	26E	1 STY RES GOOD QUAL LOG	Single family dwelling	RES1
10	26PB	1 STY RES GD Q POST/BEAM	Single family dwelling	RES1
10	27A	1 STY RES EXC QUAL	Single family dwelling	RES1
10	27A2	1STY/2STY RES EXC QUAL	Single family dwelling	RES1
10	27AH	1 STY RES EXC QUAL HISTOR	Single family dwelling	RES1
10	27B	1 STY RES EXC QUAL 2X6	Single family dwelling	RES1
10	27B2	1STY/2STY EXC QUAL 2X6	Single family dwelling	RES1
10	27C	1 STY RES EXC-SUPER EE	Single family dwelling	RES1
10	27PB	1 STY RES EXC Q POST/BEAM	Single family dwelling	RES1
10	28A	1 STY RES ARCH DESIGN	Single family dwelling	RES1
10	28A2	1STY/2STY RES ARCH DESIGN	Single family dwelling	RES1
10	28AH	1 STY RES ARC DESIGN HIST	Single family dwelling	RES1
10	28B	1 STY RES ARCH DESIGN 2X6	Single family dwelling	RES1
10	28B2	1STY/2STY ARCH DESIGN 2X6	Single family dwelling	RES1

10	28C	1 STY RES ARC DES-SUPR EE	Single family dwelling	RES1
10	28PB	1 STY RES ARC D POST/BEAM	Single family dwelling	RES1
10	33B	BI LEVEL FAIR QUAL 2X6	Single family dwelling	RES1
10	33E	BI LEVEL RES FAIR QUA LOG	Single family dwelling	RES1
10	34A	BI LEVEL RES AVG QUALITY	Single family dwelling	RES1
10	34B	BI LEVEL RES AVG QUAL 2X6	Single family dwelling	RES1
10	34C	BI LEVEL RES AVG-SUPER EE	Single family dwelling	RES1
10	34E	BI LEVEL RES AVG QUAL LOG	Single family dwelling	RES1
10	35A	BI LEVEL RES AVG GD QUAL	Single family dwelling	RES1
10	35B	BI LEVEL RES AVG GD 2X6	Single family dwelling	RES1
10	35C	BI LEVEL AVG GD-SUPER EE	Single family dwelling	RES1
10	35E	BI LEVEL RES AVG GD LOG	Single family dwelling	RES1
10	36A	BI LEVEL RES GOOD QUAL	Single family dwelling	RES1
10	36B	BI LEVEL RES GD QUAL 2X6	Single family dwelling	RES1
10	36C	BI LEVEL RES GD-SUPER EE	Single family dwelling	RES1
10	36E	BI LEVEL RES GD QUAL LOG	Single family dwelling	RES1
10	44A	4 LEVEL RES AVG QUALITY	Single family dwelling	RES1
10	44B	4 LEVEL RES AVG QUAL 2X6	Single family dwelling	RES1
10	44C	4 LEVEL RES AVG-SUPER EE	Single family dwelling	RES1
10	44E	4 LEVEL RES AVG QUAL LOG	Single family dwelling	RES1
10	45A	4 LEVEL RES AVG GD QUAL	Single family dwelling	RES1
10	45B	4 LEVEL RES AVG GD 2X6	Single family dwelling	RES1
10	45C	4 LEVEL RES AVG GD-SUP EE	Single family dwelling	RES1

10	46A	4 LEVEL RES GOOD QUAL	Single family dwelling	RES1
10	46B	4 LEVEL RES GOOD QUAL 2X6	Single family dwelling	RES1
10	46C	4 LEVEL RES GOOD-SUPER EE	Single family dwelling	RES1
10	47A	4 LEVEL RES EXC QUAL	Single family dwelling	RES1
10	47B	4 LEVEL RES EXC QUAL 2X6	Single family dwelling	RES1
10	47C	4 LEVEL RES EXC-SUPER EE	Single family dwelling	RES1
10	50UL	1 1/2 STY LOG SHACK UNLIN	Single family dwelling	RES1
10	53B	1 1/2 STY FAIR QUAL 2X6	Single family dwelling	RES1
10	53E	1 1/2 STY RES FAIR QU LOG	Single family dwelling	RES1
10	54A	1 1/2 STY RES AVG QUALITY	Single family dwelling	RES1
10	54AB	1 1/2 STY AVG Q OLD BRICK	Single family dwelling	RES1
10	54AH	1 1/2 STY RES AVG QU HIST	Single family dwelling	RES1
10	54B	1 1/2 STY RES AVG Q 2X6	Single family dwelling	RES1
10	54C	1 1/2 STY RES AVG-SUPR EE	Single family dwelling	RES1
10	54D	1 1/2 STY RES AVG DOME	Single family dwelling	RES1
10	54E	1 1/2 STY RES AVG Q LOG	Single family dwelling	RES1
10	54PB	1 1/2 STY RES A POST/BEAM	Single family dwelling	RES1
10	55A	1 1/2 STY RES AVG GD QUAL	Single family dwelling	RES1
10	55AB	1 1/2 STY AVG GD Q OLD BR	Single family dwelling	RES1
10	55AH	1 1/2 STY RES A/G QU HIST	Single family dwelling	RES1
10	55B	1 1/2 STY RES AVG GD 2X6	Single family dwelling	RES1
10	55C	1 1/2 STY AVG GD-SUPER EE	Single family dwelling	RES1
10	55D	1 1/2 STY AVG GD QUA DOME	Single family dwelling	RES1

10	55E	1 1/2 STY AVG GD QUAL LOG	Single family dwelling	RES1
10	55PB	11/2 STY R A/G Q POST/BEA	Single family dwelling	RES1
10	56A	1 1/2 STY RES GOOD QUAL	Single family dwelling	RES1
10	56AB	1 1/2 STY GD Q OLD BRICK	Single family dwelling	RES1
10	56AH	1 1/2 STY RES GD QUA HIST	Single family dwelling	RES1
10	56B	1 1/2 STY RES GD QUAL 2X6	Single family dwelling	RES1
10	56C	1 1/2 STY GOOD-SUPER EE	Single family dwelling	RES1
10	56D	1 1/2 STY RES GOOD Q DOME	Single family dwelling	RES1
10	56E	1 1/2 STY RES GOOD Q LOG	Single family dwelling	RES1
10	56PB	11/2 STY R G Q POST/BEAM	Single family dwelling	RES1
10	57A	1 1/2 STY RES EXC QUAL	Single family dwelling	RES1
10	57AH	1 1/2 STY RES EXC QU HIST	Single family dwelling	RES1
10	57B	1 1/2 STY RES EX QUAL 2X6	Single family dwelling	RES1
10	57C	1 1/2 STY RES EXC-SUPR EE	Single family dwelling	RES1
10	57PB	11/2 STY R EX Q POST/BEAM	Single family dwelling	RES1
10	58A	1 1/2 STY RES ARCH DESIGN	Single family dwelling	RES1
10	58AH	1 1/2 STY RES ARCH D HIST	Single family dwelling	RES1
10	58B	1 1/2 STY RES ARC DES 2X6	Single family dwelling	RES1
10	58C	1 1/2 STY ARC DES-SUPR EE	Single family dwelling	RES1
10	58PB	11/2 STY RES AR POST/BEAM	Single family dwelling	RES1
10	60UL	1 3/4 STY LOG SHACK UNLIN	Single family dwelling	RES1
10	64A	1 3/4 STY RES AVG QUALITY	Single family dwelling	RES1
10	64AB	1 3/4 STY AVG Q OLD BRICK	Single family dwelling	RES1

10	64AH	1 3/4 STY RES AVG QU HIST	Single family dwelling	RES1
10	64B	1 3/4 STY RES AVG QUA 2X6	Single family dwelling	RES1
10	65B	1 3/4 STY RES AVG GD 2X6	Single family dwelling	RES1
10	65C	1 3/4 STY AVG GD SUPER EE	Single family dwelling	RES1
10	65PB	1 3/4 STY AVG GD POST/BEA	Single family dwelling	RES1
10	66B	1 3/4 STY RES GD QUAL 2X6	Single family dwelling	RES1
10	66C	1 3/4 STY RES GD SUPER EE	Single family dwelling	RES1
10	66PB	1 3/4 STY GOOD POST/BEAM	Single family dwelling	RES1
10	73B	2 STY RES FAIR QUAL 2X6	Single family dwelling	RES1
10	73E	2 STY RES FAIR QUAL LOG	Single family dwelling	RES1
10	74A	2 STY RES AVG QUALITY	Single family dwelling	RES1
10	74AB	2 STY AVG QUAL OLD BRICK	Single family dwelling	RES1
10	74AH	2 STY RES AVG QUAL HISTOR	Single family dwelling	RES1
10	74B	2 STY RES AVG QUAL 2X6	Single family dwelling	RES1
10	74C	2 STY AVG QUAL-SUPER EE	Single family dwelling	RES1
10	74E	2 STY RES AVG QUALITY LOG	Single family dwelling	RES1
10	74PB	2 STY RES AVG Q POST/BEAM	Single family dwelling	RES1
10	75A	2 STY RES AVG GD QUALITY	Single family dwelling	RES1
10	75AB	2 STY AVG GD Q OLD BRICK	Single family dwelling	RES1
10	75AH	2 STY RES A/G QUAL HISTOR	Single family dwelling	RES1
10	75B	2 STY RES AVG GD QUAL 2X6	Single family dwelling	RES1
10	75C	2 STY RES AVG GD-SUPER EE	Single family dwelling	RES1
10	75E	2 STY AVG GD QUALITY LOG	Single family dwelling	RES1

10	75PB	2 STY R AV/GD Q POST/BEAM	Single family dwelling	RES1
10	76A	2 STY RES GOOD QUALITY	Single family dwelling	RES1
10	76AB	2 STY GOOD QUAL OLD BRICK	Single family dwelling	RES1
10	76AH	2 STY RES GD QUAL HISTOR	Single family dwelling	RES1
10	76B	2 STY RES GD QUAL 2X6	Single family dwelling	RES1
10	76C	2 STY RES GOOD-SUPER EE	Single family dwelling	RES1
10	76E	2 STY GOOD QUALITY LOG	Single family dwelling	RES1
10	76PB	2 STY RES GD Q POST/BEAM	Single family dwelling	RES1
10	77A	2 STY RES EXC QUAL	Single family dwelling	RES1
10	77AH	2 STY RES EXC QUAL HISTOR	Single family dwelling	RES1
10	77B	2 STY RES EXC QUAL 2X6	Single family dwelling	RES1
10	77C	2 STY RES EXC-SUPER EE	Single family dwelling	RES1
10	77PB	2 STY RES EXC Q POST/BEAM	Single family dwelling	RES1
10	78A	2 STY RES ARCH DESIGN	Single family dwelling	RES1
10	78AH	2STY RES ARCH DESIGN HIST	Single family dwelling	RES1
10	78B	2 STY RES ARC DESIGN 2X6	Single family dwelling	RES1
10	78C	2 STY RES ARC DES-SUPR EE	Single family dwelling	RES1
10	78PB	2 STY RES AR Q POST/BEAM	Single family dwelling	RES1
10	93	MOBILE HOME FAIR QLTY 2X3	Mobile home	RES2
10	91A	TRAILERS 16 FEET OR LESS	Mobile home	RES2
10	91B	TRAILERS 17 FEET TO 30 FT	Mobile home	RES2
10	92A	TRAILERS 21 FEET TO 30 FT	Mobile home	RES2
10	92B	TRAILERS 22 FEET TO 34 FT	Mobile home	RES2
10	94A	MOBILE HOME AVG	Mobile home	RES2

		QLTY		
10	94B	MOBILE HOME AVG QLTY 2X6	Mobile home	RES2
10	96A	MOBILE HOME GOOD QLTY 2X4	Mobile home	RES2
10	96B	MOBILE HOME GOOD QLTY 2X6	Mobile home	RES2
10	98A	MOBILE HOME DBL WIDE 2X4	Mobile home	RES2
10	98B	MOBILE HOME DBL WIDE 2X6	Mobile home	RES2
15	33	BI LEVEL FAIR Q DUPLEX	Duplex	RES3A
15	52	1 1/2 STY DUPLEX LOW QUAL	Duplex	RES3A
15	53	1 1/2 STY DUPLEX FAIR QUA	Duplex	RES3A
15	62	1 3/4 STY DUPLEX LOW QUAL	Duplex	RES3A
15	63	1 3/4 STY DUPLEX FAIR QUA	Duplex	RES3A
15	72	2 STY DUPLEX LOW QUALITY	Duplex	RES3A
15	73	2 STY DUPLEX FAIR QUALITY	Duplex	RES3A
15	33B	BI LEV FAIR Q 2X6 DUPLEX	Duplex	RES3A
15	34A	BI LEVEL AVG Q DUPLEX	Duplex	RES3A
15	34B	B LEVEL AVG Q 2X6 DUPLEX	Duplex	RES3A
15	35A	BI LEVEL AVG GD Q DUPLEX	Duplex	RES3A
15	35B	BI LEV AVG GD Q 2X6 DUPLX	Duplex	RES3A
15	54A	1 1/2 STY DUPLEX AVG QUAL	Duplex	RES3A
15	54AB	1 1/2 STY DUPLEX OLD BRIC	Duplex	RES3A
15	54B	1 1/2 STY DUPLEX AVG 2X6	Duplex	RES3A
15	55A	1 1/2 STY DUPLEX AVG GD	Duplex	RES3A
15	55AB	1 1/2 STY DU AVG GD BRICK	Duplex	RES3A
15	55B	1 1/2 STY DUPLEX	Duplex	RES3A

		AVG GD		
15	64A	1 3/4 STY DUPLEX AVG QUAL	Duplex	RES3A
15	64AB	1 3/4 STY DUP AVG OLD BRC	Duplex	RES3A
15	64B	1 3/4 STY DUPLEX AVG 2X6	Duplex	RES3A
15	74A	2 STY DUPLEX AVG QUALITY	Duplex	RES3A
15	74AB	2 STY DUPLEX AVG OLD BRIC	Duplex	RES3A
15	74B	2 STY DUPLEX AVG QUAL 2X6	Duplex	RES3A
15	75A	2 STY DUPLEX AVG GD QUAL	Duplex	RES3A
15	75AB	2 STY DUP AVG GD OLD BRIC	Duplex	RES3A
15	75B	2 STY DUPLEX AVG GD 2X6	Duplex	RES3A
11	21	1 STY POOR Q ROW HOUSE	5-9 Units	RES3C
11	22	1 STY LOW COST ROW HOUSE	5-9 Units	RES3C
11	23	1 STY FAIR Q ROW HOUSING	5-9 Units	RES3C
11	33	BI LEVEL FAIR Q ROW HSG	5-9 Units	RES3C
11	51	1 1/2 STY POOR Q ROW HSG	5-9 Units	RES3C
11	52	1 1/2 STY LOW COST ROW HS	5-9 Units	RES3C
11	53	1 1/2 STY FAIR Q ROW HSG	5-9 Units	RES3C
11	61	1 3/4 STY POOR Q ROW HSG	5-9 Units	RES3C
11	62	1 3/4 STY LOW Q ROW HOUSE	5-9 Units	RES3C
11	63	1 3/4 STY FAIR Q ROW HSG	5-9 Units	RES3C
11	71	2 STY POOR Q ROW HOUSING	5-9 Units	RES3C
11	72	2 STY LOW Q ROW HOUSING	5-9 Units	RES3C
11	73	2 STY FAIR Q ROW HOUSING	5-9 Units	RES3C
11	04A	3 LEVEL AVG Q ROW	5-9 Units	RES3C

		HOUSING		
11	04B	3 LEVEL AVG Q 2X6 ROW HSG	5-9 Units	RES3C
11	04C	3 LEVEL AVG Q S EE RO HS	5-9 Units	RES3C
11	05A	3 LEVEL AVG GD Q ROW HSE	5-9 Units	RES3C
11	05B	3 LEV AVG GD Q 2X6 ROW HS	5-9 Units	RES3C
11	05C	3 LEV AVG GD Q S EE RO HS	5-9 Units	RES3C
11	06A	3 LEV GOOD Q ROW HOUSE	5-9 Units	RES3C
11	06B	3 LEV GD Q 2X6 ROW HOUSE	5-9 Units	RES3C
11	06C	3 LEV GD Q S EE ROW HSG	5-9 Units	RES3C
11	23B	1 STY FAIR Q 2X6 ROW HSG	5-9 Units	RES3C
11	24A	1 STY AVG Q ROW HOUSING	5-9 Units	RES3C
11	24AB	1 STY AVG Q O BRI ROW HSG	5-9 Units	RES3C
11	24B	1 STY AVG Q 2X6 ROW HSG	5-9 Units	RES3C
11	24B2	1STY/2STY AVG Q 2X6 RH	5-9 Units	RES3C
11	24C	1 STY AVG Q S EE ROW HSG	5-9 Units	RES3C
11	25A	1 STY AVG GD Q ROW HOUSE	5-9 Units	RES3C
11	25AB	1 STY AVG GD Q A B RO HSG	5-9 Units	RES3C
11	25B	1 STY AVG GD Q 2X6 ROW HS	5-9 Units	RES3C
11	25C	1 STY AVG GD Q S EE RO HS	5-9 Units	RES3C
11	26A	1 STY GOOD Q ROW HOUSING	5-9 Units	RES3C
11	26AB	1 STY GOOD Q OLD BR RO HS	5-9 Units	RES3C
11	26B	1 STY GD Q 2X6 ROW HOUSE	5-9 Units	RES3C
11	26C	1 STY GD Q S EE ROW HOUSE	5-9 Units	RES3C
11	27A	1 STY EXC Q ROW	5-9 Units	RES3C

		HOUSING		
11	27B	1 STY EXC Q 2X6 ROW HOUSE	5-9 Units	RES3C
11	27C	1 STY EXC Q S EE ROW HSG	5-9 Units	RES3C
11	28A	1 STY ARC DES ROW HOUSING	5-9 Units	RES3C
11	28B	1 STY ARC DES ROW HSE 2X6	5-9 Units	RES3C
11	28C	1 STY ARC DES S EE ROW HS	5-9 Units	RES3C
11	33B	BI LEVEL FAIR Q 2X6 RO HS	5-9 Units	RES3C
11	34A	BI LEVEL AVG Q ROW HSG	5-9 Units	RES3C
11	34B	BI LEVEL AVG Q 2X6 ROW HS	5-9 Units	RES3C
11	34C	BI LEVEL AVG Q S EE RO HS	5-9 Units	RES3C
11	35A	BI LEV AVG G D Q ROW HSG	5-9 Units	RES3C
11	35B	BI LEV AVG GD Q 2X6 RO HS	5-9 Units	RES3C
11	35C	BI LEV AVG GD Q S EE R HS	5-9 Units	RES3C
11	36A	BI LEV GOOD Q ROW HOUSING	5-9 Units	RES3C
11	36B	BI LEV GD Q 2X6 ROW HOUSE	5-9 Units	RES3C
11	36C	BI LEV GD Q S EE ROW HSG	5-9 Units	RES3C
11	44A	4 LEVEL AVG Q ROW HOUSING	5-9 Units	RES3C
11	44B	4 LEVEL AVG Q 2X6 ROW HSG	5-9 Units	RES3C
11	44C	4 LEVEL AVG Q S EE RO HSG	5-9 Units	RES3C
11	45A	4 LEVEL AVG GD Q ROW HSG	5-9 Units	RES3C
11	45B	4 LEV AVG GD Q 2X6 ROW HS	5-9 Units	RES3C
11	45C	4 LEV AVG GD Q S EE RO HS	5-9 Units	RES3C
11	46A	4 LEV GOOD Q ROW HOUSING	5-9 Units	RES3C
11	46B	4 LEV GD Q 2X6 ROW	5-9 Units	RES3C

		HOUSNG		
11	46C	4 LEV GD Q S EE ROW HOUSE	5-9 Units	RES3C
11	47A	4 LEV EXC Q ROW HOUSING	5-9 Units	RES3C
11	47B	4 LEV EXC Q 2X6 ROW HOUSE	5-9 Units	RES3C
11	47C	4 LEV EXC Q S EE ROW HSG	5-9 Units	RES3C
11	54A	1 1/2 STY AVG Q ROW HSG	5-9 Units	RES3C
11	54AB	1 1/2 STY AVGQ A B ROW HS	5-9 Units	RES3C
11	54B	1 1/2 STY AVG Q 2X6 RO HS	5-9 Units	RES3C
11	54C	1 1/2 STY AVG Q S EE R HS	5-9 Units	RES3C
11	55A	1 1/2 STY AVG GD Q ROW HS	5-9 Units	RES3C
11	55AB	1 1/2 STY AVG GD Q A B RH	5-9 Units	RES3C
11	55B	1 1/2 STY AVG GD 2X6 RO H	5-9 Units	RES3C
11	55C	1 1/2 STY AVG GD S EE R H	5-9 Units	RES3C
11	56A	1 1/2 STY GOOD Q ROW HSG	5-9 Units	RES3C
11	56AB	1 1/2 STY GD Q O BR RO HS	5-9 Units	RES3C
11	56B	1 1/2 STY GD Q 2X6 ROW HS	5-9 Units	RES3C
11	56C	1 1/2 STY GD Q S EE RO HS	5-9 Units	RES3C
11	57A	1 1/2 STY EXC Q ROW HOUSE	5-9 Units	RES3C
11	57B	1 1/2 STY EXC Q 2X6 RO HS	5-9 Units	RES3C
11	57C	1 1/2 STY EXC Q S EE R HS	5-9 Units	RES3C
11	58A	1 1/2 STY AD Q ROW HOUSE	5-9 Units	RES3C
11	58B	1 1/2 STY AD Q 2X6 RO HSG	5-9 Units	RES3C
11	58C	1 1/2 AD Q S EE ROW HOUSE	5-9 Units	RES3C
11	64A	1 3/4 STY AVG Q ROW	5-9 Units	RES3C

		HOUSE		
11	64AB	1 3/4 STY AVQ A B ROW HSH	5-9 Units	RES3C
11	64B	1 3/4 STY AVG Q 2X6 RO HS	5-9 Units	RES3C
11	65B	1 3/4 STY AV GD 2X6 RO HS	5-9 Units	RES3C
11	65C	1 3/4 STY AVG GD S EE R H	5-9 Units	RES3C
11	66B	1 3/4 STY RES GD Q RO 2X6	5-9 Units	RES3C
11	66C	1 3/4 STY GD SUPR EE R HS	5-9 Units	RES3C
11	73B	2 STY FAIR Q 2X6 ROW HSG	5-9 Units	RES3C
11	74A	2 STY AVG Q ROW HOUSING	5-9 Units	RES3C
11	74AB	2 STY AVG Q ROW HOUSING	5-9 Units	RES3C
11	74B	2 STY AVG Q 2X6 ROW HSG	5-9 Units	RES3C
11	74C	2 STY AVG Q S EE ROW HSG	5-9 Units	RES3C
11	75A	2 STY AVG GD Q ROW HOUSE	5-9 Units	RES3C
11	75AB	2 STY AVG GD Q O BR RO HS	5-9 Units	RES3C
11	75B	2 STY AVG GD Q 2X6 ROW HS	5-9 Units	RES3C
11	75C	2 STY AVG GD Q S EE RO HS	5-9 Units	RES3C
11	76A	2 STY GOOD Q ROW HOUSE	5-9 Units	RES3C
11	76AB	2 STY GOOD Q OLD BR RO HS	5-9 Units	RES3C
11	76B	2 STY GD Q 2X6 ROW HOUSE	5-9 Units	RES3C
11	76C	2 STY GD Q S EE ROW HOUSE	5-9 Units	RES3C
11	77A	2 STY EXC Q ROW HOUSING	5-9 Units	RES3C
11	77B	2 STY EXC Q 2X6 ROW HOUSE	5-9 Units	RES3C
11	77C	2 STY EXC Q S EE ROW HSG	5-9 Units	RES3C
11	78A	2 STY AD Q ROW	5-9 Units	RES3C

		HOUSE		
11	78B	2 STY AD Q 2X6 ROW HOUSE	5-9 Units	RES3C
11	78C	2 STY AD Q S EE ROW HOUSE	5-9 Units	RES3C
11	A4A	ADD W/O BSMT ROW HOUSE	5-9 Units	RES3C
11	A4B	ADD W/O BSMT ROW HOUSE	5-9 Units	RES3C
11	A4C	ADD W/O BSMT ROW HOUSE	5-9 Units	RES3C
11	A5A	ADD W/O BSMT ROW HOUSE	5-9 Units	RES3C
11	A5B	ADD W/O BSMT ROW HOUSE	5-9 Units	RES3C
11	A5C	ADD W/O BSMT ROW HOUSE	5-9 Units	RES3C
11	A6A	ADD W/O BSMT ROW HOUSE	5-9 Units	RES3C
11	A6B	ADD W/O BSMT ROW HOUSE	5-9 Units	RES3C
11	A6C	ADD W/O BSMT ROW HOUSE	5-9 Units	RES3C
11	A7A	ADD W/O BSMT ROW HOUSE	5-9 Units	RES3C
11	A7B	ADD W/O BSMT ROW HOUSE	5-9 Units	RES3C
11	A8A	ADD W/O BSMT ROW HOUSE	5-9 Units	RES3C
11	A8B	ADD W/O BSMT ROW HOUSE	5-9 Units	RES3C
11	AB4A	ADD WITH BSMT ROW HOUSE	5-9 Units	RES3C
11	AB4B	ADD WITH BSMT ROW HOUSE	5-9 Units	RES3C
11	AB4C	ADD WITH BSMT ROW HOUSE	5-9 Units	RES3C
11	AB5A	ADD WITH BSMT ROW HOUSE	5-9 Units	RES3C
11	AB5B	ADD WITH BSMT ROW HOUSE	5-9 Units	RES3C
11	AB5C	ADD WITH BSMT ROW HOUSE	5-9 Units	RES3C
11	AB6A	ADD WITH BSMT ROW HOUSE	5-9 Units	RES3C
11	AB6B	ADD WITH BSMT	5-9 Units	RES3C

		ROW HOUSE		
11	AB6C	ADD WITH BSMT ROW HOUSE	5-9 Units	RES3C
11	AB7A	ADD WITH BSMT ROW HOUSE	5-9 Units	RES3C
11	AB7B	ADD WITH BSMT ROW HOUSE	5-9 Units	RES3C
11	FLL	LEAN-TO LINED FAIR-ROW HS	5-9 Units	RES3C
11	FUL	LEAN-TO UNLINED FAIR-ROW	5-9 Units	RES3C
11	GDAG	GAR GD DOUBLE ATT ROW HSE	5-9 Units	RES3C
11	GSAG	GAR GD SINGLE ATT ROW HSE	5-9 Units	RES3C
11	LCLL	LEAN-TO LINED LOW-ROW HSE	5-9 Units	RES3C
11	LCUL	LEAN-TO UNLINED LOW-ROW	5-9 Units	RES3C
11	PLL	LEAN-TO LINED POOR-ROW HS	5-9 Units	RES3C
11	PUL	LEAN-TO UNLINED POOR-ROW	5-9 Units	RES3C
41	00	UNIQUE FARM STRUCTURE	Agriculture	AGR1
46	10	STEEL HOPPRD FEEDMILL TNK	Agriculture	AGR1
46	11	CONCRETE GRAIN SILO	Agriculture	AGR1
46	12	STEEL ELEVATOR	Agriculture	AGR1
46	16	MODERN FEED OR SEED MILL	Agriculture	AGR1
46	17	OLDER STYLE FEED/SEED MLL	Agriculture	AGR1
46	01	FRAME ELEVATOR	Agriculture	AGR1
46	02	CONCRETE ELEVATOR	Agriculture	AGR1
46	02C	CONC INLAND GRAIN TERMINL	Agriculture	AGR1
46	03	HOPPERED ELEVATOR ANNEX	Agriculture	AGR1
46	04	FLT BTTM BIN ELEVTR ANNEX	Agriculture	AGR1
46	05	PERM ELEVTR ANNEX-BALLOON	Agriculture	AGR1
46	06	TEMP ELEVTR	Agriculture	AGR1

		ANNEX-BALLOON		
46	07	STEEL GRAIN BINS-WIDE CRG	Agriculture	AGR1
46	08	STEEL HOPPERED TANK	Agriculture	AGR1
46	12S	STEEL INLAND GRAIN TERMNL	Agriculture	AGR1
24	01CG	MULTI STY LC FRM CNV/GAS	Retail Trade	COM1
24	01G	MULTI STY LC FRM GROCERY	Retail Trade	COM1
24	24CG	MULTI STY AVG FRM CNV/GAS	Retail Trade	COM1
24	24G	MULTI STY AVG FRM GROCERY	Retail Trade	COM1
24	27CG	MULTI STY BRICK CNV/GAS	Retail Trade	COM1
24	27G	MULTI STY BRICK GROCERY	Retail Trade	COM1
24	28CG	MULTI STY C/BLK CNV/GAS	Retail Trade	COM1
24	28G	MULTI STY C/BLK GROCERY	Retail Trade	COM1
30	10	MLCC STORE	Retail Trade	COM1
30	12	MODERN CONVENIENCE STORE	Retail Trade	COM1
30	13	STRIP MALL	Retail Trade	COM1
30	14	REGIONAL MALL	Retail Trade	COM1
30	16	1 STY SUPERMARKET	Retail Trade	COM1
30	21	GOOD RETAIL	Retail Trade	COM1
30	01CG	1 STY LC FRM CONV/GAS	Retail Trade	COM1
30	01G	1 STY LC FRM GROCERY	Retail Trade	COM1
30	04CG	1 STY AVG FRM CONV/GAS	Retail Trade	COM1
30	04G	1 STY AVG FRM GROCERY	Retail Trade	COM1
30	07CG	1 STY BRICK CONV/GAS	Retail Trade	COM1
30	07G	1 STY BRICK GROCERY STORE	Retail Trade	COM1
30	08CG	1 STY C/BLK CONV/GAS	Retail Trade	COM1
30	08G	1 STY C/BLK	Retail Trade	COM1

30	14A	GROCERY NEIGHBOURHOOD MALL	Retail Trade	COM1
39	10	DEALERSHIP	Retail Trade	COM1
50	32	LIVESTOCK AUCTION MART	Retail Trade	COM1
50	02	GREENHOUSE	Retail Trade	COM1
50	03CG	LOW C WHS STYL CNVSTR/GAS	Retail Trade	COM1
50	03G	LOW CST WHSE STYL GROCERY	Retail Trade	COM1
50	04CG	FRAME WHS STYL CNVSTR/GAS	Retail Trade	COM1
50	04G	FRAME WHS STYLE GROCERY	Retail Trade	COM1
50	07CG	CNCBLK WHSSTYL CNVSTR/GAS	Retail Trade	COM1
50	07G	CONC BLK WHS STYL GROCERY	Retail Trade	COM1
50	09CG	STEEL WHS STYL CNVSTR/GAS	Retail Trade	COM1
50	09G	STEEL WHSE STYLE GROCERY	Retail Trade	COM1
50	10CG	LT STEL WHSTYL CNVSTR/GAS	Retail Trade	COM1
50	10G	LT STEEL WHS STYL GROCERY	Retail Trade	COM1
19	00	APARTMENT GARAGES	Parking	COM10
50	33	AIRCRAFT HANGAR	Parking	COM10
50	10	LIGHT STEEL WAREHOUSE	Wholesale Trade	COM2
50	20	POTATO WAREHOUSE	Wholesale Trade	COM2
50	22	OLD STYLE BGD FERT WHSE	Wholesale Trade	COM2
50	23	AVG BULK FERTILIZER WHSE	Wholesale Trade	COM2
50	24	LOW COST BULK FERT WHSE	Wholesale Trade	COM2
50	25	ARCH RIB BULK FERT WHSE	Wholesale Trade	COM2
50	28	COMINCO FERT WHSE	Wholesale Trade	COM2
50	29	STEEL QUONSET WAREHOUSE	Wholesale Trade	COM2

50	30	ARCH RIB WAREHOUSE	Wholesale Trade	COM2
50	03	LOW COST FRAME WAREHOUSE	Wholesale Trade	COM2
50	04	AVERAGE FRAME WAREHOUSE	Wholesale Trade	COM2
50	07	CONCRETE BLOCK WAREHOUSE	Wholesale Trade	COM2
50	09	HEAVY STEEL WAREHOUSE	Wholesale Trade	COM2
50	21A	MDRN BULK FERT WHSE WD FR	Wholesale Trade	COM2
50	21B	MODERN CHEMICAL WAREHOUSE	Wholesale Trade	COM2
30	11	MODERN FUNERAL FACILITY	Personal and Repair Services	COM3
30	11A	FUNERAL HOME	Personal and Repair Services	COM3
39	05	HIGHWAY SERVICE CENTRE	Personal and Repair Services	COM3
39	06	MODERN SERVICE CENTRE	Personal and Repair Services	COM3
39	07	AVERAGE SERVICE STATION	Personal and Repair Services	COM3
39	08	AUTOMATIC CAR WASH	Personal and Repair Services	COM3
39	09	SELF SERVICE CAR WASH	Personal and Repair Services	COM3
50	31	POLE TYPE MACHINE SHOP	Personal and Repair Services	COM3
94	00	FAMILY MAUSOLEUM	Personal and Repair Services	COM3
24	24	MULTI STY AVG FRM STR/OFF	Business/Professional/Tec hnical Services	COM4
24	27	MULTI STY BRICK STORE/OFF	Business/Professional/Tec hnical Services	COM4
24	28	MULTI STY CNC BLK STR/OFF	Business/Professional/Tec hnical Services	COM4
24	01	MULTI STY LC FRM STR/OFF	Business/Professional/Tec hnical Services	COM4
30	01	1 STY LC FRM STORE/OFFICE	Business/Professional/Tec hnical Services	COM4
30	03	BULK OIL/FERTILIZR OFFICE	Business/Professional/Tec hnical Services	COM4
30	04	1 STY AVG FRM STORE/OFFIC	Business/Professional/Tec hnical Services	COM4

30	05	PREFAB MODULAR OFFICE GD	Business/Professional/Technical Services	COM4
30	07	1 STY BRICK STORE/OFFICE	Business/Professional/Technical Services	COM4
30	08	1 STY C/BLK STORE/OFFICE	Business/Professional/Technical Services	COM4
43	07A	1 STY AVERAGE OFFICE	Business/Professional/Technical Services	COM4
43	08A	MULTI STY AVERAGE OFFICE	Business/Professional/Technical Services	COM4
76	01	COMMUNICATION OFFICE	Business/Professional/Technical Services	COM4
76	02	PREFAB COMMUNCATN OFFICE MDRN	Business/Professional/Technical Services	COM4
76	03	COMMUNICATION OFFICE	Business/Professional/Technical Services	COM4
76	09	ECOCENTRE BUILDING	Business/Professional/Technical Services	COM4
77	04	HYDRO DISTRICT OFFICE	Business/Professional/Technical Services	COM4
43	07	1 STY GOOD OFFICE/BANK	Depository Institutions	COM5
43	08	MULTISTY GOOD OFFICE/BANK	Depository Institutions	COM5
96	10	HOSPITAL	Hospital	COM6
57	06	VETERINARY CLINIC	Medical Office/Clinic	COM7
24	01R	MULTI STY LC FRM RESTAURN	Entertainment & Recreation	COM8
24	24R	MULTI STY AVG FRM RESTAUR	Entertainment & Recreation	COM8
24	27R	MULTI STY BRICK RESTAURAN	Entertainment & Recreation	COM8
24	28R	MULTI STY C/BLK RESTAURAN	Entertainment & Recreation	COM8
30	19	FAMILY RESTAURANT	Entertainment & Recreation	COM8
30	20	FAST FOOD RESTAURANT	Entertainment & Recreation	COM8
30	01R	1 STY LC FRM RESTAURANT	Entertainment & Recreation	COM8
30	04R	1 STY AVG FRM RESTAURANT	Entertainment & Recreation	COM8
30	07R	1 STY BRICK RESTAURANT	Entertainment & Recreation	COM8

30	08R	1 STY C/BLK RESTAURNT	Entertainment & Recreation	COM8
45	01	RESTAURANT/LOUN GE	Entertainment & Recreation	COM8
48	04	OLD STYLE ARENA	Entertainment & Recreation	COM8
48	05	MODERN ARENA	Entertainment & Recreation	COM8
50	03R	LOW CST WHSE STYL RESTRNT	Entertainment & Recreation	COM8
50	04R	FRAME WHS STYL RESTAURANT	Entertainment & Recreation	COM8
50	07R	CONC BLK WHS STYL RESTRNT	Entertainment & Recreation	COM8
50	09R	STEEL WHS STYL RESTAURANT	Entertainment & Recreation	COM8
50	10R	LT STEEL WHS STYL RESTRNT	Entertainment & Recreation	COM8
70	70	GOLF COURSE	Entertainment & Recreation	COM8
90	03	LEGION CLUB ROOM	Entertainment & Recreation	COM8
90	04H	BASIC COMMUNITY HALL	Entertainment & Recreation	COM8
90	04M	MULTIPURPSE COMMUNTY HALL	Entertainment & Recreation	COM8
90	04S	MDRN REC FACILTY/MULTIPLX	Entertainment & Recreation	COM8
96	14	MUSEUM	Entertainment & Recreation	COM8
49	01	DRIVE-IN MOVIE THEATRE	Theatres	COM9
49	02	MOVIE THEATRE	Theatres	COM9
96	13	LIBRARY	Schools/Libraries	EDU1
96	07	SCHOOL	Schools/Libraries	EDU1
96	09	POST SCNDRY EDUC FACILITY	Colleges/Universities	EDU2
43	05	COURTHOUSE	General Services	GOV1
70	04	LOCAL POST OFFICE	General Services	GOV1
70	05	REGIONAL POST OFFICE	General Services	GOV1
70	07	CUSTOMS OFFICE OLD STYLE	General Services	GOV1
70	08	CUSTOMS OFFICE MDRN STYLE	General Services	GOV1
70	01	LOCAL RCMP	Emergency Response	GOV2

		DTCHMT OLDER		
70	02	LOCAL RCMP DTCHMT MODERN	Emergency Response	GOV2
70	03	REGIONAL RCMP DETACHMENT	Emergency Response	GOV2
50	11	BULK OIL WAREHOUSE	Heavy	IND1
50	12	BULK PETROLEUM FACILITIES	Heavy	IND1
50	13	REFINERY TANKAGE	Heavy	IND1
90	04	CHURCH	Church/Membership Organizations	REL1
10	99	MOBILE HOME PARK	Mobile Home	RES2
19	13	1 STY APARTMENT	20-49 Units	RES3E
19	14	BI-LEVEL APARTMENT	20-49 Units	RES3E
19	24	2-3 STY FRAME APT NO BSMT	20-49 Units	RES3E
19	25	2-3 STY FRAME APT W BSMT	20-49 Units	RES3E
19	27	2-3 STY MASONRY APARTMENT	20-49 Units	RES3E
19	33	LIFE LEASE APT	20-49 Units	RES3E
19	36	4-6 STOREY APARTMENT	20-49 Units	RES3E
19	37	7-10 STOREY APARTMENT	20-49 Units	RES3E
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44	21	MOTEL - AVG - TYPE 1	Temporary Lodging	RES4
44	22	MOTEL - AVG - TYPE 2	Temporary Lodging	RES4
44	23	MOTEL - AVG - TYPE 3	Temporary Lodging	RES4
44	31	MOTEL - GOOD - TYPE 1	Temporary Lodging	RES4
44	32	MOTEL - GOOD - TYPE 2	Temporary Lodging	RES4
44	33	MOTEL - GOOD - TYPE 3	Temporary Lodging	RES4
44	01	MOTEL - FAIR - TYPE 1	Temporary Lodging	RES4
44	02	MOTEL - FAIR - TYPE 2	Temporary Lodging	RES4
44	03	MOTEL - FAIR - TYPE	Temporary Lodging	RES4

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44	COTT	MOTEL - MULTI-STRUCTURE	Temporary Lodging	RES4
45	22	HOTEL - AVG	Temporary Lodging	RES4
45	32	HOTEL - GOOD	Temporary Lodging	RES4
45	02	HOTEL - FAIR	Temporary Lodging	RES4
70	75	COMMERCIAL CAMPGROUND	Temporary Lodging	RES4
19	40	DORMITORY	Institutional Dormitory	RES5
43	10	JAIL	Institutional Dormitory	RES5
19	28	1 STOREY EPH	Nursing Home	RES6
19	29	2-3 STOREY EPH WITH BSMT	Nursing Home	RES6
19	30	2-3 STOREY EPH NO BSMT	Nursing Home	RES6
19	31	PERSONAL CARE HOME	Nursing Home	RES6
19	32	HIGHRISE EPH	Nursing Home	RES6
41	01	OLD STYLE 1 ST BARN	Agriculture	AGR1
41	02	OLD STYLE 1 ST BARN -LOFT	Agriculture	AGR1
41	03	BARN W/LOFT,GAMBRL/GOTHIC	Agriculture	AGR1
41	04	ARCH RIB BARNS	Agriculture	AGR1
41	05	BARN LEAN-TO	Agriculture	AGR1
41	06	1 ST MILKHOUSE ATT. BARN	Agriculture	AGR1
41	07	MILKING PARLOUR	Agriculture	AGR1
41	08	BARN ADD. - GRAIN STORAGE	Agriculture	AGR1
41	09	1 STOREY BARN ADDITION	Agriculture	AGR1
41	10A	1 STOREY POULTRY BARN	Agriculture	AGR1
41	10A1	1 STY MODERN POULTRY BARN	Agriculture	AGR1
41	10A3	1 STY MOD PLTRY BARN PCSP	Agriculture	AGR1
41	10B	1 STOREY HOG BARN	Agriculture	AGR1
41	10B1	1 STOREY MODERN HOG BARN	Agriculture	AGR1
41	10B2	1 STY MODERN HOGBARN PCMC	Agriculture	AGR1
41	10B3	1 STY MODERN	Agriculture	AGR1

		HOGBARN PCSP		
41	10C	1 STOREY DAIRY BARN	Agriculture	AGR1
41	10C1	1 STY MODERN DAIRY BARN	Agriculture	AGR1
41	10C3	1 STY MOD DAIRY BARN PCSP	Agriculture	AGR1
41	10D	1 STOREY HORSE BARN	Agriculture	AGR1
41	10D1	1 STY MODERN HORSE BARN	Agriculture	AGR1
41	12A	2 STOREY POULTRY BARN	Agriculture	AGR1
41	13	STOCK CORRALS (STEEL)	Agriculture	AGR1
41	14	STOCK CORRALS (WOOD)	Agriculture	AGR1
41	20A	FRAME GRANARY	Agriculture	AGR1
41	20B	FRAME STORAGE OR GRNARY	Agriculture	AGR1
41	21AD	PLYWOOD GRAIN BIN-D. SKIN	Agriculture	AGR1
41	21AS	PLYWOOD GRAIN BIN-S. SKIN	Agriculture	AGR1
41	21B	GRAIN BIN-FL BOT,STL	Agriculture	AGR1
41	22	GALV STEEL BULK FEED TANK	Agriculture	AGR1
41	23A	GRAIN/FERT BIN-HOP BOT,ST	Agriculture	AGR1
41	23B	WELD STEEL BULK FEED TANK	Agriculture	AGR1
41	24	ARCH RIB MACHINE SHOP	Agriculture	AGR1
41	26	LOW QUALITY MACH SHED	Agriculture	AGR1
41	27	POLE OR POST MACH STG	Agriculture	AGR1
41	27C	POLE OR POST DAIRY BARN	Agriculture	AGR1
41	27D	POLE OR POST HORSE BARN	Agriculture	AGR1
41	28	1 STOREY FRAME WORKSHOP	Agriculture	AGR1
41	30	HAY SHELTER	Agriculture	AGR1
41	35	LOOSE HOUSING	Agriculture	AGR1

41	40A	CONCRETE STAVE SILO	Agriculture	AGR1
41	40B	STEEL TANK FARM SILO	Agriculture	AGR1
41	42	TRENCH SILO	Agriculture	AGR1
41	43A	SLURRYSTORE SYSTEM	Agriculture	AGR1
41	43B	CONCRETE SLURRYSTORE SYS.	Agriculture	AGR1
41	43C	CIRCULAR CONC.SLURRY SYS.	Agriculture	AGR1
41	43D	EARTHEN SLURRYSTORE SYS.	Agriculture	AGR1
41	43E	GALVANIZED STEEL POLY FLR	Agriculture	AGR1
41	44A	STEEL QUONSET MACH. SHED	Agriculture	AGR1
41	44B	STL MACH SHED-STRT WALL	Agriculture	AGR1
41	44C	STL MACH SHED-SLANT WALL	Agriculture	AGR1
41	44D	POTATO WHSE-PRECAST CONC	Agriculture	AGR1
41	44E	POTATO WHSE-STEEL QUONSET	Agriculture	AGR1
41	44F	POTATO WHSE-STEEL OR WOOD	Agriculture	AGR1
41	45A	GLASS GREENHOUSE	Agriculture	AGR1
41	45B	POLYETHYLENE GREENHOUSE	Agriculture	AGR1

Appendix II. HAZUS Global Summary Reports

Hazus-MH: Flood Event Report

Region Name: SA100d

Flood Scenario: StAndrews100d

Print Date: Friday, July 29, 2016

Disclaimer:

Totals only reflect data for those census tracts/blocks included in the user's study region.

The estimates of social and economic impacts contained in this report were produced using Hazus loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and the actual social and economic losses following a specific Flood. These results can be improved by using enhanced inventory data and flood hazard information.

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General Description of the Region

Hazus is a regional multi-hazard loss estimation model that was developed by the Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS). The primary purpose of Hazus is to provide a methodology and software application to develop multi-hazard losses at a regional scale. These loss estimates would be used primarily by local, Province/Territory and regional officials to plan and stimulate efforts to reduce risks from multi-hazards and to prepare for emergency response and recovery.

The flood loss estimates provided in this report were based on a region that included 1 Census Division(s)

- Manitoba

Note:
Appendix A contains a complete listing of the Census Divisions contained in the region.

The geographical size of the region is 7 square miles and contains 46 Census Dissemination Blocks. The region contains over 1 thousand households and has a total population of 2,672 people (2011 Census Canada data). The distribution of population by Province/Territory and Census Division for the study region is provided in Appendix B.

There are an estimated 899 buildings in the region with a total building replacement value (excluding contents) of 164 million dollars. Approximately 96.8% of the buildings (and 92.1% of the building value) are associated with residential housing.

Building Inventory

General Building Stock

Hazus estimates that there are 899 buildings in the region which have an aggregate total replacement value of 164 million dollars. Table 1 and Table 2 present the relative distribution of the exposure values with respect to the general occupancies by Study Region and Scenario (the area affected by the flood event) respectively. Appendix B provides a general distribution of the building value by Province/Territory and Census Division.

Table 1
Building Exposure by Occupancy Type for the Study Region

Occupancy	Exposure ($1000)	Percent of Total
Residential	151,233	92.1%
Commercial	11,252	6.9%
Industrial	1,530	0.9%
Agricultural	0	0.0%
Religion	139	0.1%
Government	0	0.0%
Education	0	0.0%
Total	**164,154**	**100.00%**

Table 2
Building Exposure by Occupancy Type for the Scenario

Occupancy	Exposure ($1000)	Percent of Total
Residential	54,629	86.3%
Commercial	7,769	12.3%
Industrial	770	1.2%
Agricultural	0	0.0%
Religion	139	0.2%
Government	0	0.0%
Education	0	0.0%
Total	**63,307**	**100.00%**

Essential Facility Inventory

For essential facilities, there are no hospitals in the region with a total bed capacity of no beds. There are no schools, no fire stations, no police stations and no emergency operation centers.

Flood Scenario Parameters

Hazus used the following set of information to define the flood parameters for the flood loss estimate provided in this report.

Study Region Name:	SA100d
Scenario Name:	StAndrews100d
Return Period Analyzed:	100
Analysis Options Analyzed:	No What-Ifs

Building Damage

General Building Stock Damage

Hazus estimates that about 15 buildings will be at least moderately damaged. This is over 4% of the total number of buildings in the scenario. There are an estimated 3 buildings that will be completely destroyed. The definition of the 'damage states' is provided in Chapter 5 of the US Hazus-MH Flood Model Technical Manual. Table 3 below summarizes the expected damage by general occupancy for the buildings in the region. Table 4 summarizes the expected damage by general building type.

Table 3: Expected Building Damage by Occupancy

	1-10		11-20		21-30		31-40		41-50		>50	
Occupancy	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Agriculture	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Commercial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Education	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Government	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Industrial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Religion	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Residential	0	0.00	0	0.00	1	6.67	5	33.33	6	40.00	3	20.00
Total	**0**		**0**		**1**		**5**		**6**		**3**	

Table 4: Expected Building Damage by Building Type

Building Type	1-10		11-20		21-30		31-40		41-50		>50	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Concrete	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
ManufHousing	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Masonry	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Steel	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Wood	0	0.00	0	0.00	1	6.67	5	33.33	6	40.00	3	20.00

Special Notice Regarding Building Count:

Unlike the earthquake and hurricane models, the flood model performs its analysis at the census block level. This means that the analysis starts with a small number of buildings within each census block and applies a series of distributions necessary for analyzing the potential damage. The application of these distributions and the small number of buildings make the flood model more sensitive to rounding errors that introduces uncertainty into the building count results. Please use these results with suitable caution.

Essential Facility Damage

Before the flood analyzed in this scenario, the region had 0 hospital beds available for use. On the day of the scenario flood event, the model estimates that 0 hospital beds are available in the region.

Table 5: Expected Damage to Essential Facilities

		# Facilities		
Classification	Total	At Least Moderate	At Least Substantial	Loss of Use
Fire Stations	0	0	0	0
Hospitals	0	0	0	0
Police Stations	0	0	0	0
Schools	0	0	0	0

If this report displays all zeros or is blank, two possibilities can explain this.

(1) None of your facilities were flooded. This can be checked by mapping the inventory data on the depth grid.

(2) The analysis was not run. This can be tested by checking the run box on the Analysis Menu and seeing if a message box asks you to replace the existing results.

Induced Flood Damage

Debris Generation

Hazus estimates the amount of debris that will be generated by the flood. The model breaks debris into three general categories: 1) Finishes (dry wall, insulation, etc.), 2) Structural (wood, brick, etc.) and 3) Foundations (concrete slab, concrete block, rebar, etc.). This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 467 tons of debris will be generated. Of the total amount, Finishes comprises 58% of the total, Structure comprises 24% of the total. If the debris tonnage is converted into an estimated number of truckloads, it will require 19 truckloads (@25 tons/truck) to remove the debris generated by the flood.

Social Impact

Shelter Requirements

Hazus estimates the number of households that are expected to be displaced from their homes due to the flood and the associated potential evacuation. Hazus also estimates those displaced people that will require accommodations in temporary public shelters. The model estimates 45 households will be displaced due to the flood. Displacement includes households evacuated from within or very near to the inundated area. Of these, 97 people (out of a total population of 2,672) will seek temporary shelter in public shelters.

Economic Loss

The total economic loss estimated for the flood is 3.40 million dollars, which represents 5.36 % of the total replacement value of the scenario buildings.

Building-Related Losses

The building-related losses are broken into two categories: direct building losses and business interruption losses. The direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the flood. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the flood.

The total building-related losses were 3.39 million dollars. 0% of the estimated losses were related to the business interruption of the region. The residential occupancies made up 87.60% of the total loss. Table 6 below provides a summary of the losses associated with the building damage.

Table 6: Building-Related Economic Loss Estimates

(Millions of dollars)

Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	1.96	0.05	0.05	0.00	2.07
	Content	1.01	0.15	0.13	0.00	1.29
	Inventory	0.00	0.00	0.03	0.00	0.03
	Subtotal	**2.97**	**0.20**	**0.22**	**0.00**	**3.39**
Business Interruption						
	Income	0.00	0.00	0.00	0.00	0.00
	Relocation	0.01	0.00	0.00	0.00	0.01
	Rental Income	0.00	0.00	0.00	0.00	0.00
	Wage	0.00	0.00	0.00	0.00	0.00
	Subtotal	**0.01**	**0.00**	**0.00**	**0.00**	**0.01**
ALL	**Total**	**2.97**	**0.20**	**0.22**	**0.00**	**3.40**

Appendix A: Census Division Listing for the Region

Manitoba

- Division No. 13

Appendix B: Regional Population and Building Value Data

	Population	Building Value (thousands of dollars)		
		Residential	Non-Residential	Total
Manitoba				
Division No. 13	2,672	151,233	12,921	164,154
Total	**2,672**	**151,233**	**12,921**	**164,154**
Total Study Region	**2,672**	**151,233**	**12,921**	**164,154**

Hazus-MH: Flood Event Report

Region Name: SA100m

Flood Scenario: StAndrew100m

Print Date: Saturday, July 30, 2016

Disclaimer:

Totals only reflect data for those census tracts/blocks included in the user's study region.

The estimates of social and economic impacts contained in this report were produced using Hazus loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and the actual social and economic losses following a specific Flood. These results can be improved by using enhanced inventory data and flood hazard information.

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General Description of the Region

Hazus is a regional multi-hazard loss estimation model that was developed by the Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS). The primary purpose of Hazus is to provide a methodology and software application to develop multi-hazard losses at a regional scale. These loss estimates would be used primarily by local, Province/Territory and regional officials to plan and stimulate efforts to reduce risks from multi-hazards and to prepare for emergency response and recovery.

The flood loss estimates provided in this report were based on a region that included 1 Census Division(s)

- Manitoba

Note:
Appendix A contains a complete listing of the Census Divisions contained in the region.

The geographical size of the region is 7 square miles and contains 46 Census Dissemination Blocks. The region contains over 1 thousand households and has a total population of 2,672 people (2011 Census Canada data). The distribution of population by Province/Territory and Census Division for the study region is provided in Appendix B.

There are an estimated 899 buildings in the region with a total building replacement value (excluding contents) of 164 million dollars. Approximately 96.8% of the buildings (and 92.1% of the building value) are associated with residential housing.

Building Inventory

General Building Stock

Hazus estimates that there are 899 buildings in the region which have an aggregate total replacement value of 164 million dollars. Table 1 and Table 2 present the relative distribution of the exposure values with respect to the general occupancies by Study Region and Scenario (the area affected by the flood event) respectively. Appendix B provides a general distribution of the building value by Province/Territory and Census Division.

Table 1
Building Exposure by Occupancy Type for the Study Region

Occupancy	Exposure ($1000)	Percent of Total
Residential	151,233	92.1%
Commercial	11,252	6.9%
Industrial	1,530	0.9%
Agricultural	0	0.0%
Religion	139	0.1%
Government	0	0.0%
Education	0	0.0%
Total	**164,154**	**100.00%**

Table 2
Building Exposure by Occupancy Type for the Scenario

Occupancy	Exposure ($1000)	Percent of Total
Residential	54,629	86.3%
Commercial	7,769	12.3%
Industrial	770	1.2%
Agricultural	0	0.0%
Religion	139	0.2%
Government	0	0.0%
Education	0	0.0%
Total	**63,307**	**100.00%**

Essential Facility Inventory

For essential facilities, there are no hospitals in the region with a total bed capacity of no beds.
There are no schools, no fire stations, no police stations and no emergency operation centers.

Flood Scenario Parameters

Hazus used the following set of information to define the flood parameters for the flood loss estimate provided in this report.

Study Region Name:	SA100m
Scenario Name:	StAndrew100m
Return Period Analyzed:	100
Analysis Options Analyzed:	No What-Ifs

Building Damage

General Building Stock Damage

Hazus estimates that about 16 buildings will be at least moderately damaged. This is over 7% of the total number of buildings in the scenario. There are an estimated 2 buildings that will be completely destroyed. The definition of the 'damage states' is provided in Chapter 5 of the US Hazus-MH Flood Model Technical Manual. Table 3 below summarizes the expected damage by general occupancy for the buildings in the region. Table 4 summarizes the expected damage by general building type.

Table 3: Expected Building Damage by Occupancy

	1-10		11-20		21-30		31-40		41-50		>50	
Occupancy	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Agriculture	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Commercial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Education	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Government	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Industrial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Religion	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Residential	0	0.00	0	0.00	2	12.50	5	31.25	7	43.75	2	12.50
Total	**0**		**0**		**2**		**5**		**7**		**2**	

Table 4: Expected Building Damage by Building Type

Building Type	1-10		11-20		21-30		31-40		41-50		>50	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Concrete	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
ManufHousing	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Masonry	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Steel	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Wood	0	0.00	0	0.00	2	12.50	5	31.25	7	43.75	2	12.50

Special Notice Regarding Building Count:

Unlike the earthquake and hurricane models, the flood model performs its analysis at the census block level. This means that the analysis starts with a small number of buildings within each census block and applies a series of distributions necessary for analyzing the potential damage. The application of these distributions and the small number of buildings make the flood model more sensitive to rounding errors that introduces uncertainty into the building count results. Please use these results with suitable caution.

Essential Facility Damage

Before the flood analyzed in this scenario, the region had 0 hospital beds available for use. On the day of the scenario flood event, the model estimates that 0 hospital beds are available in the region.

Table 5: Expected Damage to Essential Facilities

		# Facilities		
Classification	Total	At Least Moderate	At Least Substantial	Loss of Use
Fire Stations	0	0	0	0
Hospitals	0	0	0	0
Police Stations	0	0	0	0
Schools	0	0	0	0

If this report displays all zeros or is blank, two possibilities can explain this.

(1) None of your facilities were flooded. This can be checked by mapping the inventory data on the depth grid.

(2) The analysis was not run. This can be tested by checking the run box on the Analysis Menu and seeing if a message box asks you to replace the existing results.

Induced Flood Damage

Debris Generation

Hazus estimates the amount of debris that will be generated by the flood. The model breaks debris into three general categories: 1) Finishes (dry wall, insulation, etc.), 2) Structural (wood, brick, etc.) and 3) Foundations (concrete slab, concrete block, rebar, etc.). This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 403 tons of debris will be generated. Of the total amount, Finishes comprises 64% of the total, Structure comprises 20% of the total. If the debris tonnage is converted into an estimated number of truckloads, it will require 16 truckloads (@25 tons/truck) to remove the debris generated by the flood.

Social Impact

Shelter Requirements

Hazus estimates the number of households that are expected to be displaced from their homes due to the flood and the associated potential evacuation. Hazus also estimates those displaced people that will require accommodations in temporary public shelters. The model estimates 43 households will be displaced due to the flood. Displacement includes households evacuated from within or very near to the inundated area. Of these, 92 people (out of a total population of 2,672) will seek temporary shelter in public shelters.

Economic Loss

The total economic loss estimated for the flood is 3.19 million dollars, which represents 5.04 % of the total replacement value of the scenario buildings.

Building-Related Losses

The building-related losses are broken into two categories: direct building losses and business interruption losses. The direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the flood. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the flood.

The total building-related losses were 3.18 million dollars. 0% of the estimated losses were related to the business interruption of the region. The residential occupancies made up 87.68% of the total loss. Table 6 below provides a summary of the losses associated with the building damage.

Table 6: Building-Related Economic Loss Estimates

(Millions of dollars)

Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	1.84	0.04	0.05	0.00	1.94
	Content	0.95	0.14	0.13	0.00	1.22
	Inventory	0.00	0.00	0.03	0.00	0.03
	Subtotal	**2.79**	**0.18**	**0.21**	**0.00**	**3.18**
Business Interruption						
	Income	0.00	0.00	0.00	0.00	0.00
	Relocation	0.01	0.00	0.00	0.00	0.01
	Rental Income	0.00	0.00	0.00	0.00	0.00
	Wage	0.00	0.00	0.00	0.00	0.00
	Subtotal	**0.01**	**0.00**	**0.00**	**0.00**	**0.01**
ALL	**Total**	**2.80**	**0.18**	**0.21**	**0.00**	**3.19**

Appendix A: Census Division Listing for the Region

Manitoba

- Division No. 13

Appendix B: Regional Population and Building Value Data

	Population	Building Value (thousands of dollars)		
		Residential	Non-Residential	Total
Manitoba				
Division No. 13	2,672	151,233	12,921	164,154
Total	**2,672**	**151,233**	**12,921**	**164,154**
Total Study Region	**2,672**	**151,233**	**12,921**	**164,154**

Hazus-MH: Flood Event Report

Region Name: SA300d

Flood Scenario: StAndrews300

Print Date: Saturday, July 30, 2016

Disclaimer:

Totals only reflect data for those census tracts/blocks included in the user's study region.

The estimates of social and economic impacts contained in this report were produced using Hazus loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and the actual social and economic losses following a specific Flood. These results can be improved by using enhanced inventory data and flood hazard information.

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General Description of the Region

Hazus is a regional multi-hazard loss estimation model that was developed by the Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS). The primary purpose of Hazus is to provide a methodology and software application to develop multi-hazard losses at a regional scale. These loss estimates would be used primarily by local, Province/Territory and regional officials to plan and stimulate efforts to reduce risks from multi-hazards and to prepare for emergency response and recovery.

The flood loss estimates provided in this report were based on a region that included 1 Census Division(s)

- Manitoba

Note:
Appendix A contains a complete listing of the Census Divisions contained in the region.

The geographical size of the region is 7 square miles and contains 46 Census Dissemination Blocks. The region contains over 1 thousand households and has a total population of 2,672 people (2011 Census Canada data). The distribution of population by Province/Territory and Census Division for the study region is provided in Appendix B.

There are an estimated 899 buildings in the region with a total building replacement value (excluding contents) of 164 million dollars. Approximately 96.8% of the buildings (and 92.1% of the building value) are associated with residential housing.

Building Inventory

General Building Stock

Hazus estimates that there are 899 buildings in the region which have an aggregate total replacement value of 164 million dollars. Table 1 and Table 2 present the relative distribution of the exposure values with respect to the general occupancies by Study Region and Scenario (the area affected by the flood event) respectively. Appendix B provides a general distribution of the building value by Province/Territory and Census Division.

Table 1
Building Exposure by Occupancy Type for the Study Region

Occupancy	Exposure ($1000)	Percent of Total
Residential	151,233	92.1%
Commercial	11,252	6.9%
Industrial	1,530	0.9%
Agricultural	0	0.0%
Religion	139	0.1%
Government	0	0.0%
Education	0	0.0%
Total	**164,154**	**100.00%**

Table 2
Building Exposure by Occupancy Type for the Scenario

Occupancy	Exposure ($1000)	Percent of Total
Residential	82,285	89.2%
Commercial	9,105	9.9%
Industrial	770	0.8%
Agricultural	0	0.0%
Religion	139	0.2%
Government	0	0.0%
Education	0	0.0%
Total	**92,299**	**100.00%**

Essential Facility Inventory

For essential facilities, there are no hospitals in the region with a total bed capacity of no beds. There are no schools, no fire stations, no police stations and no emergency operation centers.

Flood Scenario Parameters

Hazus used the following set of information to define the flood parameters for the flood loss estimate provided in this report.

Study Region Name:	SA300d
Scenario Name:	StAndrews300
Return Period Analyzed:	300
Analysis Options Analyzed:	No What-Ifs

Building Damage

General Building Stock Damage

Hazus estimates that about 36 buildings will be at least moderately damaged. This is over 3% of the total number of buildings in the scenario. There are an estimated 22 buildings that will be completely destroyed. The definition of the 'damage states' is provided in Chapter 5 of the US Hazus-MH Flood Model Technical Manual. Table 3 below summarizes the expected damage by general occupancy for the buildings in the region. Table 4 summarizes the expected damage by general building type.

Table 3: Expected Building Damage by Occupancy

	1-10		11-20		21-30		31-40		41-50		>50	
Occupancy	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Agriculture	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Commercial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Education	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Government	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Industrial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Religion	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Residential	0	0.00	0	0.00	1	2.78	3	8.33	10	27.78	22	61.11
Total	**0**		**0**		**1**		**3**		**10**		**22**	

Table 4: Expected Building Damage by Building Type

Building Type	1-10		11-20		21-30		31-40		41-50		>50	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Concrete	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
ManufHousing	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Masonry	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Steel	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Wood	0	0.00	0	0.00	1	2.78	3	8.33	10	27.78	22	61.11

Special Notice Regarding Building Count:

Unlike the earthquake and hurricane models, the flood model performs its analysis at the census block level. This means that the analysis starts with a small number of buildings within each census block and applies a series of distributions necessary for analyzing the potential damage. The application of these distributions and the small number of buildings make the flood model more sensitive to rounding errors that introduces uncertainty into the building count results. Please use these results with suitable caution.

Essential Facility Damage

Before the flood analyzed in this scenario, the region had 0 hospital beds available for use. On the day of the scenario flood event, the model estimates that 0 hospital beds are available in the region.

Table 5: Expected Damage to Essential Facilities

		# Facilities		
Classification	Total	At Least Moderate	At Least Substantial	Loss of Use
Fire Stations	0	0	0	0
Hospitals	0	0	0	0
Police Stations	0	0	0	0
Schools	0	0	0	0

If this report displays all zeros or is blank, two possibilities can explain this.

(1) None of your facilities were flooded. This can be checked by mapping the inventory data on the depth grid.

(2) The analysis was not run. This can be tested by checking the run box on the Analysis Menu and seeing if a message box asks you to replace the existing results.

Induced Flood Damage

Debris Generation

Hazus estimates the amount of debris that will be generated by the flood. The model breaks debris into three general categories: 1) Finishes (dry wall, insulation, etc.), 2) Structural (wood, brick, etc.) and 3) Foundations (concrete slab, concrete block, rebar, etc.). This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 2,178 tons of debris will be generated. Of the total amount, Finishes comprises 28% of the total, Structure comprises 42% of the total. If the debris tonnage is converted into an estimated number of truckloads, it will require 87 truckloads (@25 tons/truck) to remove the debris generated by the flood.

Social Impact

Shelter Requirements

Hazus estimates the number of households that are expected to be displaced from their homes due to the flood and the associated potential evacuation. Hazus also estimates those displaced people that will require accommodations in temporary public shelters. The model estimates 63 households will be displaced due to the flood. Displacement includes households evacuated from within or very near to the inundated area. Of these, 151 people (out of a total population of 2,672) will seek temporary shelter in public shelters.

Economic Loss

The total economic loss estimated for the flood is 8.60 million dollars, which represents 9.32 % of the total replacement value of the scenario buildings.

Building-Related Losses

The building-related losses are broken into two categories: direct building losses and business interruption losses. The direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the flood. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the flood.

The total building-related losses were 8.58 million dollars. 0% of the estimated losses were related to the business interruption of the region. The residential occupancies made up 86.27% of the total loss. Table 6 below provides a summary of the losses associated with the building damage.

Table 6: Building-Related Economic Loss Estimates

(Millions of dollars)

Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	4.88	0.18	0.12	0.00	5.18
	Content	2.53	0.54	0.26	0.01	3.34
	Inventory	0.00	0.00	0.06	0.00	0.07
	Subtotal	**7.41**	**0.72**	**0.45**	**0.01**	**8.58**
Business Interruption						
	Income	0.00	0.00	0.00	0.00	0.00
	Relocation	0.01	0.00	0.00	0.00	0.01
	Rental Income	0.00	0.00	0.00	0.00	0.00
	Wage	0.00	0.00	0.00	0.00	0.00
	Subtotal	**0.01**	**0.01**	**0.00**	**0.00**	**0.02**
ALL	**Total**	**7.42**	**0.72**	**0.45**	**0.01**	**8.60**

Appendix A: Census Division Listing for the Region

Manitoba

- Division No. 13

Appendix B: Regional Population and Building Value Data

		Building Value (thousands of dollars)		
	Population	Residential	Non-Residential	Total
Manitoba				
Division No. 13	2,672	151,233	12,921	164,154
Total	**2,672**	**151,233**	**12,921**	**164,154**
Total Study Region	**2,672**	**151,233**	**12,921**	**164,154**

Hazus-MH: Flood Event Report

Region Name: SA300m

Flood Scenario: StAndrews300m

Print Date: Saturday, July 30, 2016

Disclaimer:

Totals only reflect data for those census tracts/blocks included in the user's study region.

The estimates of social and economic impacts contained in this report were produced using Hazus loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and the actual social and economic losses following a specific Flood. These results can be improved by using enhanced inventory data and flood hazard information.

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General Description of the Region

Hazus is a regional multi-hazard loss estimation model that was developed by the Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS). The primary purpose of Hazus is to provide a methodology and software application to develop multi-hazard losses at a regional scale. These loss estimates would be used primarily by local, Province/Territory and regional officials to plan and stimulate efforts to reduce risks from multi-hazards and to prepare for emergency response and recovery.

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Note:
Appendix A contains a complete listing of the Census Divisions contained in the region.

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There are an estimated 899 buildings in the region with a total building replacement value (excluding contents) of 164 million dollars. Approximately 96.8% of the buildings (and 92.1% of the building value) are associated with residential housing.

Building Inventory

General Building Stock

Hazus estimates that there are 899 buildings in the region which have an aggregate total replacement value of 164 million dollars. Table 1 and Table 2 present the relative distribution of the exposure values with respect to the general occupancies by Study Region and Scenario (the area affected by the flood event) respectively. Appendix B provides a general distribution of the building value by Province/Territory and Census Division.

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Building Exposure by Occupancy Type for the Study Region

Occupancy	Exposure ($1000)	Percent of Total
Residential	151,233	92.1%
Commercial	11,252	6.9%
Industrial	1,530	0.9%
Agricultural	0	0.0%
Religion	139	0.1%
Government	0	0.0%
Education	0	0.0%
Total	**164,154**	**100.00%**

Table 2
Building Exposure by Occupancy Type for the Scenario

Occupancy	Exposure ($1000)	Percent of Total
Residential	82,285	89.2%
Commercial	9,105	9.9%
Industrial	770	0.8%
Agricultural	0	0.0%
Religion	139	0.2%
Government	0	0.0%
Education	0	0.0%
Total	**92,299**	**100.00%**

Essential Facility Inventory

For essential facilities, there are no hospitals in the region with a total bed capacity of no beds.
There are no schools, no fire stations, no police stations and no emergency operation centers.

Flood Scenario Parameters

Hazus used the following set of information to define the flood parameters for the flood loss estimate provided in this report.

Study Region Name:	SA300m
Scenario Name:	StAndrews300m
Return Period Analyzed:	300
Analysis Options Analyzed:	No What-Ifs

Building Damage

General Building Stock Damage

Hazus estimates that about 33 buildings will be at least moderately damaged. This is over 0% of the total number of buildings in the scenario. There are an estimated 22 buildings that will be completely destroyed. The definition of the 'damage states' is provided in Chapter 5 of the US Hazus-MH Flood Model Technical Manual. Table 3 below summarizes the expected damage by general occupancy for the buildings in the region. Table 4 summarizes the expected damage by general building type.

Table 3: Expected Building Damage by Occupancy

	1-10		11-20		21-30		31-40		41-50		>50	
Occupancy	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Agriculture	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Commercial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Education	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Government	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Industrial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Religion	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Residential	0	0.00	0	0.00	0	0.00	3	9.09	8	24.24	22	66.67
Total	**0**		**0**		**0**		**3**		**8**		**22**	

Table 4: Expected Building Damage by Building Type

Building Type	1-10		11-20		21-30		31-40		41-50		>50	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Concrete	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
ManufHousing	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Masonry	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Steel	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Wood	0	0.00	0	0.00	0	0.00	3	9.09	8	24.24	22	66.67

Special Notice Regarding Building Count:

Unlike the earthquake and hurricane models, the flood model performs its analysis at the census block level. This means that the analysis starts with a small number of buildings within each census block and applies a series of distributions necessary for analyzing the potential damage. The application of these distributions and the small number of buildings make the flood model more sensitive to rounding errors that introduces uncertainty into the building count results. Please use these results with suitable caution.

Essential Facility Damage

Before the flood analyzed in this scenario, the region had 0 hospital beds available for use. On the day of the scenario flood event, the model estimates that 0 hospital beds are available in the region.

Table 5: Expected Damage to Essential Facilities

		# Facilities		
Classification	Total	At Least Moderate	At Least Substantial	Loss of Use
Fire Stations	0	0	0	0
Hospitals	0	0	0	0
Police Stations	0	0	0	0
Schools	0	0	0	0

If this report displays all zeros or is blank, two possibilities can explain this.

(1) None of your facilities were flooded. This can be checked by mapping the inventory data on the depth grid.

(2) The analysis was not run. This can be tested by checking the run box on the Analysis Menu and seeing if a message box asks you to replace the existing results.

Induced Flood Damage

Debris Generation

Hazus estimates the amount of debris that will be generated by the flood. The model breaks debris into three general categories: 1) Finishes (dry wall, insulation, etc.), 2) Structural (wood, brick, etc.) and 3) Foundations (concrete slab, concrete block, rebar, etc.). This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 2,054 tons of debris will be generated. Of the total amount, Finishes comprises 27% of the total, Structure comprises 42% of the total. If the debris tonnage is converted into an estimated number of truckloads, it will require 82 truckloads (@25 tons/truck) to remove the debris generated by the flood.

Social Impact

Shelter Requirements

Hazus estimates the number of households that are expected to be displaced from their homes due to the flood and the associated potential evacuation. Hazus also estimates those displaced people that will require accommodations in temporary public shelters. The model estimates 58 households will be displaced due to the flood. Displacement includes households evacuated from within or very near to the inundated area. Of these, 137 people (out of a total population of 2,672) will seek temporary shelter in public shelters.

Economic Loss

The total economic loss estimated for the flood is 7.93 million dollars, which represents 8.59 % of the total replacement value of the scenario buildings.

Building-Related Losses

The building-related losses are broken into two categories: direct building losses and business interruption losses. The direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the flood. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the flood.

The total building-related losses were 7.91 million dollars. 0% of the estimated losses were related to the business interruption of the region. The residential occupancies made up 85.84% of the total loss. Table 6 below provides a summary of the losses associated with the building damage.

Table 6: Building-Related Economic Loss Estimates

(Millions of dollars)

Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	4.47	0.17	0.11	0.00	4.75
	Content	2.33	0.52	0.24	0.01	3.10
	Inventory	0.00	0.00	0.06	0.00	0.06
	Subtotal	**6.80**	**0.70**	**0.41**	**0.01**	**7.91**
Business Interruption						
	Income	0.00	0.00	0.00	0.00	0.00
	Relocation	0.01	0.00	0.00	0.00	0.01
	Rental Income	0.00	0.00	0.00	0.00	0.00
	Wage	0.00	0.00	0.00	0.00	0.00
	Subtotal	**0.01**	**0.01**	**0.00**	**0.00**	**0.02**
ALL	**Total**	**6.81**	**0.70**	**0.41**	**0.01**	**7.93**

Appendix A: Census Division Listing for the Region

Manitoba

- Division No. 13

Appendix B: Regional Population and Building Value Data

	Population	Building Value (thousands of dollars)		
		Residential	Non-Residential	Total
Manitoba				
Division No. 13	2,672	151,233	12,921	164,154
Total	**2,672**	**151,233**	**12,921**	**164,154**
Total Study Region	**2,672**	**151,233**	**12,921**	**164,154**

UNIVERSITY OF MANITOBA | Research Ethics and Compliance
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APPROVAL CERTIFICATE

September 17, 2014

NRCan
41974

TO: **Angela Howells** (Advisor D. Walker)
Principal Investigator

FROM: **Susan Frohlick, Chair** [redacted]
Joint-Faculty Research Ethics Board (JFREB)

Re: **Protocol #J2014:132**
"Dasymetric stratification of a flood plain: Development and refinement of the HAZUS flood mapping tool for Canada"

Please be advised that your above-referenced protocol has received human ethics approval by the **Joint-Faculty Research Ethics Board**, which is organized and operates according to the Tri-Council Policy Statement (2). **This approval is valid for one year only.**

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.

Please note:

- **If you have funds pending human ethics approval, please mail/e-mail/fax (261-0325) a copy of this Approval (identifying the related UM Project Number) to the Research Grants Officer in ORS in order to initiate fund setup. (How to find your UM Project Number: http://umanitoba.ca/research/ors/mrt-faq.html#pr0)**

- **if you have received multi-year funding for this research, responsibility lies with you to apply for and obtain Renewal Approval at the expiry of the initial one-year approval; otherwise the account will be locked.**

The Research Quality Management Office may request to review research documentation from this project to demonstrate compliance with this approved protocol and the University of Manitoba *Ethics of Research Involving Humans*.

The Research Ethics Board requests a final report for your study (available at: http://umanitoba.ca/research/orec/ethics/human_ethics_REB_forms_guidelines.html) **in order to be in compliance with Tri-Council Guidelines.**