Using GIS to Analyze the Economic and Social Benefits of a Flood Control Levee in Mankato, Minnesota USA

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Abstract

This study analyzes the economic benefits of a levee constructed for the purposes of flood damage reduction in Mankato, Minnesota. The study also analyzes social benefits of the levee by assessing the demographic changes after the creation of the levee. Four analyses were developed to analyze the economic and social benefits of the levee. The first analysis was developed to evaluate property value. A second analysis was developed to evaluate tax revenue. A third analysis was developed to evaluate economic benefits of the levee. A fourth analysis was developed to assess population change after the creation of the levee. The calculation of property value focused on all land and buildings in flood zones while the calculation of tax revenue focused on buildings in the flood zones that were built after the levee project started. The overall results show the levee plays a significant role in protecting the economic well being of the city of Mankato. Results also show despite decreases in population in the flood zones, the overall population of the city of Mankato has increased significantly after the construction of the levee system.

Introduction

In the United States, property damage from floods averaged an estimated $5.9 billion annually from 1955 to 1999 (Charles, 2003). The most costly flood in United States history was the Flood of 1993, which involved the Mississippi and Missouri Rivers, causing economic losses of nearly $20 billion in nine states (Charles). In Minnesota, the 1997 spring flooding in the Minnesota River and Red River had total flood damage and associated economic impacts estimated to be as high as $1.5 billion (Minnesota Department of Natural Resources, 2001).

The most important element of any comprehensive hazard mitigation program is hazard identification according to Lear, Zheng, and Dunnigan (n.d.). As indicated by Coulibaly (2004), areas prone to flash flooding are located near rivers or water bodies and are not easily identified by people living around that area due to the complexity of the terrain. Flood prone areas may be identified through a variety of methods such as studying historical events, visual observations and scientific analysis. When resources are limited, visual observation is used because it is a cheap method for mapping flood-prone areas (Prathumchai and Samarakoon, n.d.). However, this may yield misleading results since visual interpretations do not provide enough current information for valid decision making. As also confirmed by Mertens (2008), methods of examining historical data may be an unreliable guide to the future flood

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management. A scientific analysis, which takes into consideration factors like elevation and the volume of the water to depict reality through a simulation model could be more reliable in identifying flood prone areas. However, inaccurate scientific analysis may also result into poor planning during a major flood. Communities typically plan without taking into account environmental changes that could effect flooding and increase damage in the future (Mertens). Studies have also shown due to suitability of land and transportation demands, many people prefer to live in flood prone areas such as along rivers, in deltas, and along coastlines (Kersting, n.d.).

Areas where hazard identification had not been properly conducted before people moved in and established settlements faced greater potential for property damage from flooding. People and infrastructure in a flood plain could be protected through a variety of mitigation programs such as levees. According to the U.S. Army Corps of Engineers (n.d.), a levee is defined as "an earth embankment, floodwall, or structure along a water course whose purpose is flood damage reduction or water conveyance." Artificial levees were first built in New Orleans in 1726 and became the favored flood control method used today (Charles). According to Strickland, Logan, and Hoffman (2006), levees properly designed and constructed will provide many years of service to the public. Levees provide both economic and social benefit to the population by protecting land, buildings, and human life from inundated by flood waters (Strickland et al). In addition, levees provide indirect economic and social benefits to society as they create a protected barrier to floodplains creating open space for recreation, wildlife habitat, and farming.

Study Area

Mankato is located in Minnesota's Blue Earth County, about 67.1 miles from Minneapolis, and 70.1 miles from St. Paul (Mankato Profile, 2009). According to the U.S. Census Bureau (2009), the city of Mankato has a total area of 15.4 square miles, of which 15.2 square miles is land and 0.2 square miles is water. In 2006, the city of Mankato's population was estimated to be 34,970, compared to 32,427 in 2000, which is equivalent to a 7.4% increase (U.S. Census Bureau). Mankato is located in an area where the Blue Earth and the Minnesota Rivers meet and typically experiences a number of floods each year (City of Mankato, 2007). Mankato has a long history of flooding due to its location along the Minnesota River (Mankato History). The Minnesota River flows in a south to north direction from Big Stone Lake to Mankato, and then flows in a northwestern direction to the Mississippi River (U.S. Army Corps of Engineers, 1991).

The first recorded flood in Mankato occurred in 1881 with very little damage. Major flooding occurred again in 1951 when the Minnesota River overflowed but Mankato received little damage (Mankato History). During the 1965 flood, homes and other property were destroyed; the damage was estimated at $5.5 million (Mankato and the River, n.d.).

Mitigation actions have been implemented in the city of Mankato to reduce/eliminate the long-term flood risk to property and people through emergency services planning. The city of

Mankato is protected by a levee that has a total length of about 2.7 miles, which extend from U.S. Highway 169 to Rock Creek, Minnesota. The levee construction project started in 1958 and was completed in 1989 at a cost of $97,270,500 (U.S. Army Corps of Engineers). Catch basins, manholes, channels, and underground pipes that carry storm-water to drainage ponds have been installed (Storm Drain System, 2007). As a result, the effects from the floods in 2001 were greatly reduced as compared to the 1951 flooding (Flooding, n.d.). Figure 1 illustrates the location of the city of Mankato.

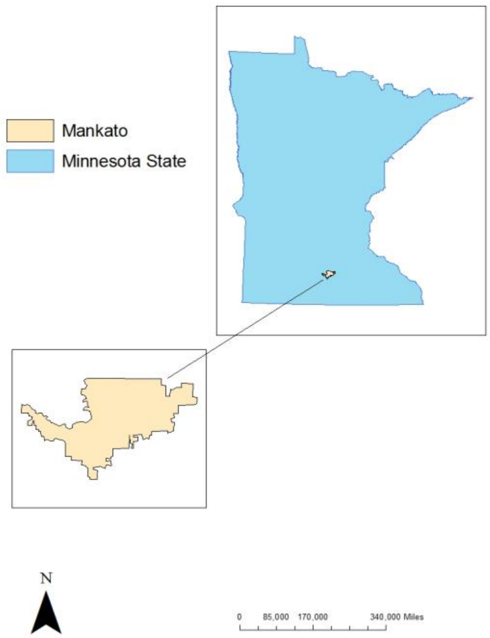

Figure 1. Study area – Mankato, Minnesota.

Since the construction of the levee nearly 20 years ago, it is not known how effectively the levee is functioning from an efficiency perspective. According to Linehan and Fischenich (2009), now the city of Mankato is facing a levee certification challenge. The proposed study will ensure the levee system is still in a good working condition. Linehan and Fischenich added that the study could cost the city an estimated $100,000 per mile of levee.

Methods

This project analyzes the economic benefit of the levee by comparing the protection benefit gained from land and buildings value and income generated from tax through reduction of flood damage with the construction and maintenance cost of the levee. In addition, this project analyses demographic changes in the flood zones between 1990 and 2000. Also, this project analyses the land use changes for the whole city of Mankato.

Software Requirements

ArcGIS 9.3, produced by Environmental Systems Research Institute Inc. (ESRI), was used as the primary analysis software in this project. Microsoft Excel was also used to prepare census data before importing it into ArcGIS.

Data Acquisition

Datasets were obtained from various sources. Demographic information was downloaded from the United States Census Bureau website (Population Factfinder, n.d.). Land parcel data was obtained from Blue Earth County, which provided geographically referenced information about the ownership of land, year built, and its value. Flood zones were downloaded from the Minnesota Department of Natural Resources website (The DNR Data Deli.). Aerial photos, river basin, and transportation data were obtained from the city of

Mankato. Figure 2 illustrates the levee along the Minnesota River.

Figure 2. The levee along the Minnesota River. The area shown here is approximately 100 feet from left to right.

Data Manipulation

Much of the data required pre-processing and editing in order to extract the necessary information. The first task was formatting and projecting the datasets. All data used in this study were originally represented in shapefile format with undefined coordinate system except for data from Blue Earth County and Mankato which were defined in the following coordinate system: NAD_1983_HARN_Adj_MN_Blue_Earth_Feet. All data were converted into shapefile format. U.S. Census data were defined in the following coordinate system: GCS_North_American_1983. FEMA data were defined in GCS_North_American_1983 and NAD_1983_UTM_Zone_15N. Data from Blue Earth County and Mankato were first added in ArcMap, then U.S. Census data and FEMA data were projected on the fly to match each other.

Flood zones were downloaded from FEMA website, which contained flood zones for the entire blue earth county. In ArcMap, two shapefiles were created, queried, and parsed out of the original flood zone data: a 100-year flood zone and a 500-year flood zone. Figure 3 illustrates the flood zones in the city of Mankato.

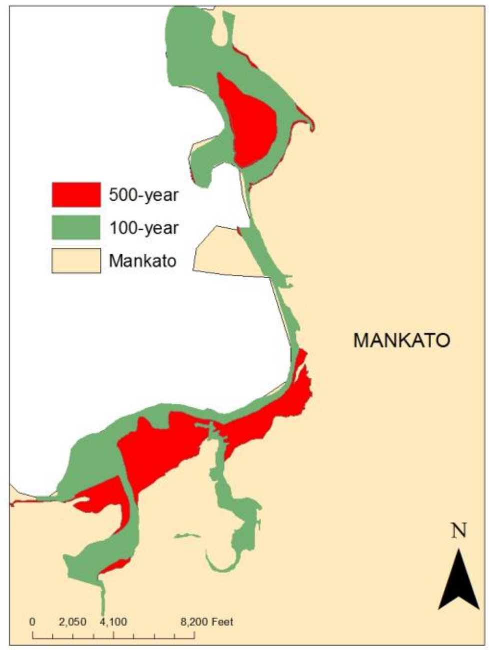

Figure 3. Flood zones in the city of Mankato. Areas in green represent 100-year flood zones. Areas in red represent 500-year flood zones.

Demographic data was downloaded from U.S. Census Bureau website. This data was originally represented in a Summary File 3 (SF3) format. The analysis was conducted at the census tract level. The United States census data is presented in a hierarchical form in terms of the nation, region, counties, census tracts, block groups, and blocks.

SF3 provides information relating to the social, economic, and housing characteristics. Variables from the SF3 files used for this study included the total population. The census data was downloaded as Microsoft Excel tables then was imported into ArcGIS and joined to the corresponding boundary file. The boundary files (Tiger/lines) were downloaded from ESRI and imported into ArcGIS. The data was projected in Universal Transverse Mercator (UTM), North American Datum of 1983 (NAD83), Zone 15. The boundary data then was joined to the Census data in ArcMap. Figure 4 shows geographic boundary data types available from the U.S. Census Bureau.

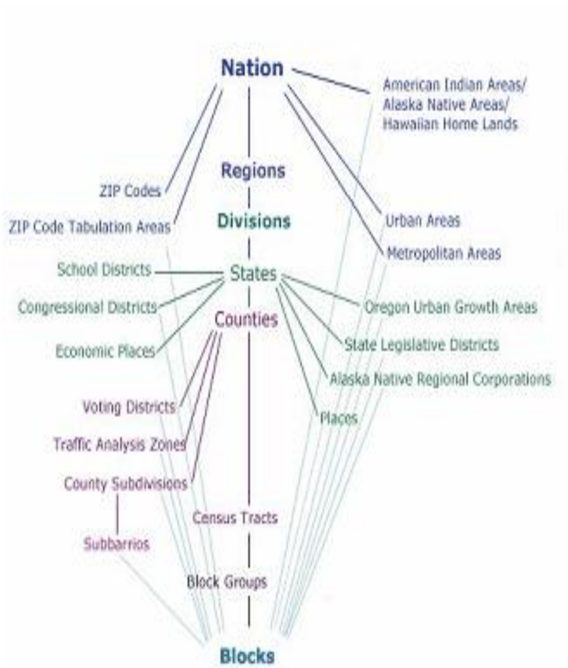

Figure 4. A hierarchical form of United States Census data.

Analysis

This research was designed for assessing the economical and social benefits of the levee. The economic benefit of the levee was calculated by considering the parcels in the flood zones. The social benefit of the levee was analyzed by assessing demographic changes after the creation of the levee. In addition to the economic and social benefit of the levee, the total areas of the land built during and after levee constructions for the whole city of Mankato were calculated.

The analysis of economic benefits of the levee involved three evaluation processes. First, an evaluation of total value of property was developed. The total value of property, measured in U.S. dollars, includes the value of land and the value of buildings. The evaluation required a parcel identification number and value attribute datasets. The calculation of total property value considered only parcels in the 100 and 500-year flood zones. This calculation was based on one major assumption: The value of property in the flood zone is influenced by the presence of a levee. The total value of all properties in the 100-year and 500-year flood zone was calculated using Equation 1.

$$\sum_{i-1}^{N} TPV = PV_1 + PV_2 + PV_3 .... PV_N$$

Equation 1. TPV = Total property value, and PV = Property value.

Second, an evaluation of total Tax Revenue was developed. The total tax revenue was calculated by extracting revenue for buildings in the 100 and 500-year flood zones built after the levee project started. Building taxes paid by the owners were used to calculate total tax revenue. Buildings built before the levee construction project started were not included in the total tax revenue calculation because the evaluation focuses on the benefit of the levee. This process required a parcel identification number with a “year built” and tax attributes. The attribute, “year built” was divided in two categories: “residential year built” and “commercial year built.” The calculation of the tax revenue was based on two assumptions and is probably a conservative estimate: first, taxes paid for each building remained the same each year. Second, all the buildings built in the flood zones after the levee construction project started were influenced by the presence of the levee. The total tax revenue was calculated using Equation 2.

$$\sum_{i-1}^{N} TTR = T_1 + T_2 .... T_N$$

Equation 2. TTR = total tax revenue per year and T = Taxes.

Third, an evaluation of the economic benefit of the levee was developed. The total property value and total income from tax revenue obtained from equation 1 and 2 above were summed to obtain gross economic benefit. The net economic benefit was obtained by subtracting the gross benefit with the construction cost and maintenance cost. The net economic benefit was calculated using Equation 3.

$$NB = \sum_{i=1}^{N} TPV + (\sum_{i=1}^{N} TTR * 51) - CC + (MC * 21)$$

Equation 3. NB = net economic benefit, TPV = total property value, TTR = total tax revenue per year, CC = construction cost, MC = maintenance cost per year, 21 = age of the levee (the levee project was completed in 1989; that means twenty-one years to date of this research. Total maintenance cost was obtained by multiplying maintenance cost per year by 21). 51= number of years since project started (total tax revenue was obtained by multiplying total tax revenue per year by 51).

Results/Discussion

Land and Buildings Value

Out of the 8703 acres within the city of Mankato, approximately 12.8% are in designated flood zones. This includes nearly 952 acres of land within the 100-year flood zone with an additional 192 acres of land area within the 500-year zone. Susceptibility to flooding in the city of Mankato area is based on FEMA's flood zone delineations.

The city of Mankato has 12194 parcels. Of these parcels, 1052 parcels are lying within a flood zone. Out of 1052 flood zones parcels, 305 parcels are include in the 100-year flood zone and 747 parcels are in the 500-year flood zone. Table 1 shows a measure of variability in prices of land and buildings in the city of Mankato flood zone area.

Table 1. Property values (in U.S. dollars) of land and buildings from different flood zones. N represents the count of properties, μ represents population mean and σ represent standard deviation.

Flood Zone Properties	N	μ ± σ (Range in parentheses)
Land in 100-year zone	374	93,844 ± 283,705 (100 to 4,230,800)
Buildings in 100-year zone	251	145,097 ± 148,253 (35,400 to 1,528,500)
Land in 500-year zone	679	43,726 ± 65,948 (400 to 875,600)
Buildings in 500-year zone	608	114,239 ± 168,394 (2,600 to 2,499,400)

Parcels in the 100-year flood zone have average building values equivalent to \$145,097 and average land values equivalent to \$93,844. Parcels in the 500-year flood zone have average buildings values of $114,239, with an average land value of $43,726. The total value of all properties affected by both 100-year and 500-year flood zones amounted to $128,395,000.

Tax Revenue

Tax revenues were calculated based on revenue obtained from taxes paid each year by building owners. Tax revenue obtained from the buildings built before the levee constructions began were not included in the calculation since total tax revenue is design to reflects the benefit of the levee.

Of the 859 buildings in the flood zones, approximately 4% are tax-exempt; including churches and government buildings. The most significant land-use changes that have occurred in flood zones before the construction of the levee were mainly due to residential building construction. Out of 670 properties built in the flood zone before the levee construction, approximately 77% were residential buildings. Of the remaining 131 properties, approximately 33% were classified as commercial buildings. The most significant land-use changes that have occurred in the flood zones during and after the construction of the levee were a result of new commercial construction. Out of 185 properties built in the flood zones during and after the levee construction, approximately 36% were residential and 64% were commercial. Among these properties, 135 were built during the levee construction, and 50 were built after construction was completed between 1989 and 2009.

Total tax revenue was obtained by summing tax revenues generated during and after the completion of the levee. Results show total tax revenues generated every year by parcels built during and after the levee amounted to $89,826,185. Figure 5 shows parcels in the flood zones built during and after the levee construction

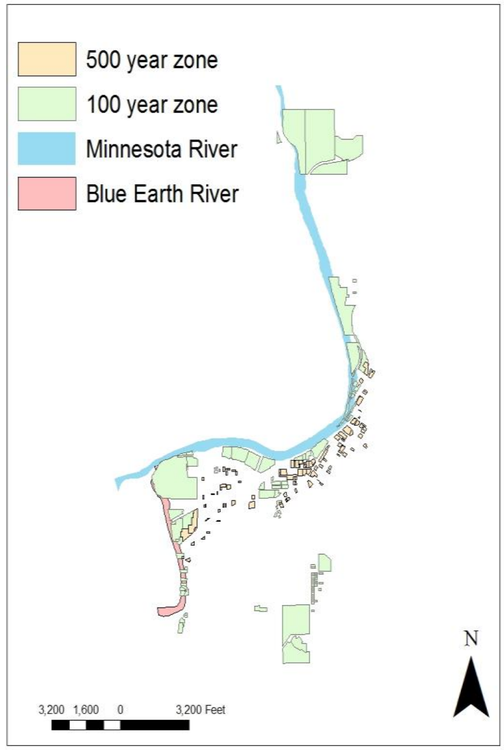

Figure 5. Parcels built during and after the levee construction in the flood zones.

Economic Benefit

The economic benefit of the levee was obtained by deducting the levee construction and maintenance costs from the total tax revenue and total properties value. The levee construction project started in 1958 and was completed in 1989 at a cost of $97,270,500 (U.S. Army Corps of Engineers). Data available from the city of Mankato indicated that levee maintenance costs amounts up to $50,000 per year. Table 2 shows the construction and maintenance costs of the levee.

Table 2. Construction and maintenance costs (in U.S. dollars).

Description	Costs
Construction Cost	$97,270,500
Annual Maintenance Cost 50,000 x 21 years	$1,050,000
Total Cost	$98,320,500

Total property value in the 100-year and 500-year flood zones is estimated to be $128,395,000. Total tax revenue generated every year by the buildings built during and after the completion of the levee is estimated to be $89,826,185. These measurements were integrated into equation 3 where: Total tax revenue generated was obtained by multiplying the total revenue per year by 51 (the number of years since the project started). The total maintenance cost was obtained by multiplying the maintenance cost per year by 21 (the age of the levee).

$$NB = \sum_{i=1}^{N} TPV + (\sum_{i=1}^{N} TR * 51) - CC + (MC * 21)$$

NB = net economic benefit, TPV = total properties value, TR = tax revenue, CC = construction cost and MC = maintenance cost per year.

The results suggest the levee has generated a net economic benefit of $4.3 billion dollars to-date to the city of Mankato.

Population Change

In 1970, the population of the city of Mankato was approximately 30,895; in 1980, the population was approximately 28,651, which was equivalent to a 7.8% decrease (Mankato and North Mankato Area, n.d.). In 1990, the population of the city of Mankato was approximately 31,477. Ten years later, in 2000, it reached 32,427, which was a 5% increase. In 2008, the population was estimated to be 36,245, which was equivalent to an 11.8% increase from 2000 (U.S. Census Bureau). Table 3 obtained from U.S Census Bureau (2009) and North Mankato Area (n.d.) shows the population of the city of Mankato from 1970 to 2008.

Table 3. Population change in the city of Mankato.

Year	Population
2008	36,245
2000	32,427
1990	31,477
1980	28,651
1970	30,895

Source: U.S. Census Bureau (2009) and Mankato and North Mankato Area (n.d.).

Table 4 shows population change by census tract in the city of Mankato between 1990 and 2000.

Table 4. Census tract population change. These tracts represent tracts contained within the city of Mankato's flood zone.

Tracts	1990	2000	Pop change	%Δ
232nd st	2484	2744	260	10
Spruce st	3420	3210	-210	-6
N Broad st	2600	2438	-162	-5
E Liberty st	2927	2783	-144	-5
W 10th st	4832	4483	-349	-7
Birch Ave	3112	3077	-45	-1
Warren st	7675	7856	181	2

In 1990, the average population for tracts in the flood zone was 3,863 people per census tract. By 2000, the average population decreased to 3,323 people. The decrease in population could be due to rapid commercial development from 1989 to 2009 as during this time there was less residential and increase commercial development. Figure 6 shows a map of flood zone population change in the city of Mankato.

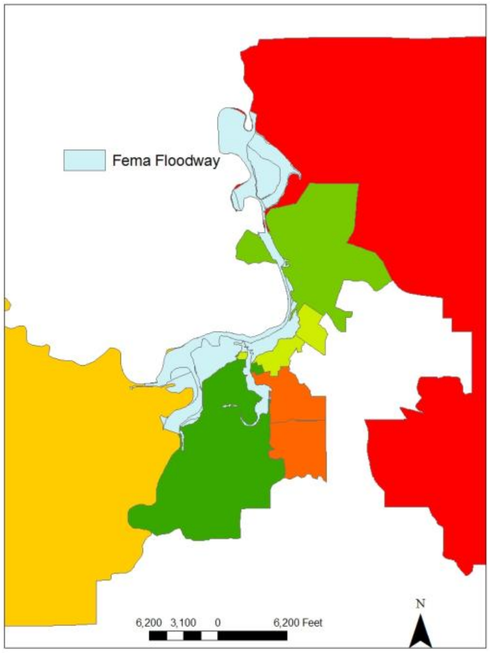

Figure 6. Population change in the city of Mankato flood zones. Green colors represent population decrease, while red and dark red areas represent population increase.

Land Use Change

The construction of levee has brought changes not only to the flood zone area but also to the whole city of Mankato. The city of Mankato has changed since the levee project began. Many of the farmlands and open spaces that existed before the levee have been transformed over the past 51 years into human settlements. Figure 7 shows the total area developed 51 years before the levee project started.

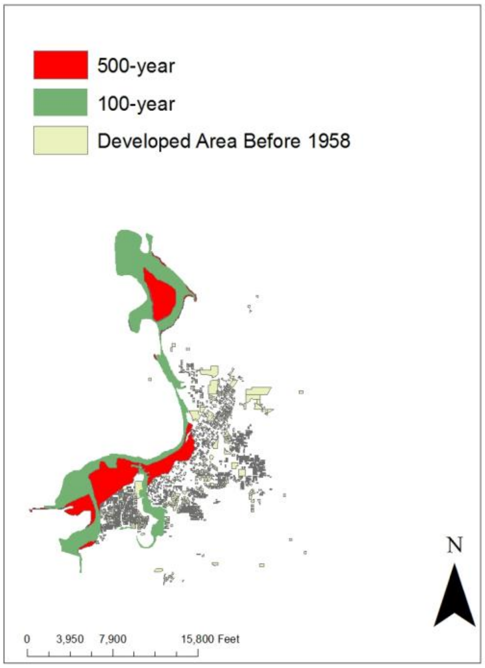

Figure 7. Land area built 51 years before the levee construction project started in 1958. Red colors indicate a 500-year flood zone, while green colors indicate a 100-year flood zone.

The development rates 51 years after the levee project started were five times faster than the development rate 51 years before the levee project started. Despite the fact that many factors have contributed to rapid development, there is no doubt that the existence of levee has played significant role toward this changes. Out of 8703 acres developed in urban Mankato, 903.907 acres were developed 51 years before the levee project started; 4299.529 acres of land has been developed since. This may suggest the construction of the levee played a significant role in protecting the city of Mankato, which may have increased the development potential because of improved flood safety. Figure 8 shows total area developed 51 years after the levee project started in the city of Mankato.

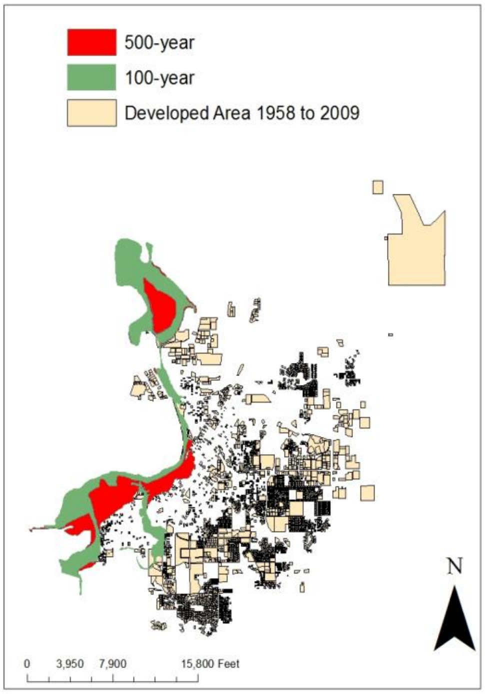

Figure 8. Land area built 51 years after the levee construction project started in 1958 for the whole city of Mankato. Red colors indicate a 500-year flood zone, while green colors indicate a 100-year flood zone.

Conclusions

This study used GIS and descriptive statistical comparisons to evaluate the levee benefit and to analyze population change in the flood zones in the city of Mankato, Minnesota. The study shows the levee has economic benefits which exceed the construction and maintenance costs estimated to be a bit better than 4 to 1. It appears the overall population of the city of Mankato has increased, but the population in the flood zone area has decreased during and after the completion of the levee. This population decrease could be due to higher construction rates of commercial buildings compared to that of residential buildings within the flood zone areas. The calculation of the benefit of the levee is based on a number of assumptions. The first evaluation which calculated the total value of properties has the assumptions that the value of property in the flood zone is influenced by the presence of a levee. For the second evaluation which calculated tax revenue, the assumptions were as follows. First, taxes paid for each building remained the same each year. Second, all buildings built in the flood zones after the levee project began were influenced by the presence of the levee. However, because the value of property and buildings built in the flood zone were influenced not only by the presence of the levee, this suggests that, more studies are needed which incorporate other factors like the presence of Mankato University. Also, since the conclusion of this research was based on 1990 and 2000 census tract data, more studies are needed with more current population information.

Although the levee in the city of Mankato has done its job in preventing flooding, the levee does pose potential threats if failure occurs. Levee failure could cause a wall of water to breech and flow down through protected areas causing destruction. It is also possible, although highly unlikely that water could top the levee and finds its way to the protected areas under an unprecedented flood event. In addition, since some flood risks by overland flow, poor drainage, and lateral or underground movement of water are possible, levees should be used wisely in conjunction with other structural and nonstructural flood control measures.

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