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Spatial, Temporal Variability and Trends within the Tributaries of the Huron River: Effects on the Frequency of Flooding

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SPATIAL, TEMPORAL VARIABILITY AND TRENDS WITHIN THE TRIBUTARIES OF THE HURON RIVER: EFFECTS ON THE FREQUENCY OF FLOODING

by

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SPATIAL, TEMPORAL VARIABILITY AND TRENDS WITHIN THE TRIBUTARIES OF THE HURON RIVER: EFFECTS ON THE FREQUENCY OF FLOODING

Cheyenne India Stewart, M.A.

Western Michigan University, 2016

The Huron River, located in the Great Lakes Region, Michigan, USA is a symbol of success, wealth and prosperity to the residents of Southeast Michigan. In the last 20 years, the river has been subject to degradation due to high growth rates of urban cities and often experience the cumulative effects of channelization, pollution from point and nonpoint sources, as well as a decline in wetland area and quality. Urbanization in watersheds of stream channels has intensified many incidences of flooding in metropolitan areas over the past few decades. Causes for the decrease in the capacity of the Huron River to handle streamflow are not limited to channelization, changing climate, and urbanization. This study will investigate possible influences from land use/land cover change (LULCC) and precipitation to extreme streamflows in selected subwatersheds during the summer season (June, July, August). Spatial and temporal variations will be presented for both extreme streamflows and precipitation, as well as their associations with the LUCCC between 1992 and 2011 to address and quantify how LUCCC and precipitation alter the flooding risk (frequency and magnitude of extreme discharges) in selected watersheds of the Huron River.

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This thesis represents not only my work at the keyboard, it is a milestone of two years of work at Western Michigan University, specifically within the department of Geography. Since my first day on September 1st 2014, my experience at WMU has been nothing short of amazing. Therefore, I would like to extend my thanks for the many people who made this thesis possible.

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Acknowledgments—Continued

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Cheyenne India Stewart

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CHAPTER I

INTRODUCTION

Rivers and streams are crucial dynamic features which sculpt the Earth's landscape that they meander across. The intimate relationship between rivers and the land dates back to ancient times, where earth and water were used to sustain life. This custom persists even today, as towns, cities and industries seek land close to rivers for growth, mobility and accessibility. Geography is playing a more important role in studying and understanding how anthropogenic activities transform land use and land cover and water quality regionally and globally through remote sensing, historical data analysis, climate change, and Geographic Information Systems (GIS) (Henderson et al. 2001; Grimm et al. 2008).

The Huron River watershed is a major watershed located in southeastern Michigan and has many concerns including increased erosion, water quality, pollution and change in the river's regime. These affect residents, stakeholders, government and regional agencies who look to the river for subsistence, recreation, hydropower and revenue. The watershed and the riverbed has fluctuated within the last twenty years, due to channelization, urbanization, loss of sustainable vegetation and inconsistent conversation efforts (Carpenter et al., 1998; Klose, 2012). Studies have analyzed small portions of the Huron River (Aichele 2005), in an attempt to understand and mitigate the effects of river flooding. Results have yielded only the tip of the iceberg in understanding the delicate nature of the Huron River watershed as it has been rapidly urbanized.

Problem Statement

Hydrological studies are performed at different spatial scales, the spatial scale almost always being closely related to the study purpose. Understanding the behavior of a river at a watershed scale allows for the analysis and comparison of different subwatersheds, which are crucial in explaining how an entire system functions. The watershed scale allows for the opportunity for large scale best practices to be implemented effectively, while still understanding small, localized scale components of the watershed.

This study will investigate possible influences from land use/land cover change (LULCC) and precipitation, and correlate these variables to extreme stream flows in selected subwatersheds during the summer season (June, July and August). Spatial and temporal variations will be presented for both extreme stream discharge flows and precipitation, as well as their associations with the LULCC between 1992, 2001, 2006 and 2011 to address and quantify how changes in LULCC and precipitation such as frequency and magnitude of extreme discharges in selected watersheds alter the flooding risk of the Huron River.

The results of this study will not only help improve the management of water quality within the Huron River system, but will also create a reference for adjacent rivers and tributaries near the Huron. While standing on the shoulders of other geographers that have come before me, this study will lay the foundation for further work related to the improvement of water quality within the Huron River drainage basin. If the water resources in the Huron River are properly managed for the present and in the future, crises like the 2014 Lake Erie’s toxic bloom will never occur. This study will also provide information about the change in LULC over twenty years, and the implications of those land changes. Finally, I also hope to determine water quality in the Huron river tributaries, which presently is in good condition, but still requires continued monitoring to maintain adequate drinking water quality and natural sustainability.

Organization of Thesis

The thesis is structured into seven (7) chapters. Chapter II reviews relevant literature on global analysis of flooding, factors that affect flooding, past studies on the Huron River watershed, public awareness and impact factors, and other research methods already used. Chapter III discusses the study area, as well as geomorphology of its accompanying subwatersheds. Chapter IV describes the methodology used in this study; including data sources, GIS techniques, variables considered, and analysis of change. Chapter V analyzes the impacts of each variable, while Chapter VI discusses how each variable affects flooding within the Huron River watershed. Finally Chapter VII provides conclusions for this study and provides recommendations for future research.

CHAPTER II

REVIEW OF LITERATURE

Analysis of Flooding

There are many anthropogenic causes that account for the degradation of water quality and increasing flood events in rivers globally. Major categories of these causes include population increases, human activities, land use, and land cover changes, etc.

Population Density

Population has had unprecedented growth in the last century, contributing vastly to land changes to build cities and to support the demands of the rising population (Ehrlich & Holdren, 1971; Daily & Ehrlich, 1992; Cohen 1995; Grimm et al., 2008). Many of these cities have settled within the floodplain of rivers and it presents an ever-increasing problem. Expanding population settlements tend to cause higher stakes of flooding risk within urbanized regions (Klein, 1979; Pielke & Downton, 2000), while urbanization leads to fragmentation of diverse landscape, massive changes in biogeochemical (CO_2, O_3) and climate (temperature) cycles, air pollution, generated wastes and increased precipitation (Grimm et al., 2008). Increased population also affects the channelization of rivers, and therefore their ability to carry excess loads of precipitation. Human activities also strongly influence light and nutrient concentration, conductivity, sedimentation, and disturbance frequencies in river and lake systems.

Channelization

Channelization is a mitigation technique for draining non-permeable surfaces and flood control. It involves altering the river’s natural flow patterns by restructuring and relocating the streambed and stream banks, as well as removing riparian and surrounding vegetation which acts as a natural buffer for the river (Brookes, 1985). When a riverbed or tributary is channelized, the riverbed is usually widened, deepened, straightened and cleared of any vegetation which may make it look unappealing (Brookes, 1985). The changes in streamflow, pattern and path can have immense effects on stream hydrology and morphology (Klein, 1979; Newbury & Marcel, 1988; Paetzold et al., 2008), and can in turn cause a river to develop 'flashy' characteristics (Nelson & Palmer, 2007). Consequences of channelization may include increased stream velocities (Harvey & Watson, 1986; Paezold et al., 2008), increased sedimentation and erosion along the lower reaches of the river (Klein, 1979; Ruhl, 2000), decreased bank stability, decreased flow retention, decreased aquatic invertebrates (Ragan et al., 1977; Gregory et al., 1991; Osborne & Kovacic, 1993), decreased stream length and decreased potential for any remaining marine or streambank vegetation that promote flood control (Cobb et al., 1992).

Land Use & Land Cover Change

Land use and land cover is not only affected by population increases, but also by urban growth, agriculture and economic activities. Impervious surface introduced by urbanization is one of the major causes of intensified surface runoff and commercial, industrial and municipal discharges of contaminants into streams. These surfaces lead to impairment of stream biology, stream ecology and the change in stream hydrology and geomorphology (Paul & Meyer, 2001; Strayer et al. 2003; Walsh et al. 2005; Li et al., 2008). Ragan et al. in 1977 studied LULC and the impact of urbanization on stream quality on tributaries within Washington DC, United States. His area focused in populated areas close to the river bed, and in areas where storm sewers entered the stream directly. His results showed that although most areas of the tributaries still showed good water quality, and urban land use was well planned for the region, the magnitude and frequency of flooding had increased due to impervious surfaces.

Agriculture is also an important human necessity in sustaining population. Irrigation promotes manmade nutrients such as nitrogen (N) and phosphorus (P) and increases eutrophication and degradation of rivers (Anderson et al., 2002; Li et al 2008). These nutrients inhibit marine and riparian growth, which act as buffers against volatile rivers. Klose (2012) in his research showed increased water temperature and deteriorated water quality in the Ventura River in California though the increase in nutrients and algal biomass.

Wetland filling and drainage are also important factors affecting land use and land cover change within a watershed. Approximately 80% to 95% of wetlands are drained and converted for agricultural purposes (Meyer & Turner, 1992), while human constructed drainage results in massive reductions in wetland area, both at local and regional scales (Allan et al., 1997). These drainage systems such as storm sewers, not only directly impact the land cover by its impermeable surfaces, but also affect watershed and wetland area and effectiveness by changes in drainage densities and overland flow paths (Hollis, 1975; Knighton, 2014).

Wealth is also another important factor in the changes in land use and land cover. The proportion of a country’s population residing in urban regions is highly correlated to its level of income. (Bloom et al., 2008). Pielke & Downton (2000) showed that an increased wealth of the population was a causation to higher damages and increased precipitation throughout the United States over time. This was due to land use, climate, human impact on hydrology and the lack of enforcement and mitigation methods. These factors resulted in varying degrees of costs of flooding damages. In addition, many urban areas around the world, especially in developing countries, are developing at an substantial rate with significant population growth and asset accumulation, which further exacerbates the vulnerability of cities and urban regions to climate-related hazards like floods (Lebel et al., 2011).

Impacts of Anthropogenic Activities & Public Awareness

In the United States, urbanized wetlands have been wrought with underlying problems of impervious surfaces due to parking lots, high housing density areas, and roads. They lead to less infiltration of precipitation, more surface runoff, and ultimately, more flooding occurrences (Carpenter et al., 1998). Active environmentalists have raised awareness on issues of water quality, urbanization, and the effects of flooding and the economic and ecological importance of the river through the use of events, cleanups and public education. However, the importance of human expansion for irrigation, residential and commercial areas often outweigh the drawbacks of settling within a watershed. Galat et al. (1998) performed controlled flooding since 1993 and has mitigated against losses in wetlands, and rising flooding occurrences in urban regions along the Mississippi river, using controlled flooding. This was completed in an effort to lessen flooding occurrences along the Mississippi River, a major industrial and commerce location. However, the water passing through these controlled flooding events is only a miniscule portion of actual problems of channelization, decreased waterways, and increased precipitation in urbanized watersheds.

Public awareness though regional and local agencies have also risen within the last 30 years due to concern of that degraded rivers may finally affect the lives of communities who lived alongside failing flood control, foul smells from industrial and agricultural wastes, and erosion of properties (Carpenter et al., 1998; Ruhl, 2000). However, a greater extent of education and understanding is needed before larger decisions are made in the protection of urban rivers. Flood insurance and flood policies today have given the public the misconception that insurance, levees, embankments and dams will protect against floods, causing people to build and settle in floodplains (Ntelekos et al., 2010). National Flood Insurance Program (NFIP) plans in the United States today also do not effectively address the flood problem, instead only addresses outcomes, damages and future projections of flood costs within cities (Ntelekos et al., 2010). These plans act as a 'safety net' for flood prone developed regions and cities, where having insurance lessens the perceived risk of river floods and increases the attraction of settling in floodplains (Oosterberg et al., 2005).

In attempts to manage watershed quality and sustainability, local and regional agencies have adopted practices to minimize the impacts of anthropogenic activities. As public participation is seen as a viable method in watershed management, contact through newsletters, public meetings, informational programs and door-to-door contact were used to educate people living in proximity of tributaries (Duram & Brown, 1999). Integration of federal and state efforts to reduce erosion and nutrient loading has also been implemented to improve watershed quality. These include planting of riparian vegetation to increase channel shading as well as storm water management (Paul & Meyer, 2001; Taylor et al., 2004). Watershed councils also have introduced programs where landowners in proximity to a tributary adopt a stewardship role in an effort to maintain stream health (Booth et al., 2003). These best practices have been important in maintaining stream health to a certain degree, however, are only effective when implemented consistently and maintained year round. At present time, restoration processes and storm water management due to inhibited streams have now become the forefront of sustaining these rivers, which are located at many urban centers (Paul & Meyer, 2001).

The Huron River System

These changes are not just problems of coastal areas of Lake Huron, but also along other Great Lakes regions in Michigan. The Southeast Michigan Council of Governments projected that between 1990 and 2010, the population of southeastern Michigan will increase by 6% percent and urban land area will expand by 40% (Hay-Chmielewski et al., 1995). The watershed area has experienced substantial economic growth and development due to its proximity to suburban Detroit, with high growth rates and the accompanying problems that stem from population increases, highway and infrastructure improvements, as well as the desire for open spaces (Bobrin & Huron River Watershed Council, 2008).

Part of this expansion has occurred within the Huron River watershed. The Huron River is a symbol of peace, prosperity and wealth to the people of Southeast Michigan. The river flows approximately 130 miles through three (3) counties and joins Lake Erie at Pointe Mouilee (Knott & Taylor, 2000). The river has tremendous recreational potential as it flows through major population centers including Ann Arbor, Ypsilanti, and Detroit (Hay-Chmielewski et al., 1995). Many people, both residents and tourists, flock to the river and its tributaries and lakes to take advantage of fishing, canoeing, rowing, motor-boating, wind surfing, sailing, swimming, picnicking, hunting, trapping, nature study, and bird watching opportunities (Hay-Chmielewski et al., 1995; City of Ann Arbor, 1999). In the north of the watershed, counties such as Livingston and Oakland have seen some of the fastest increases in development growth within the state of Michigan. Within Livingston County, less than 15% of the land within town areas of Hamburg, Brighton and Genoa are in agricultural use and more than 51% of available land is used for single family residential development (“Comprehensive Economic Development Strategy (CEDS)”, 2014).

Water samples from most stretches of the river system demonstrated good water quality, however, due to urbanization, certain portions now suffer some degree of degradation through both point and non-point source pollution (Hay-Chmielewski et al., 1995). Urbanization has also caused a decline in wetland area and quality, as well as a loss of resident native plants (Rutledge & Lepczyk, 2002). Even in the 1990's, much of the mainstream Huron River was affected by moderate nutrient enrichment and turbidity from tributaries including Mill Creek, Honey Creek, Allen Drain, Traver Creek, Fleming Creek, Pittsfield Drain, Swift Run Drain, North Campus Drain (Hay-Chmielewski et al., 1995)

Through regulations associated with the Federal Clean Water Act of 1972, the amount of untreated waste dumped into the Huron River has been curbed, but urbanization and non-point source runoff from agriculture still play major roles in the degradation of the Huron River (Knott & Taylor, 2000). The Huron River Watershed Council (HRWC), through the use of events, cleanups and public education has helped raise awareness on issues of water quality and the economic and ecological importance of the river (Knott & Taylor, 2000). To combat flooding, about 650 communities or local units of government that have flood-prone areas participate in the National Flood Insurance Program within Michigan. This flood-hazard program documents floods, mitigates and regulates against flooding disasters within the state of Michigan (Paulson et al., 1991). However, increased urbanization bring a variety of problems including polluted storm runoff, stream channelization and issues related to the integrity of the tributaries as the paved surfaces associated with the growth in residential and transport areas expand. Continued growth of urban centers could also have drastic effects on watersheds including public health, stream diversity and the vitality of impacted areas. Maintaining good water quality is a key method to providing short and long term solutions to many of problems discussed above, therefore, analysis of water quality variables such as precipitation and stream discharge will be an important part of the thesis analysis.

Methodologies Used

Scientists have used a wide range of methods to determine spatial and temporal variability of rivers. Those include basic observation of the river discharges and water quality monitoring, visual interpretation of patterns and trends through historical data and graphs, as well as statistical tests such as the non-parametric Mann-Kendal Test and rigorous physical hydrological models such as the Soil and Water Assessment Tool (SWAT) and Regression Analysis (Spruil et al., 2000; Gemmer et al., 2004; Gao et al., 2013).

Water quality monitoring by collection of water samples is a common strategy in tracking spatial and temporal changes within a tributary or watershed (Lumb, 2011). The Water Quality Index (WQI) is created by the National Science Foundation (NSF) in 1965 to express water quality by an indexed numerical value that is based on physical, chemical and biological measurements (Lumb, 2011). The model yields a number that can be categorized as excellent, good, fair, marginal or poor.

$$\text{WQ Index} = \{100 - \left(\sqrt{(F1^2 + F2^2 + F3^2)}\right) / 1.732\}$$

The Oregon Water Quality Index is quite similar, as it measures water quality through the assessment of eight variables. These variables are temperature, pH, dissolved oxygen, oxygen demand, total phosphorus, total solids, ammonia/nitrate and fecal coliform (Cude, 2001). This test is usually used to determine the quality of water for recreational uses, to scout for algae and to determine other water quality issues. Lehman (2007) used the WQI to collect water samples weekly in the Huron River from June through October and analyzed them using the WQI for pigment determination. Busse et al., (2006) used regression models to analyze correlations between total phosphorus (TP) and other variables such as nitrogen, water temperature and conductivity.

Observation of historical discharges is a strong method in determining factors that may be related to deteriorating conditions, such as flooding or sediment discharge, within watersheds. Chen et al., (2001) analyzed historical stream discharge observations that were being diverted for irrigation, and the effect they had on the Yangtze River watershed within China. There was an increase in sediment load along the river and at dams due to human settlement. They also demonstrated how sediment discharge within the river increased due to irrigation, urbanization and agriculture along the middle and lower reaches the river, where precipitation and urbanization was more prominent. Within the United States, Zhu et al. (2013; 2015) analyzed daily precipitation and river stream discharges over 60 years within the San Jacinto River watershed, located in Houston, Texas. It showed that extreme precipitation affected approximately 65% of observed extreme discharge events recorded. Results also showed that due to changes in land use and land cover within the vastly populated regions of Houston, the more developed watersheds tended to have higher ranges and frequencies of extreme stream discharges. In Michigan, USA, Aichele (2005) observed effects of urbanization on the water quality of tributaries within 14 watersheds Oakland County, Michigan from 1996 to 2000 using variables such as urban development, stream discharge variability, nutrient enrichment and population density. His results showed that stream discharge had increased, while water quality had decreased in certain sub-watersheds in Oakland County, Michigan. This was due to urbanization processes and increases in impervious surfaces.

Spruill et al. (2000) utilized the Soil and Water Assessment Tool (SWAT) that includes stream discharge, temperature and precipitation to determine simulated streamflows from excess precipitation in Karst regions. This model was created and calibrated to predict and explain monthly discharges variations related to changes in precipitation, fast drainage and lateral subsurface flows. Physical based hydrological models like SWAT is a strong tool in determining stream flows within watersheds, but the purpose of this research is to explore the historical flooding events and LUCCC within the Huron River basin. So those hydrological modeling work will be the next step plan after the completion of this thesis.

The non-parametric Mann Kendal Test for observing spatial and temporal trends is another common strategy for determining temporal changes in different streams, climate and human variables. Factors such as air temperature, precipitation, stream discharge and population are some of the variables can be observed over time and correlated with urbanization and changes in the watershed. (Gemmer et al., 2004; Jiang et al., 2007; Kumar et al., 2009; Gao et al., 2013). This statistical test is viable for trend detection because it is extremely robust against outliers, unbiased against missing data, and works well for long time series (Gao et al., 2013). Many past studies on hydrological trends were performed this powerful statistical analysis.

Jiang et al. (2007) analyzed precipitation data in the Yangtze River basin between 1961 and 2000 and showed a positive trend of precipitation within the watershed during the summer months. This increase in precipitation was due to increasing rainstorm frequency, due to changes in atmospheric circulation and monsoon season fluctuations. Results showed that this increased precipitation and the resulting increased surface runoff could have serious impacts to the human settlement along the lower the Yangtze River, which are extremely vulnerable to flooding.

Gao et al. (2013) also utilized the Mann Kendal test to analyze observe trends in stream discharge, precipitation and air temperature over a period of 75 years within the Wei River Basin, China, which is the largest tributary of the Yellow River. Trend analyses showed correlations between urbanization contributing to stream sediment and stream discharge fluctuations, which may affect the sustainability of the watershed in future years.

Finally, regression analysis is also used to determine correlation between variables to explore their statistical relationships. It has been used to determine how variables can have an effect on flooding. Jiang et al. (2007) in his Mann-Kendal test also utilized simple regression to measure the relationship between precipitation and runoff over time. In analyzing the impact of human activities and precipitation on stream flow and sediment discharge, Gao et al. (2013) also determined the statistical significant correlation between increasing human activities and sediment discharge along the Wei River in China.

From many applicable methods which were used by scientists in their research, this thesis focuses on observation of the river discharges, water quality monitoring, visual interpretation of trends and patterns within historical data and graphs, observed digital changes in land use and land cover, as well as patterns in summer precipitation to understand how the Huron River tributaries and its subwatersheds varies spatially and temporally.

CHAPTER III

STUDY AREA

Huron River Watershed

Over 15,000 years ago, the Huron River originated as a small stream draining the late Pleistocene landscape (Wittersheim 1993). The Huron River currently flows approximately 130 miles through seven (7) counties and joins Lake Erie at Pointe Mouilee (Knott & Taylor 2000). The Huron River flows from Oakland County through Livingston, Washtenaw and Wayne County, with tributaries in small portions of Ingham and Jackson County. It finally drains into Lake Erie in Monroe County (see figure 1). The Huron River watershed is located in the south-eastern part of Michigan, United States of America, longitude 83°29'43.5"W and latitude 42°42'41.5"N. The basin area is 908 square miles (2,350 km) and has a length of 130 square miles (210 km). The river flows in a south-westerly direction from its origin in the Huron Swamp in Andersonville village, Oakland County, Michigan to Dexter, Michigan, and then changes direction to flow in a south-eastern direction through Ann Arbor, Ypsilanti, and Flat Rock, Michigan respectively. The elevation of the river ranges from its source elevation of 1001 feet (305m) to 571 feet (174m) at its mouth above mean sea level and empties into Lake Erie at Rockwood and Pointe Mouliee, Michigan.

As a region of mostly recessional moraines, the current surface topology of the watershed was created by the last continental glacial period called the Wisconsin (Michigan Department of Natural Resources, 2002). This glacial retreat gouged out the current drainage patterns to what it is today. On September 27, 1963, the city of Ann Arbor agreed to pay $400,000 over a five year period to Detroit Edison for the purchase of land along the Huron River. This purchase tripled the land owned by the city of Ann Arbor for park and recreation purposes (Butz 1993). The Huron's upper third reach is clear and fast, even supporting a modest trout fishery. The middle third passes through and around many lakes in Livingston and Washtenaw Counties. Prior to European settlement, the land cover consisted of mostly forested regions including oak, hardwood, lakeplain prairie and wetland, however, due to human settlement, the land cover has been converted to the clearing of grassland and forests for cultivated crops, housing and development (Bobrin & Huron River Watershed Council, 2008). The lower third reach consists of an elongated riverbed due to dammed streamflow where commerce, industry, and highly developed areas dominate the land use around the lower tributaries of the Huron River. Eight dams impede much of the Huron's lower third as it flows through the populated regions the river helped create. From these eight dams, Kent Lake, Barton Pond, Argo Pond, Ford Lake, Belleville Lake, Geddes Pond and Flat Rock Pond were formed.

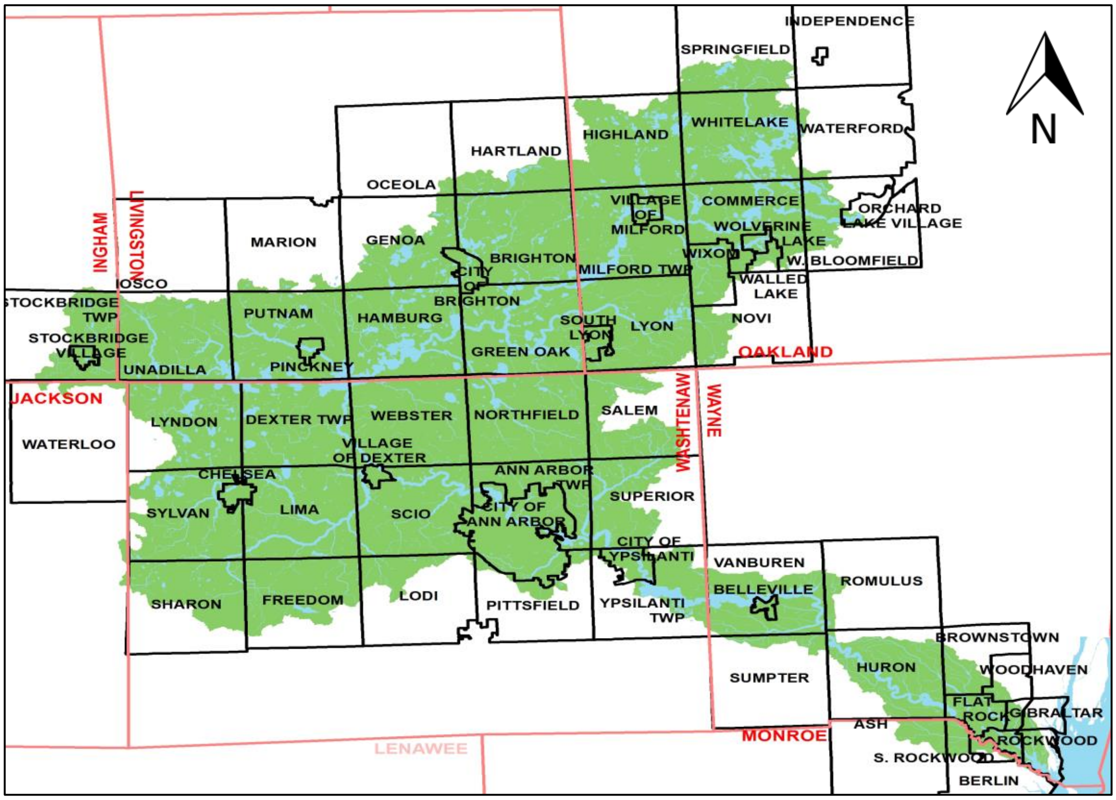


Figure 1. The Huron River and its tributaries, situated in Southeast Michigan, USA. Source: http://www.hrwc.org/wp-content/uploads/2015/01/CreekshedsCommunitiesForBlog2015.jpg

Geomorphology

According to the Michigan Data Library for Geographic Information, the Huron River has unique subwatersheds within its compound. For the sake of the study area and its research, these watersheds were combined into six (6) main subwatersheds using baseflows, digital elevation models and global positioning system coordinates of known stream gauges within the watershed. These subwatersheds are Milford, New Hudson, Hamburg, Dexter Mill-Creek, Ann Arbor and Into Lake Erie (Figure 2).

Each subwatershed has its own unique properties including its geology, hydrology, and how each subwatershed affects ones in the lower stream. Most of the soils in the upper watershed of the Huron River above Ann Arbor are made up of sandy loam and sand-clay mixtures, while clay and silt loam make up the contents of soil mixtures around the Ann Arbor area (Michigan Department of Natural Resources, 2002). Below Ann Arbor, most of the soils are a mixture of pebble clay and sand while the soil close to the mouth of the river is made up of mostly wet, fine sand. Precipitation and snowfall throughout the Huron River watershed is fairly well distributed with the average rainfall being approximately 30.6 inches and snowfall 37.5 inches annually (Michigan Department of Natural Resources, 2002). Since its cutout from the first glaciers, the Huron River has changed course multiple times, even reversing at one point, until it settled into its current pattern.

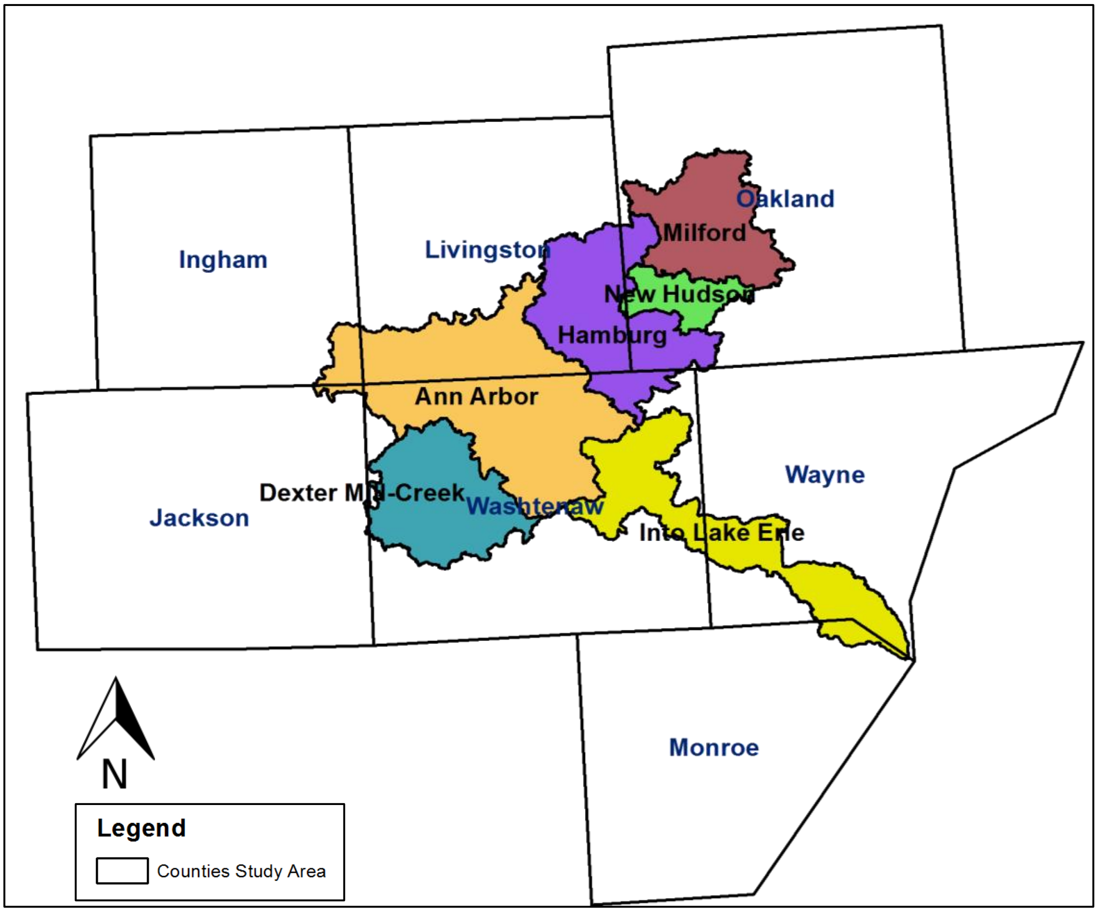


Figure 2. The Subwatersheds of the Huron River within the Study Area

Milford’s subwatershed is located at the northernmost portion of the Huron River watershed, in Oakland County, Michigan. The city of Milford is well known for its proving grounds for the multinational corporation General Motors Company, an entity that tests, manufactures, and produces vehicles and vehicle parts for sale worldwide. The watershed is mostly forest and agricultural land with a small population centered in its city. The city of Milford takes water from both the Huron Lake and Lake St. Clair, as well as the Huron River and its tributaries. Much of the infrastructure and rises in population today is due to expansion and production of cars which are tested inside testing facilities, as well as around the roads of Milford, but most of the watershed was largely untouched in the early 1990's.

New Hudson is a small but recognized community within Lyon Charter Township, located within Oakland County, Michigan. It is the smallest subwatershed within the Huron River watershed, at a size of only 40 square miles, but supports a larger population density than that of Milford. Compared to the larger subwatersheds, much of New Hudson's land cover is mostly forest.

The Hamburg subwatershed is located within the county of Livingston, Michigan. The northwest portion of the county is generally composed of till or outwash plains, while the southeastern portion of the county is generally characterized by end moraines ("Comprehensive Economic Development Strategy (CEDS)", 2014). As the largest township in Livingston County, much of its population is centered in suburbs, more notable ones including Hamburg, Whitmore, Pinckney and Brighton. Much of the water in this watershed is contained in ponds, marshes and lakes as well as large sections of the Huron River, which has caused numerous flooding incidents since the early 2000's ("*Hamburg Township Flooding Response Action Plan*", 2014; National Weather Service, 2015). Flooding occurrences are well known throughout the townships, with notable stream discharge records and destruction of property in Hamburg townships causing some of this watershed to be a participant of the National Flood Insurance program and policy. Hamburg's watershed was mostly agriculture in the 1990's, however, now it lends its land cover for more urbanized purposes, such as housing.

Ann Arbor's subwatershed spans three (3) counties, which include Ingham, Jackson and Washtenaw County. It is currently the largest subwatershed in the study, with a size of approximately 296 square miles. According to the 2010 United States census, Ann Arbor is the sixth largest city in Michigan and the largest city within the Huron River watershed at a population of 113, 934 people, and 344,000 in its surrounding metropolitan areas. The majority of the land was used for agriculture in the 1990's, with concentrated pockets of urbanized areas.However, this has changed in recent years, with urbanized regions expanding more and encroaching on forested and cultivated cropland. Most of the growth within Ann Arbor is due to higher education opportunities, and research and development. The University of Michigan is one of the most renowned research universities in the United States, and its health and medical center has been growing. Another major factor of growth is due to the increasing density infrastructure of roads, industrial railways and surrounding international airport gateways.

The final watershed of the Huron River encompasses the mouth of the river, draining into Lake Erie. Beginning at Ypsilanti, this subwatershed's river topology is narrow and flat, and continues to widen slowly each year. Located in Wayne and Monroe County, Michigan, this elongated watershed is lined with industries and urbanization all along its banks. One of the most notable firms along the riverbank is the Ford Motor Company, which assembles and manufactures vehicles and automotive parts. This subwatershed also includes important infrastructure such as railways and major highways, and is in close proximity to international boundary of Canada. This watershed also includes Edison Lake, which was created from a large dam situated along the Huron River and provided hydroelectric power until 1962. Much of this watershed is urbanized, with most of its population being shared in the metropolitan areas of Ann Arbor and Detroit.

CHAPTER IV

METHODOLOGY

In understanding spatial and temporal variations in a river and its potential for flooding, many variables can be explored. Three major components were investigated: land use and land cover, trends of occurring stream discharge, and precipitation from rain and snowmelt.

Assessment of LULC Change

In monitoring the change in land use and land cover over a period of time, scientists have discovered that urbanization is one of the leading causes of flooding in rivers (Hollis, 1975; Brown et al., 1997; Petchprayoon et al., 2010). Increases in urban regions lead to a decrease in farmland area and surface roughness to slow surface runoff while a marked increase is seen in impermeable land surfaces and peak discharges (Barlage et al, 2002; Shi et al., 2007). Land use and land cover data can be monitored though the acquisition of aerial photos or satellite imagery taken from LANDSAT MSS and TM images taken over a period of years (Pelorosso, Leone & Boccia 2009). Software methods used to analyze this remotely sensed data can vary from ArcGIS (Dewan & Yamaguchi 2009), Erdas Imagine (Yuan et al., 2005) to ENVI (Srivastava et al., 2012), with each software posing advantages. Each software package has its own advantages, with ENVI effectively interpreting remote sensing imagery, and Erdas Imagine with is ease of analyzing land use, land cover change of urban development and change detection studies. Within this thesis, ArcGIS will be the software of choice as its advantages include GIS processing and analysis, interactive map querying, being able to handle large amounts of data, and the ease of accessing and exporting digital map data.

Data retrieval and usage

To investigate the relationship between urbanization, river discharge and precipitation, land use and land cover data was downloaded from the Multi-Resolution Land Characteristics Consortium National Land Cover Database (MRLC NLCD, 2016). The MRLC Consortium is a department within the United States Geological Survey Land cover Institute (USGS LCI), and is a partnership of federal agencies that coordinate and generate land cover information for personal, environmental and modeling applications. Digital maps were retrieved for the years 1992, 2001, 2006 and 2011. For each year the LULC raster file was imported into ArcGIS. Each dataset had a pixel size and resolution of 30 meters by 30 meters. From the Michigan Data Library (MiGDL), which provides geospatial data of the state of Michigan to the public, the shape file layers for Michigan State's counties, watershed boundaries, river baseflow and digital elevation models were downloaded and imported into ArcGIS. Using the Spatial Analysis Tool within the ArcTooblox of ArcGIS, The extraction tool was used. From this tool, I extracted the data by the 'Extract by Mask' command. The data was then extracted to a state boundary of Michigan shapefile map. Using research on the counties where the Huron River flows through, the seven (7) counties of Washtenaw, Livingston, Oakland, Wayne, Jackson, Monroe and Lenawee were selected from the Michigan State Boundary shapefile map using the 'Select by Location' and 'Identify' tools. LULC data was further extracted for this study area using the 'Extract by Mask' command again to narrow the study area down to the counties in which the Huron River flows through.

To determine the Huron River watershed boundary, the counties in which the Huron River flows through shapefile map extracted from the MiGDL was cut down to the shape of the Huron River watershed. This was completed by using Michigan's baseflow shapefile map and identifying the subwatersheds in the shape of the Huron River Boundary and creating a layer from the selected features. Finally, with the boundaries identified, the LULC data of the whole study region was then masked using the ‘Extract by Mask’ command with the newly created watershed layer and the former extracted LULC from the seven Michigan counties. This allowed the analysis of LULC only within the Huron River watershed (Figure 3).

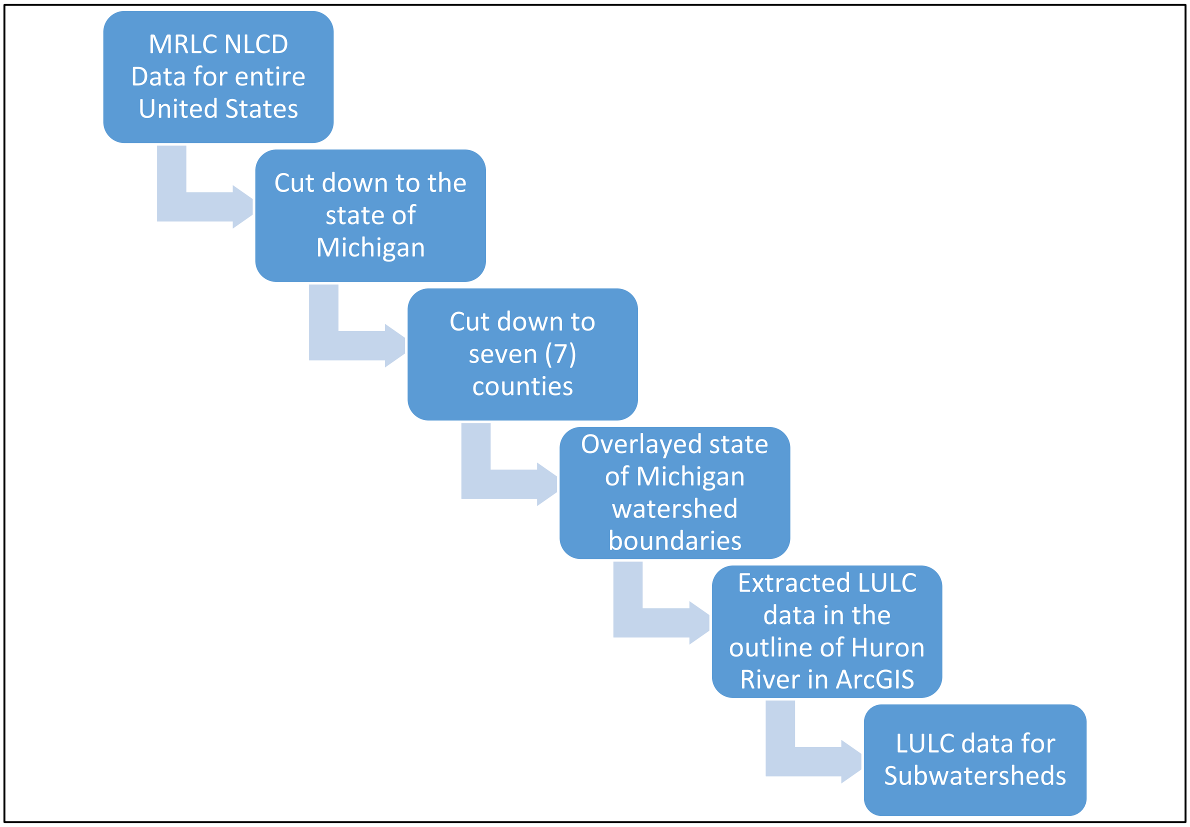


Figure 3. Breakdown of Land Use Land Cover Data for Study Area

Reclassifying LULC data

The legend of the MRLC LULC data have a total of 21 different classes for 1991 and 20 different classes for 2001, 2006 and 2011 for the United States of America. This classification was deemed too specific for proper analysis of the Huron River LULC data, therefore the categories were reclassified to ensure that all 4 years of my LULC data would be consistent. The reclassification of the LULC data was preformed within ArcGIS, utilizing the Reclassify command in the Reclass toolset.

Table 1

Reclassified Legend in ArcGIS for Land Use and Land Cover

Original Classification Legend	**Reclassification Legend**	**Description**
Open water, Perennial Ice/Snow, Woody Wetlands, Emergent Herbaceous Wetlands	Water/ Hydric	Areas of open water. Areas of wetland regions.
Developed: Low Intensity	Developed: Low Intensity	Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover.
Developed: Medium Intensity	Developed: Medium Intensity	Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover.
Developed: High Intensity	Developed: High Intensity	Highly developed areas where people reside or work in high numbers. Impervious surfaces account for 80% to 100% of the total cover.
Barren Land, Quarries	Quarries/ Barren	Strip mines, gravel pits, areas of bedrock. Generally, vegetation accounts for less than 15% of total cover.
Deciduous Forest, Evergreen Forest, Mixed Forest	Forest	Areas dominated by trees generally greater than 5 meters tall. Greater than 20% of total vegetation cover.
Developed: Open Space, Shrub, Grassland, Sedge, Pasture/ Hay, Cultivated Crops	Grasses & Agriculture	Areas used for the production of annual crops. Areas of grasses or herbaceous vegetation.

There were 10 new classes within the new legend for the LULC data. The color scheme for my reclassified data was determined to correspond as close as possible to natural colors of that class. This is shown by water being colored as blue, urban areas colored as varying shades of red to portray density, quarries as light purple, forests as green, and agriculture and grasses as yellow (Table 1).

Determining subwatersheds

Global positioning system (GPS) coordinates were taken from each of the stream gauges within the Huron River watershed and converted from Degrees Minutes Seconds to Decimal Degrees coordinates. These coordinates were imported into ArcGIS as coordinate data, georeferenced and overlaid onto the Huron River shapefile. A digital elevation model (DEM) of Michigan from the MiGDL was also masked and extracted down to the Huron River watershed using the Huron River boundary layer and the “Extract by Mask’ command. Finally, the river baseflow digital map from the Michigan Data Library was obtained for the Huron River.

Using these parameters available, the Huron River watershed was then delineated into six (6) subwatersheds based on elevation of the land, the flow of the tributaries and the placement of stream discharge gauges from the United States Geological Survey National Water Information System (USGS NWIS). This was done by placing the DEM within the Data View window and displaying colored ‘Unique Values’ symbology to identify areas of high and low elevation. The placement of stream gauges at areas of low elevation on top of the DEM, as well as identifying choke points and lower order streams from the flow of the tributaries within the Data View window also helped delineate subwatershed boundaries. The final subwatersheds were renamed to their respective geographical areas as well as their USGS stream discharge gauges. The names are as follows: Milford, New Hudson, Hamburg, Dexter Mill Creek, Ann Arbor and Into Lake Erie subwatersheds (Figure 4).

Change Detection

Using ArcGIS area function, the area of the Huron River watershed and each subwatershed were calculated. Each subwatershed map was analyzed for total areas based on pixel numbers and percentages of each land use category, which include total urban area, total forested area and total agricultural & grasses area for 1992, 2001, 2006 and 2011. Data analyzed within each subwatershed scrutinized temporal changes within each watershed and determined which LULC categories had been most affected by spatial and temporal changes.

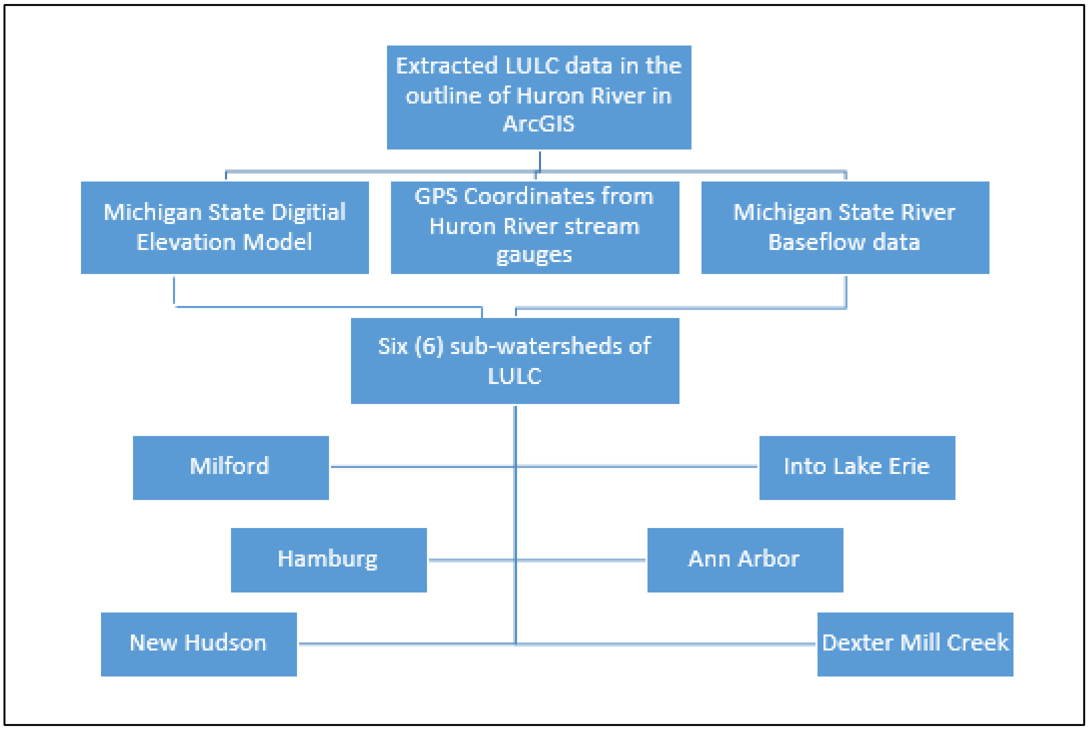


Figure 4: Breakdown of the Huron River into its Subwatersheds for the Study Area

Hydrological and Meteorological Data and Analysis

Precipitation

Extreme precipitation is a major factor contributing to flooding within urban rivers (Barrera-Escodea & Llasat 2015). As the water-holding capacity of the atmosphere increases with temperature, warmer temperatures suggest a higher potential of precipitation as well as more frequent rainfall events (Jiang et al., 2006). Higher temperature can be introduced by urban centers and impervious surface percentages, which intensifies localized precipitation events. Precipitation data in the United States is usually retrieved from the National Oceanic and Atmospheric Administration National Climatic Data Center (NOAA NCDC), a federal agency focusing on conditions of the atmosphere and oceans. Data was used from NOAA due to being easy in obtaining historic precipitation data and is a good source for accurate climatic data. Data retrieved is analyzed for variability in precipitation values and events (Karl & Knight, 1998; Jiang et al., 2006) and changes in seasonal or annual rainfall (Kumar et al., 2009). CPC Unified Gauge-Based Analysis of Daily Precipitation was extracted from CONUS Data using matrix laboratory (MATLAB) software with the help from my committee chair professor. The precipitation data was extracted for summer months of June, July and August for the years 1992, 2001, 2006 and 2011. Those daily precipitation observations were analyzed in comparison with their concurrent maximum stream discharge events, with a time threshold of four (4) days. The four days accumulative precipitation are calculated for all maximum stream discharge events. The total precipitation data was used for normalizing the stream discharges for each subwatershed.

Stream Discharge

Stream discharge data and their respective hydrologic codes (HU Code) were downloaded from the United States Geological Survey National Water Information System (USGS NWIS).

There are five (5) stream gauges, from which data were retrieved: Milford, New Hudson, Hamburg, Dexter Mill Creek and Ann Arbor gauges (See table 2). These stream gauges are maintained by the combined efforts of the U.S Geological Survey and partnerships between state, county, local and regional government entities (Huron River Watershed Council, 2016). The data from these gauges were recorded daily from 1950 to 2015.

Daily discharges in 5 stream gauges were generally low throughout the winter months from November to March, and then they had a large increase during the spring months from March to May. These changes were due to snow cover accumulation in the winter, and spring thawing respectively. This study will investigate summer months extreme flows cause by severe thunderstorms, so spring and winter months were excluded to avoid data noise.

Stream discharge time series were extracted for each subwatershed during June, July and August. Two (2) different datasets were constructed: the whole time series between 1990 and 2015, and 1992, 2001, 2006 and 2011 years when LULC data from the MRLC is available. The annual maximum summer month stream discharges were graphed for each subwatershed to identify trends temporally for the 1990 - 2005 dataset. For the 1992, 2001, 2006 and 2011 dataset, distributions of all summer daily stream discharge data for each subwatershed were explored by histograms with intervals of 25 mm. Stream discharge was then normalized by the area and the precipitation of each subwatershed and compared with percentages of urban, forested, and agricultural/grass land in the total area of subwatershed. Those analyses have purposes including determining if there has been an increase in stream discharge over the past 20 years, and determining if stream discharge is higher in different regions of the watershed based on land use change.

Table 2

USGS Data for Stream Gauges in the Huron River

Stream Gauges	HU Code	Latitude	Longitude
HURON RIVER AT MILFORD, MI	4170000	42°34'44"	83°37'36"
HURON RIVER NEAR NEW HUDSON, MI	4170500	42°30'46"	83°40'35"
HURON RIVER NEAR HAMBURG, MI	4172000	42°27'55"	83°48'00"
HURON RIVER AT ANN ARBOR, MI	4174500	42°17'13"	83°44'02"
MILL CREEK NEAR DEXTER, MI	4173500	42°18'01"	83°53'54"

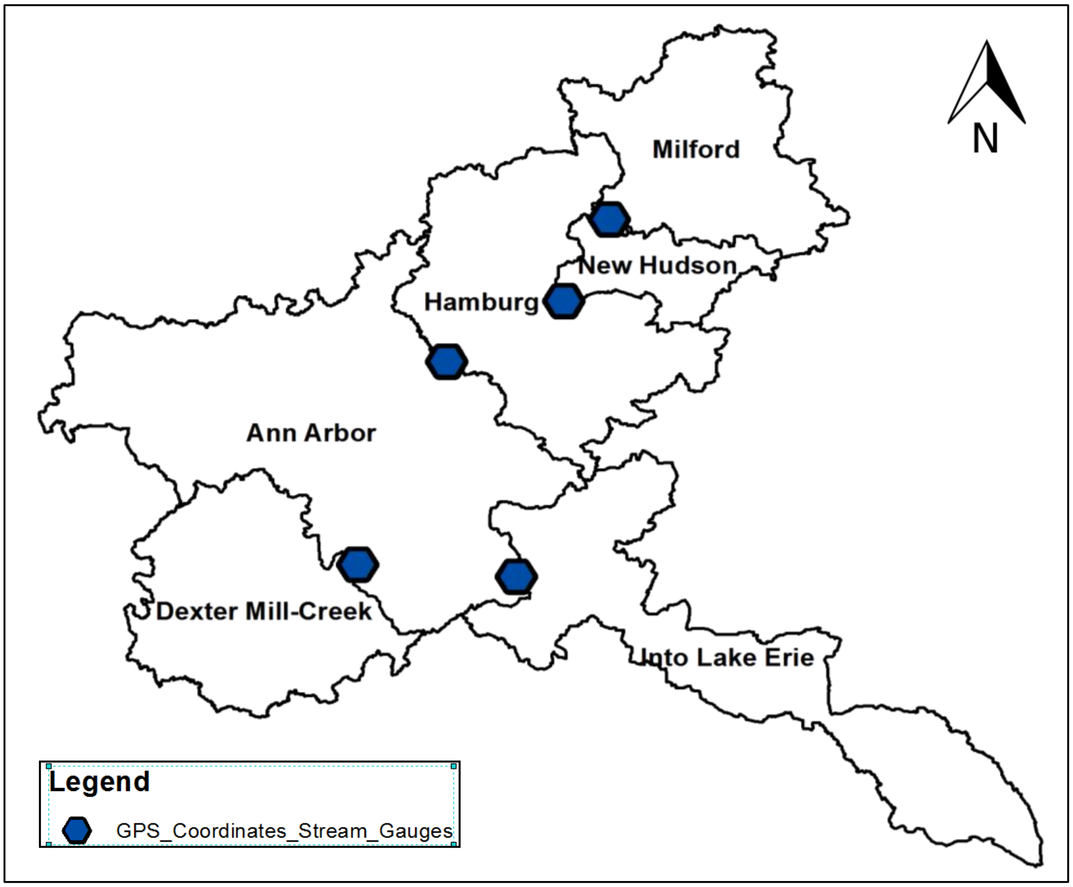


Figure 5. Stream Gauge Locations within the Huron River Watershed, Michigan

CHAPTER V

RESULTS

This chapter includes three (3) main parts. The first is the descriptive analysis of land use and land cover change for the whole Huron River basin as well as each subwatershed from 1992 to 2011. The second part investigates temporal variations in normalized stream discharge within subwatersheds of the Huron River and influences from different LULC. The third part looks at variations in precipitation and its relationship with the LULC. Each main part will focus on their specific prospective that is related to flooding within the Huron River watershed.

Land Use and Land Cover Change

Huron River Watershed

The MRLC National Land Cover 30m by 30m pixel values were analyzed in ArcGIS. It was noted that land use in the Huron River watershed is mostly agriculture and grasses, with the second highest land use category being forested regions during the study period (table 3). Between the periods of 1992 and 2001, most types of urban areas experienced some increases in size, while agricultural areas experienced major declines (7%). Between 2001 and 2006, there were still small increases in urban areas with at least a 0.2% increase in medium intensity urban and a 0.1% increase in high intensity urban areas. Between 2006 and 2011, urbanization stabilized somewhat, with marginal increases of 0.1% to 0.2% for each category of urban area. Agriculture, forest and grassland areas also decreased slowly throughout these same years, with an average loss of 1% in each category. Barren and quarry areas fluctuated slightly throughout the study while agriculture and grasses decreased by an average of 0.5%.

Table 3

LULC Pixel Counts & Area Percentage in Huron River Watershed, Michigan

LULC Pixel Counts					
Value	**Category**	**Count / (%)** 1992	**Count / (%)** 2001	**Count / (%)** 2006	**Count / (%)** 2011
11	Water / Hydric	361381 (13.68%)	503267 (19.05%)	502120 (19.01%)	501341 (18.98%)
22	Developed: Low Intensity	126456 (4.79%)	265877 (10.06%)	268786 (10.17%)	272027 (10.30%)
23	Developed: Medium Intensity	35331 (1.34%)	107761 (4.08%)	114020 (4.32%)	119066 (4.51%)
24	Developed: High Intensity	67424 (2.55%)	40054 (1.52%)	43277 (1.64%)	45787 (1.73%)
31	Quarries / Barren	15223 (0.58%)	14200 (0.54%)	21496 (0.81%)	18594 (0.70%)
43	Forest	732693 (27.73%)	589053 (22.30%)	581492 (22.01%)	576893 (21.84%)
71	Grasses / Agriculture	1303345 (49.33%)	1121641 (42.46%)	1110662 (42.04%)	1108145 (41.95%)

Figure 6 visually shows LULC categories with the most change. Just under 50% of the watershed is classified as Grasses/Agriculture in 1992, but decreases to only 42% in 2011. Developed regions increased from 8.5% in 1992 to accounting for 16.5% of the land cover in 2011, just under one fifth of the entire watershed's LULC. Cities such as Ann Arbor, Milford, and metropolitan Detroit experienced the fastest urban growth, demonstrated in increases in Low Intensity, Medium Intensity, and High Intensity development areas. Most of the forested regions are within the lower reaches of the Milford subwatershed and the Hamburg subwatershed in 1992. However, those areas showed extensive urbanization from as early as 2001. Therefore, a lot of forested regions in Milford and Hamburg's subwatershed have started to be depleted since 1992 and replaced by urban landscapes. Water bodies such as lakes and ponds seem to have developed within Dexter subwatershed throughout the study period, while the lower regions of the watershed slowly but gradually became more developed. The digital maps between 2006 and 2011 were mostly found to be almost identical, with most changes being from low urban development densities to higher urban densities, which was located in the most south-eastern part of the Huron River watershed.

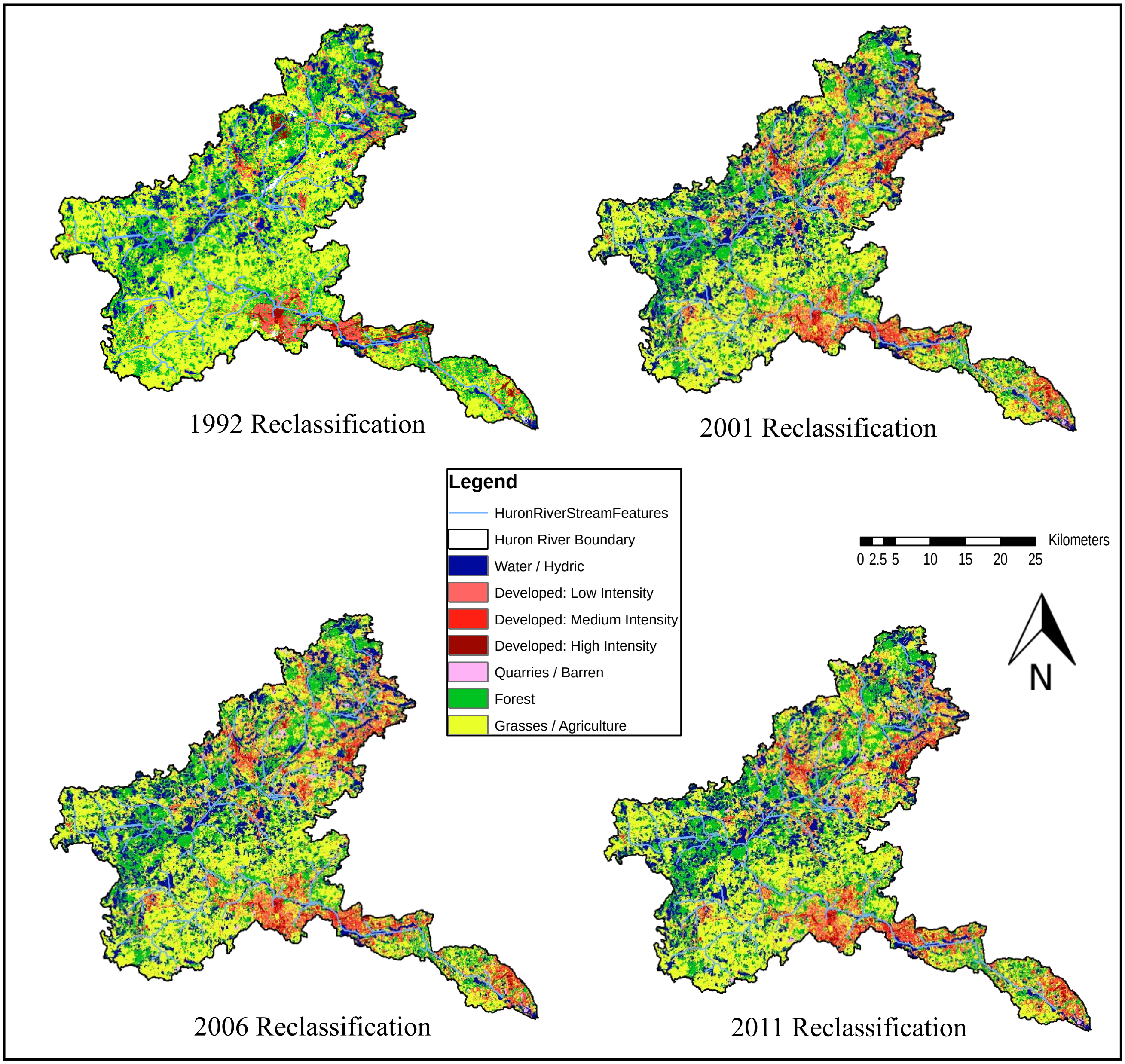


Figure 6. Land Use and Land Cover Change from NLCD for the Huron River, Michigan 1992 – 2011

Subwatersheds

On closer analysis of each subwatershed within the Huron River watershed, three (3) land use categories were considered due to their direct and indirect effect on flooding within the urbanized regions. These major categories are ‘Total Urban Area Pixels’, ‘Total Agriculture & Grasses Area Pixels’ and ‘Total Forest Area Pixels’ (Table 4). The percentage of each category was calculated to each subwatershed’s area as well as the whole Huron River watershed itself. The highest total percent changes occurred between 1992 and 2001 and urban regions had the largest increase of those categories. In 1992, only 8.62% of the watershed was classified as developed, however, development rose to 15.63% in 2001. The percentage of urban regions increased from 3.47% in 1992 to 5.43% in 2001 for Lake Erie’s watershed, and 0.46% in 1992 to 1.21% in 2011 for New Hudson’s subwatershed. The majority of the change to urban pixels occurred within the higher reaches of the watershed, as such as the case of Milford, New Hudson and Hamburg subwatersheds. Between 2001 and 2011, there was a continued expansion of urbanized areas, with an average of 0.2% in each of the subwatersheds. At the end of the study, approximately 16.51% of land cover was classified as urban development in the entire Huron River watershed.

Agriculture and grassland dropped by almost 10% in all subwatersheds between 1991 and 2001. Between 2001 to 2006, and 2006 to 2011, the decreases in agricultural areas continued with averages of 1%. The decline was not as large as between years 1992 to 2001, probably because so much transition from agriculture to urban land had already occurred. Agricultural pixel counts did not increase in any subwatershed during this time period.

Forested regions also declined throughout the study period. From 1992 to 2001, the New Hudson subwatershed decreased the most in forested area by 0.32%. Hamburg and Dexter Mill-Creek watershed followed with similarly decreases from 4.5% to 3.7% and 3.4% to 2.7%

respectively. Between 2001 and 2011, forested areas continued to decline, with the entire watershed having only 21.8% of its land cover classified as forest by 2011.

Table 4

Total Urban, Agricultural and Forested Pixel Percentages for Huron River, Michigan, Subwatersheds: 1992 – 2011

Total Urban Area Percentages					
Subwatershed	Area (Sq Mi)	1992	2001	2006	2011
Milford	114.5	1.36%	2.30%	2.34%	2.40%
New Hudson	40.5	0.46%	1.21%	1.25%	1.28%
Hamburg	164.5	1.45%	3.33%	3.44%	3.57%
Dexter Mill Creek	130.6	0.25%	0.61%	0.63%	0.65%
Ann Arbor	296.2	1.44%	2.75%	2.81%	2.85%
Into Lake Erie	167.1	3.70%	5.43%	5.62%	5.76%
Total % of Watershed		**8.66%**	**15.63%**	**16.10%**	**16.51%**

Total Forest Area Pixel Percentages					
Subwatershed	Area (Sq Mi)	1992	2001	2006	2011
Milford	114.5	3.83%	3.11%	3.08%	3.04%
New Hudson	40.5	1.31%	0.99%	0.97%	0.96%
Hamburg	164.5	4.65%	3.71%	3.63%	3.57%
Dexter Mill Creek	130.6	3.40%	2.69%	2.68%	2.67%
Ann Arbor	296.2	9.34%	8.30%	8.24%	8.22%
Into Lake Erie	167.1	5.17%	3.48%	3.40%	3.36%
Total % of Watershed		**27.71%**	**22.27%**	**21.99%**	**21.82%**

Total Grasses / Agriculture Area Pixel Percentages					
Subwatershed	Area (Sq Mi)	1992	2001	2006	2011
Milford	114.5	4.24%	3.94%	3.92%	3.92%
New Hudson	40.5	1.90%	1.38%	1.34%	1.33%
Hamburg	164.5	8.86%	7.49%	7.30%	7.31%
Dexter Mill Creek	130.6	9.43%	8.24%	8.21%	8.20%
Ann Arbor	296.2	16.57%	13.59%	13.57%	13.53%
Into Lake Erie	167.1	8.28%	7.78%	7.66%	7.60%
Total % of Watershed		**49.28%**	**42.41%**	**41.99%**	**41.90%**

Milford’s subwatershed in 1992 was classified as agriculture and grassland regions (33.94%), with forest (30.72%) and water-bodies (24.07%) following respectively. Much of the former categories were lost to developed regions in 2001, with low and medium intensity development showing the highest increased change. In 2011, 14.04% of the land was classified as low intensity, 4% as medium and 1.15% as high intensity development, totaling just under 20% of the entire LULC in Milford, up from only 10% in 1992 (Table 5). Forest, agriculture and grasses pixel values continued to decline throughout 2001 to 2011, while quarries shows marginal increases in expanded regions. Interestingly, as much of the water in Milford’s watershed is retained in natural lakes, wetlands and ponds, this category experienced the least change in pixel values. Much of urban development was also visually observed occurring alongside the main tributaries of the Huron River (Appendix B).

Table 5

Land Use and Land Cover Change Percentages for Milford Subwatershed,
Huron River, Michigan

LULC Pixel Counts Milford Subwatershed					
Value	**Category**	**Count / (%)** 1992	**Count / (%)** 2001	**Count / (%)** 2006	**Count / (%)** 2011
11	Water / Hydric	79359 (24.07%)	80538 (24.43%)	80392 (24.38%)	80111 (24.30%)
22	Developed: Low Intensity	27364 (8.30%)	45766 (13.88%)	45905 (13.92%)	46307 (14.04%)
23	Developed: Medium Intensity	4667 (1.42%)	11792 (3.58%)	12528 (3.80%)	13193 (4.00%)
24	Developed: High Intensity	3903 (1.18%)	3120 (0.95%)	3477 (1.05%)	3795 (1.15%)
31	Quarries / Barren	1220 (0.37%)	2270 (0.69%)	2624 (0.80%)	2519 (0.76%)
43	Forest	732693 (30.72%)	589053 (24.94%)	581492 (24.67%)	576893 (24.32%)
71	Grasses / Agriculture	1303345 (33.94%)	1121641 (31.54%)	1110662 (31.38%)	1108145 (31.42%)

New Hudson’s subwatershed is observed to be the smallest watershed within the Huron River, with a size of only 40.5 square miles (401.30 Km²). Approximately 50% of the water is located on the western portion of the watershed, while most of the developed regions are located along the north to eastern side. In 1992, 29.69% of the LULC was classified as forest, with agriculture & grasses occupying 43.15%. Most developed regions were situated to the north eastern portion of the watershed. In 2001, substantial decreases in forested regions (22.39%), and agriculture & grasses (31.19%) were seen, while urban regions saw a drastic increase in developed areas with much of development alongside the main riverbed. By 2011, urban regions increased to 14.74%, 9.66% and 4.64%, up approximately 7% to 9% in low, medium and high intensities respectively from 1992. By 2011, developed regions accounted for almost 30% of the current LULC within New Hudson’s watershed, up from only 10% in 1992 (Table 6, Appendix C).

Table 6

Land Use and Land Cover Change Percentages for New Hudson Subwatershed, Huron River, Michigan

LULC Pixel Counts New Hudson Subwatershed					
Value	**Category**	**Count / (%)** 1992	**Count / (%)** 2001	**Count / (%)** 2006	**Count / (%)** 2011
11	Water / Hydric	17413 (14.95%)	20497 (17.59%)	20280 (17.41%)	20257 (17.39%)
22	Developed: Low Intensity	6502 (5.58%)	17232 (14.79%)	17192 (14.76%)	17177 (14.74%)
23	Developed: Medium Intensity	2270 (1.95%)	10265 (8.81%)	10815 (9.28%)	11255 (9.66%)
24	Developed: High Intensity	3402 (2.92%)	4579 (3.93%)	5040 (4.33%)	5410 (4.64%)
31	Quarries / Barren	2051 (1.76%)	1498 (1.29%)	2215 (1.90%)	1934 (1.66%)
43	Forest	34585 (29.69%)	26085 (22.39%)	25523 (21.91%)	25356 (21.77%)
71	Grasses / Agriculture	50271 (43.15%)	36338 (31.19%)	35429 (30.41%)	35105 (30.13%)

Hamburg’s subwatershed saw interesting increases in pixel values, with features such as lakes, streams and ponds rising from 14.84% in 1992 to 18.12% in 2011. This increase in hydric regions may have been due to better detection, documentation and classification of water regions, such as wetlands, ponds, streams and lakes over the 20 year study period. There is a high likelihood that this stemmed from better software manipulation, variability in rainfall and snowmelt, and conservation efforts in urban regions throughout Michigan. Developed spaces such as low intensity for planning and subdivision and medium intensity saw meaningful growth up to 13.44% and 4.83% respectively between 1992 and 2001, and continued to grow slowly up to 2011. By 2011, developed regions accounted for almost 20% of the current land use and land cover within Hamburg watershed, up from only 8% in 1992.

Forested areas, which covered 26% of the land in 1992, decreased to only occupy 20.7% of the land in 2001 and steadily decreased by approximately 0.5% between the other years of study. Agricultural & Grasses areas also saw a decrease in their category, dropping from 49.46% in 1992 to only covering 40.80% of the land in 2011. High intensity developed regions interestingly saw small decreases in land usage throughout the study period, from 3.01% in 1992 to only 1.67% in 2011 (Table7, Appendix D).

Table 7

Land Use and Land Cover Change Percentages for Hamburg Subwatershed, Huron River, Michigan

LULC Pixel Counts Hamburg Subwatershed					
Value	**Category**	**Count / (%)** 1992	**Count / (%)** 2001	**Count / (%)** 2006	**Count / (%)** 2011
11	Water / Hydric	70223 (14.84%)	86117 (18.20%)	85882 (18.15%)	85729 (18.12%)
22	Developed: Low Intensity	19905 (4.21%)	61660 (13.03%)	62379 (13.18%)	63615 (13.44%)
23	Developed: Medium Intensity	4084 (0.86%)	19815 (4.19%)	21282 (4.50%)	22875 (4.83%)
24	Developed: High Intensity	14263 (3.01%)	6462 (1.37%)	7335 (1.55%)	7914 (1.67%)
31	Quarries / Barren	7737 (1.64%)	3280 (0.69%)	7663 (1.62%)	5803 (1.23%)
43	Forest	122957 (25.98%)	97936 (20.70%)	95800 (20.24%)	94189 (19.90%)
71	Grasses / Agriculture	234038 (49.46%)	197937 (41.83%)	192866 (40.76%)	193082 (40.80%)

Although Dexter Mill-Creek is one of the larger subwatersheds within the Huron River system, the changes seen in this basin were insubstantial. Forest, agriculture & grasses regions remained at the forefront of land use classification from 1992 to 2011. These two categories alone accounted for approximately 89% of the LULC in 2011, a 13% total decrease from 76% in 1992, but nonetheless, still a meaningful portion of land cover stability. Urban regions within the Dexter Mill-Creek watershed, situated in the north-westerly portion, increased marginally, with most of the growth occurring between 1992 and 2001 along with main tributaries of the Huron River. Total developed regions only accounted for 4.3% of total LULC in 2001 and 4.5% in 2011. There were no recorded pixels of barren or quarry regions within Dexter Mill-Creek's subwatershed in 1992, however this LULC category rose to 0.48% in 2011.

Water regions increased substantially within this watershed, both from observation of data and from total percentages. This water increase was seen mostly in the extreme northern and southern portions of the watershed, where previous land use was agriculture or pasture. As there was not a large influx of developed regions occurring within this subwatershed, hydric regions were probably allowed to expand and increase naturally. Subsequently, Dexter Mill-Creek showed the highest increase in hydric regions throughout 1992 to 2011 (Table 8, Appendix E).

Table 8

Land Use and Land Cover Change Percentages for Dexter Mill-Creek Subwatershed, Huron River, Michigan

LULC Pixel Counts Dexter Mill Creek Subwatershed					
Value	**Category**	**Count / (%)** 1992	**Count / (%)** 2001	**Count / (%)** 2006	**Count / (%)** 2011
11	Water / Hydric	30383 (8.08%)	69563 (18.51%)	69642 (18.53%)	69685 (18.54%)
22	Developed: Low Intensity	2365 (0.63%)	12046 (3.20%)	12317 (3.28%)	12473 (3.32%)
23	Developed: Medium Intensity	709 (0.19%)	3109 (0.83%)	3265 (0.87%)	3442 (0.92%)
24	Developed: High Intensity	3541 (0.94%)	1053 (0.28%)	1099 (0.29%)	1147 (0.31%)
31	Quarries / Barren		1521 (0.40%)	1900 (0.51%)	1807 (0.48%)
43	Forest	89793 (23.89%)	71019 (18.89%)	70680 (18.80%)	70598 (18.78%)
71	Grasses / Agriculture	249088 (66.27%)	217568 (57.88%)	216976 (57.72%)	216727 (57.66%)

Ann Arbor’s subwatershed is the largest subwatershed within this study of the Huron River. Much of this region is classified as forest and agriculture, while developed regions are tightly concentrated in various urban pockets. There was a decline the main categories of forest and agriculture & grasses from 1992 to 2011. Between 1992 and 2001, forested regions decreased by 3%, while agriculture & grasses decreased by almost 10%. These land use categories continued to show a small decline throughout 2006 and 2011. High intensity development within the region of Ann Arbor has also decreased, with greater emphasis on expanding low and medium intensity regions. Interestingly, water also increased, both visually, through pixel counts and from total percentages. Hydric regions increased to 23.23% in 2001, compared to only 15.04% in 1992, which was a 52% increase in pixel value counts (Table 9, Appendix F). This may have been due to an increase in public awareness and conservation efforts of this extremely large urbanized region.

Table 9

Land Use and Land Cover Change Percentages for Ann Arbor Subwatershed, Huron River, Michigan

LULC Pixel Counts Ann Arbor Subwatershed					
Value	**Category**	**Count / (%)** 1992	**Count / (%)** 2001	**Count / (%)** 2006	**Count / (%)** 2011
11	Water / Hydric	128152 (15.04%)	197992 (23.23%)	197915 (23.22%)	197942 (23.23%)
22	Developed: Low Intensity	20806 (2.44%)	51092 (6.00%)	51646 (6.06%)	51943 (6.10%)
23	Developed: Medium Intensity	7356 (0.86%)	15141 (1.78%)	15864 (1.86%)	16512 (1.94%)
24	Developed: High Intensity	9921 (1.16%)	6286 (0.74%)	6691 (0.79%)	6949 (0.82%)
31	Quarries / Barren	1376 (0.16%)	3433 (0.40%)	3797 (0.45%)	4035 (0.47%)
43	Forest	246746 (28.95%)	219230 (25.72%)	217817 (25.56%)	217281 (25.50%)
71	Grasses / Agriculture	437858 (51.38%)	359041 (42.13%)	358485 (42.07%)	357553 (41.96%)

The final watershed within the Huron River boundary is situated downstream of Ann Arbor’s watershed and drains into Lake Erie. Almost 30% of this land cover was classified as forest in the early 1990’s, however has lost just under half of its category to developed regions and waterbodies. In 2011, forested regions only accounted for 18.04% of the land cover, while combined, developed regions accounted for 31% of land use and land cover within the watershed. Interestingly, waterbodies also increased 37% from covering 7.28% in 1992 to 9.67% in 2011 (Table 10, Appendix G). There are many dams situated along the lower portion of the Huron River, which, along with precipitation, clean water actions, conservations efforts within Metropolitan Detroit and the slow widening of the lower Huron River channel annually due to streamflow and erosion may have allowed for the increase in hydric regions.

Table 10

Land Use and Land Cover Change Percentages for Into Lake Erie’s Subwatershed, Huron River, Michigan

LULC Pixel Counts Into Lake Erie Subwatershed

Value	**Category**	**Count / (%)** 1992	**Count / (%)** 2001	**Count / (%)** 2006	**Count / (%)** 2011
11	Water / Hydric	35787 (7.28%)	48500 (9.86%)	47948 (9.75%)	47558 (9.67%)
22	Developed: Low Intensity	49318 (10.03%)	77648 (15.79%)	78914 (16.05%)	80085 (16.28%)
23	Developed: Medium Intensity	16182 (3.29%)	47451 (9.65%)	50069 (10.18%)	51585 (10.49%)
24	Developed: High Intensity	32310 (6.57%)	18474 (3.76%)	19549 (3.98%)	20476 (4.16%)
31	Quarries / Barren	2827 (0.57%)	2191 (0.45%)	3297 (0.67%)	2484 (0.51%)
43	Forest	136714 (27.80%)	91959 (18.70%)	89764 (18.25%)	88718 (18.04%)
71	Grasses / Agriculture	218640 (44.46%)	205555 (41.80%)	202237 (41.12%)	200872 (40.85%)

Summary

Within the Huron River watershed, much of the land is classified as developed, agricultural and forest, followed by smaller areas of water, grassland, barren regions and pasture. Between the study period of 1992 and 2001, much of the change in LULC occurred in approximately 20% of total watershed area. Between 1992 and 2011, developed regions saw the highest increases in low, medium and high intensity development regions, while agricultural & grasses and forested regions decreased. Most of the loss in forested area is located within the upper reaches of the watershed, including Milford, New Hudson and Hamburg watersheds. Quarry and barren regions saw little change, while agriculture & grasses had more changes in the upper watershed. Within the lower watershed, agriculture and grassland have less drastic changes as compared to upper subwatersheds.

Much of Milford, New Hudson and Hamburg subwatersheds was classified into low intensity developed areas. But in their lower portions, much of the land has changed into medium and high intensity developed regions. Much of the developed regions within the watershed and subwatershed closely follows the outline of the main river and are clustered in major cities such as Ann Arbor, Milford, Hamburg and metropolitan Detroit.

Water saw a small increase in every subwatershed, mostly occurring in lakes and ponds, which could be due to increases in wetland. Other factors which could have allowed the increase in hydric regions may have been due to the introduction of conservation efforts of wetlands, ponds and lakes. The removal of old dams to allow for nature to recover naturally into wetlands and natural habitats in lesser developed subwatersheds such as Dexter Mill-Creek could have also enabled an increase in waterbodies. Proper reconstruction of dams within the Huron River has also been underway throughout the study period to allow for better flood control through the use of miniature lakes and ponds. These efforts have attempted to mitigate against concentrated flows at high velocity from heavy rainfall. These waterbodies will have also contributed to a rise in hydric regions from 1992 to 2011.

Stream Discharge

Maximum Stream Discharge

A variety of methods have been applied to determine the relationship between discharge and flooding within the Huron River watershed. There is an increasing pattern in maximum stream discharge time series from 1990 to 2015 at Milford, New Hudson, Hamburg, Dexter Mill-Creek and Ann Arbor (Figure 7) during the summer months. Over the past 20 years, maximum stream discharge patterns also demonstrate strong inter-annual variability. They also tended to have higher mean and variability in the lower reaches of the watershed, as demonstrated in Ann Arbor, Hamburg and Dexter Mill-Creek subwatershed. These observations in data were also similar when analyzing data for the study periods of 1992, 2001, 2006 and 2011 from the former graph. Regions in the upper watershed experienced much more stable and slow patterns of increasing stream discharge as seen in Milford and New Hudson watersheds, compared to the lower reaches.

Distribution of Daily Stream Discharges

Histograms of all summer season daily stream discharges have been plotted for all subwatersheds and compared to the maximum stream discharges in Figure 8. Maximum stream discharges taken in 1992, 2001, 2006 and 2011 all locate far outside of the mean of the distribution, respectively. This held true for all five subwatersheds. Subwatersheds in the lower reaches of the Huron River exhibited more pronounced skewness in their histograms of stream discharge. They are demonstrating longer tails in their distribution. The wider distribution of those extreme discharge events could be related to the both the relative lower position of the subwatershed, as well as the rapid urbanization seen in the LULCC from 1992 to 2011.

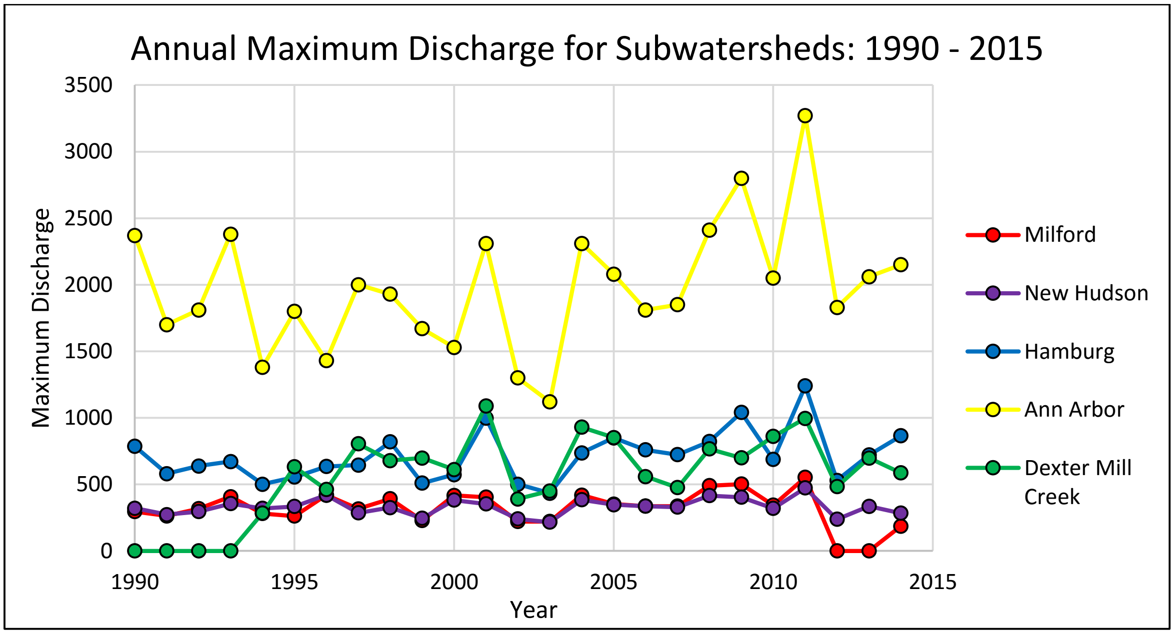


Figure 7. Annual Maximum Stream Discharge for Huron River Subwatersheds: 1990 – 2011

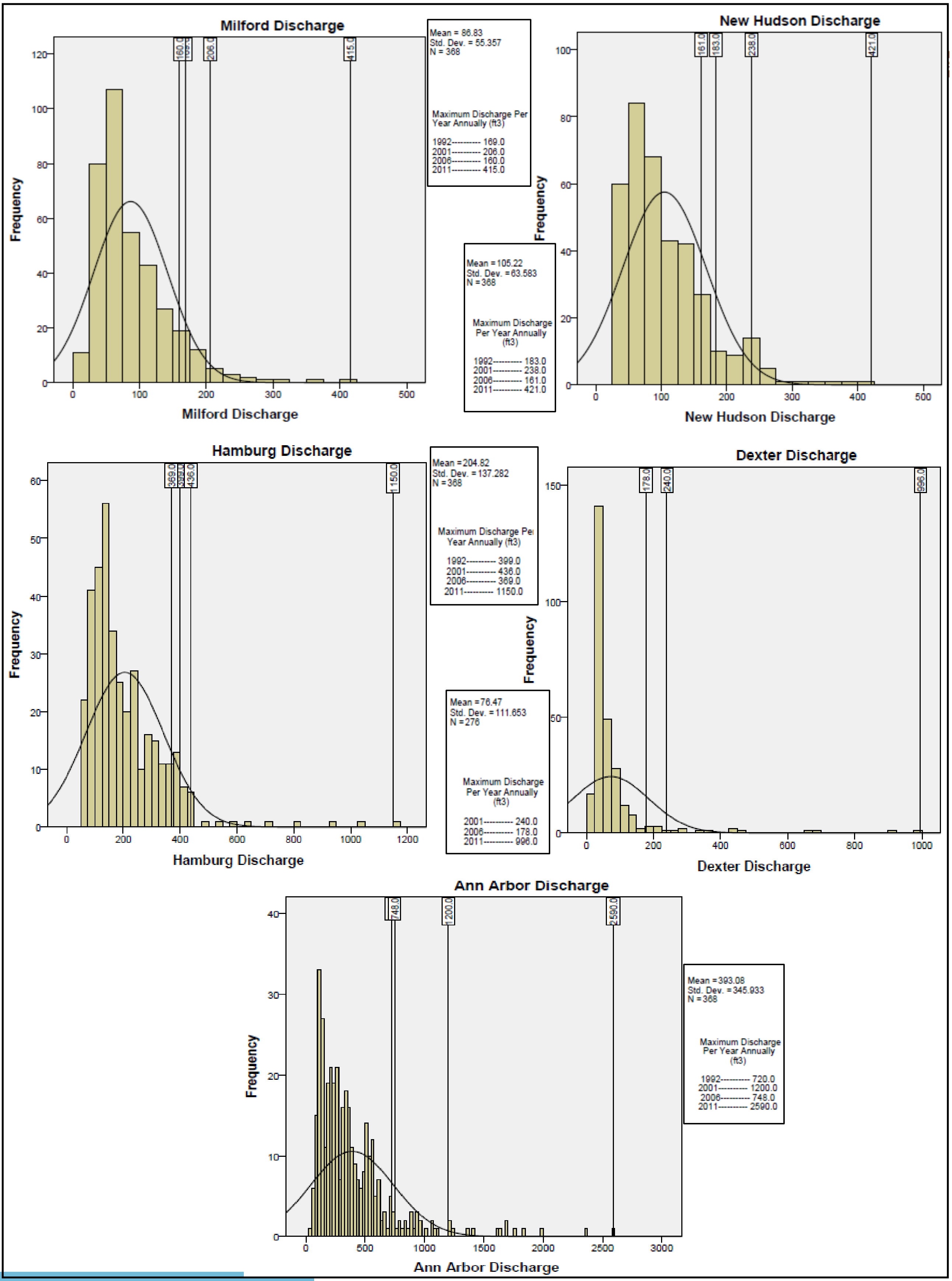

Milford Discharge
Frequency
0
20
40
60
80
100
120
160.0
169.0
206.0
415.0
0
100
200
300
400
500
Milford Discharge
Mean = 86.83
Std. Dev. = 55.357
N = 368
Maximum Discharge Per Year Annually (ft3)
1992---------- 169.0
2001---------- 206.0
2006---------- 160.0
2011---------- 415.0
New Hudson Discharge
Frequency
0
20
40
60
80
100
161.0
183.0
238.0
421.0
0
100
200
300
400
500
New Hudson Discharge
Mean = 105.22
Std. Dev. = 63.583
N = 368
Maximum Discharge Per Year Annually (ft3)
1992---------- 183.0
2001---------- 238.0
2006---------- 161.0
2011---------- 421.0
Hamburg Discharge
Frequency
0
10
20
30
40
50
60
369.0
399.0
436.0
1150.0
0
200
400
600
800
1000
1200
Hamburg Discharge
Mean = 204.82
Std. Dev. = 137.282
N = 368
Maximum Discharge Per Year Annually (ft3)
1992---------- 399.0
2001---------- 436.0
2006---------- 369.0
2011---------- 1150.0
Dexter Discharge
Frequency
0
50
100
150
178.0
240.0
996.0
0
200
400
600
800
1000
Dexter Discharge
Mean = 76.47
Std. Dev. = 111.653
N = 276
Maximum Discharge Per Year Annually (ft3)
2001---------- 240.0
2006---------- 178.0
2011---------- 996.0
Ann Arbor Discharge
Frequency
0
10
20
30
40
748.0
1200.0
2590.0
0
500
1000
1500
2000
2500
3000
Ann Arbor Discharge
Mean = 393.08
Std. Dev. = 345.933
N = 368
Maximum Discharge Per Year Annually (ft3)
1992---------- 720.0
2001---------- 1200.0
2006---------- 748.0
2011---------- 2590.0

Figure 8. Normal Distribution of Annual Maximum Stream Discharge for Huron River Subwatersheds: 1992 – 2011

Normalized Stream Discharge

In determining the factors affecting stream, normalized stream discharges are calculated for each subwatershed by dividing the actual discharge by the watershed area cumulatively, and then by precipitation. Those normalized discharges are calculated for the largest streamflows in summer seasons of 1992, 2001, 2006 and 2011.

$$\text{Normalized cumulative stream discharge} = \frac{\text{Discharge (ft}^3\text{)}}{\text{Watershed Area (mi}^2\text{) * Precipitation (mm)}}$$

Normalizing discharge data provides an effective way in comparing streams of different sizes (Leppi et al., 2012). This normalization is to compare discharge efficiency for each subwatershed by removing the influence from noise factors (Rickert, 1985; Harned et al., 1981), in this case; watershed size and precipitation magnitude. The value indicates the capacity that a stream could handle a large volume of water. A larger normalized stream discharge value tending towards infinity usually suggests a more water passing through a watershed, a greater dominance of flow, and the potential for flooding events.

There is a meaningful relationship between LULCC and normalized stream discharge. Cumulative normalized stream discharge increased in every single subwatershed from throughout the study period. In 1992, normalized stream discharge averaged around 0.02 ft3/mi^2*mm, rose to an average of 0.07 ft3/mi^2*mm in 2001, again to 0.25 ft3/mi^2*mm in 2006 and averaged around 0.22 ft3/mi^2*mm by 2011 (Table 11). These values showed that there was a decrease in the capacity of the rivers to mitigate against flooding due to precipitation events occurring. In the upper reaches of the watershed, Milford alone rose from a 0.02 ft3/mi^2*mm normalized value to a 0.28 ft3/mi^2*mm, while this similar increase in normalized cumulative discharge values was seen as Ann Arbor rose from a 0.03 ft3/mi^2*mm in 1992 to 0.25 ft^3/mi^2*mm in 2011.

Table 11

Urban, Forest and Agricultural Land within the Huron River Watershed Compared to Normalized Stream Discharge

Year	**Subwatershed**	**Total Precip (mm)**	**Cumulative Normalize Discharge from Precipitation (ft^3/mi^2*mm)**	**% of Urban Land**	**% of Grasses / Agriculture Land**	**% of Forest**
2011	Milford	12.72	0.28	19.22	31.45	24.35
	New Hudson	12.72	0.21	21.79	31.11	23.67
	Hamburg	12.92	0.28	20.84	36.10	21.73
	Dexter Mill	144.26	0.05	4.56	57.95	18.88
	Ann Arbor	14.02	0.25	13.23	42.20	22.71
2006	Milford	3.68	0.38	18.80	31.41	24.70
	New Hudson	4.71	0.22	21.30	31.15	23.97
	Hamburg	2.97	0.39	20.23	36.09	22.05
	Dexter Mill	43.57	0.03	4.46	58.02	18.90
	Ann Arbor	4.82	0.21	12.89	42.26	22.88
2001	Milford	21.47	0.07	18.42	31.57	24.97
	New Hudson	21.62	0.05	20.80	31.47	24.29
	Hamburg	24.26	0.05	19.66	36.80	22.44
	Dexter Mill	24.81	0.07	4.33	58.18	18.99
	Ann Arbor	21.48	0.04	12.55	42.61	23.13
1992	Milford	74.42	0.02	10.91	33.98	30.75
	New Hudson	45.15	0.03	10.79	36.37	30.47
	Hamburg	55.78	0.02	9.40	43.11	28.16
	Dexter Mill	0.00	0.00	1.77	66.61	24.01
	Ann Arbor	48.91	0.03	6.10	50.45	27.73

Comparing Normalized Stream Discharge to Urban Land

Within each subwatershed, percent of agricultural, urban and forested land was calculated by determining ratio between cumulative pixels and the total area of each subwatershed (Table 11). In analyzing urban land area compared to normalized stream discharge, it was seen that the percent of urban land per square mile increased substantially throughout each unique watershed, regardless of its area. All subwatersheds saw an increase in developed regions from the period of 1992 to 2011. Most of the noted growth occurred between 1992 and 2001, where the average change of growth was around 8%. An example of this growth was shown in the Milford subwatershed where developed regions increased from 10.91% per square mile in 1992 to 19.22% in 2011. Dexter Mill-Creek subwatershed experienced the smallest substantial increase in developed regions with only an increase of 1.77% per square mile in 1992 to 4.56% in 2011.

Positive relationships are shown between percent urban land and normalized stream discharge. An example is Hamburg subwatershed, where in 1992, 9.40% of urban area corresponds to a 0.02 $ft3/mi^2*mm$ normalized stream discharge value. However, by 2011, 20.84% of urban area is related to a much more increased normalized stream discharge value of 0.28 $ft3/mi^2*mm$. The same trend held true for all other subwatersheds, where increased urban land is related to a higher cumulative normalized stream discharge value. These observations portrayed a marked significant increase in the chance that tributaries will exhibit flooding tendencies in developed areas (Figure 9). This is shown by a R^2 correlation value of 0.36. This indicates that 36% of increased normalized stream discharge is explained by increasing percentages of urban land.

Developed regions are affecting the rate and capacity at which water ran overland, and drained into each tributary. Therefore, overland water was unable to infiltrate into the soil due to impervious surface from development. Due to higher volumes of water from channelization, high concentrated flows were being forced past stream gauges. It was noted that the higher the density of urban regions, the more likely it was that the tributaries within the Huron River were unable to handle higher precipitation and stream discharges and, therefore were more likely to exhibit more dominant flows and flashy characteristics. Therefore, urban land is a crucial factor in affecting stream discharge efficiency, especially for those extreme cases observed.

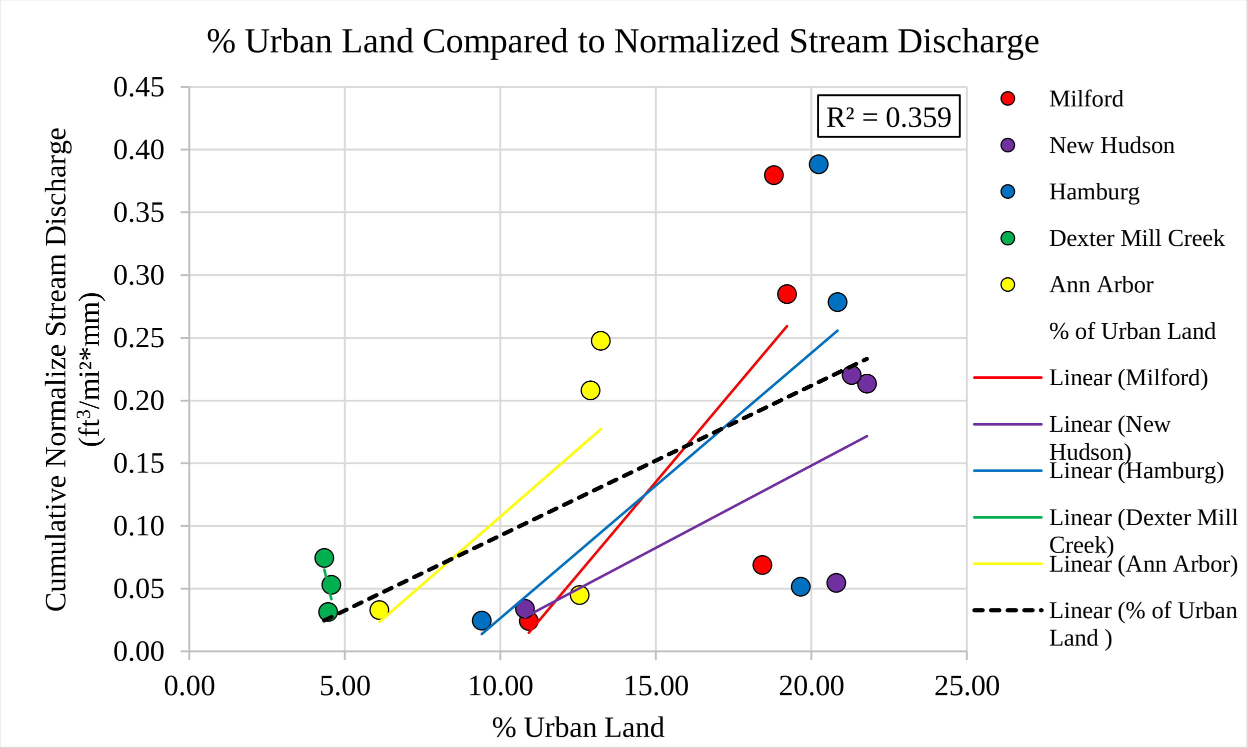


Figure 9. Percent Urban Land within the Huron River Watershed per Square Mile Compared to Normalized Stream Discharge

Comparing Normalized Stream Discharge to Agriculture & Grasses

It was noted that percentage of cultivated cropland decreased significantly within the Huron River watershed throughout the study period. Agricultural areas within the watershed dropped from an average of 4% to 6% between 1992 and 2011. These changes in land use and land cover have been most prominently seen in the upper reaches of the watershed, such as Milford and New Hudson. The agricultural land in these areas account for 33.98% and 36.37% respectively 1992, but both decreased to ~ 31% in 2011. Normalized discharge also rose considerably with the decrease in the percentage of cropland and agricultural area. When plotting the trendline for Agriculture & Grasses versus normalized stream discharge, it was observed that the normalized stream discharge has a negative relationship with the percent of agricultural and grassland (Figure 10). This indicated that less crop area, grasses and agriculture within each subwatershed resulted in a decrease in the tributaries effect to sustain stream discharge within the riverbed. An example is seen in Ann Arbor's subwatershed, where in 1992, 50.45% of the agriculture and grassland LULC corresponds to a 0.03 ft3/mi^2*mm normalized stream discharge value. However, by 2011, only 42.20% is classified as agricultural land per square mile, but corresponds to an increased normalized stream discharge value of 0.25 ft3/mi^2*mm. The same trend held true for all other subwatersheds, where decreased agriculture and grassland are related to a higher cumulative normalized stream discharge value. The R^2 trendline in figure 10 shows a 0.19 correlation. This indicates that 19% of increasing normalized stream discharge is explained by declining agriculture and grassland. It is noted that the significance is not as pronounced compared to increasing urban land, however, this value still explains a meaningful portion of the disappearance of vegetation affecting extreme stream discharges.

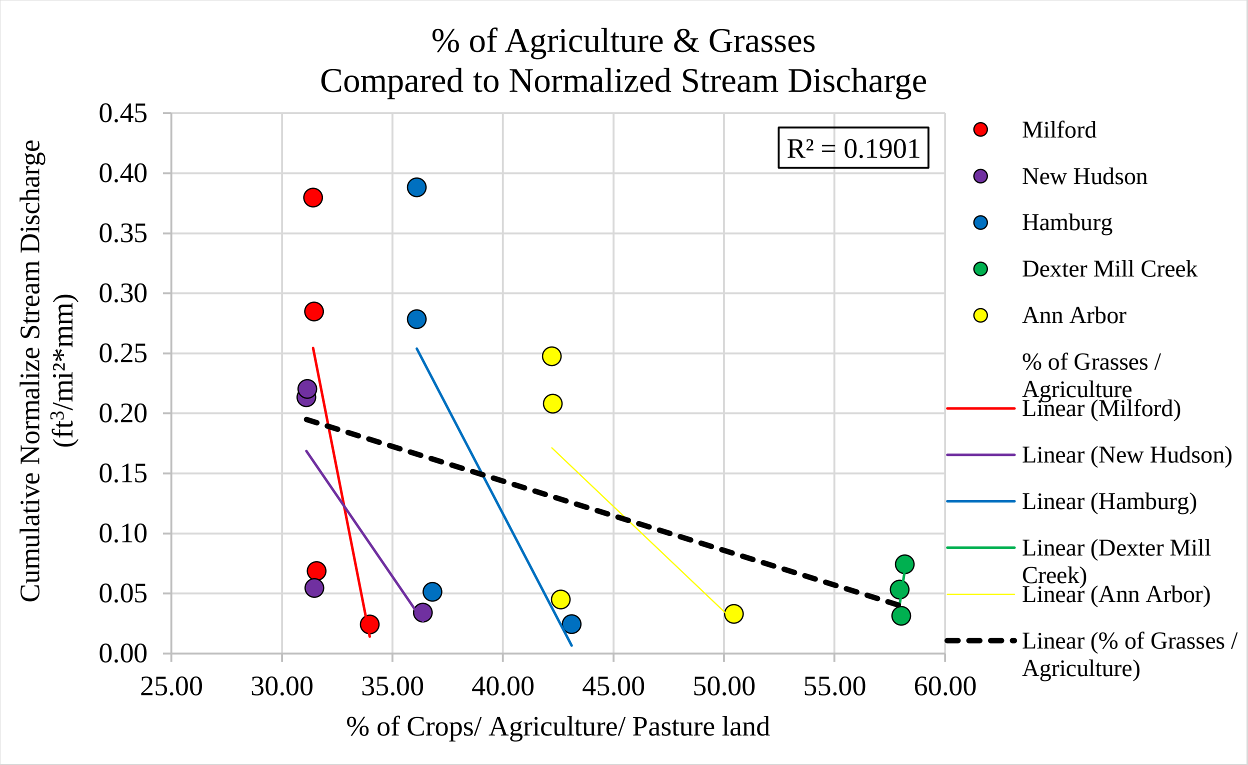


Figure 10. Percent Agriculture and Grasses within the Huron River Watershed per Square Mile Compared to Normalized Stream Discharge

Comparing Normalized Stream Discharge to Forest

In the final variable observed in analyzing stream discharge, I compared forested regions within the Huron River watershed to cumulative normalized stream discharge. It was observed that the decrease in forested regions was not as pronounced as compared to urban and agricultural regions. Within the Huron River boundary, each subwatershed only decreased by an average of 5% to 7% from 1992 to 2011. An example of this minor decrease in forested regions is the Milford subwatershed, which decreased from 30.75% in 1992 to 24.35% in 2011.

When comparing normalized stream discharge to percent forested regions, a negative pattern can be observed. Figure 11 showed that as the percent of forested area decreased, the normalized stream discharge values increased. This indicated that similar to agriculture, when forested regions decline, the capacity of the tributaries within the subwatersheds to sustain streamflow also decline. An example is seen in Milford's subwatershed, where in 1992, 30.75% of the land classified as forest showed a 0.02 ft3/mi^{2}*mm normalized stream discharge value. In 2011, even a normalized stream discharge value of 0.28 ft3/mi^{2}*mm is corresponded to 24.35% of forested region. Although we observed higher normalized discharge 0.38 ft3/mi^{2}*mm in 2006, the discharge pattern is influenced by multiple factors, including the intensity and timing of the precipitation. Although the coefficient of determination that explains increasing normalized stream discharge compared to forest is much lower than agriculture and developed regions, a value of 0.048 explains that 4% of decreasing forest is affecting the increase of normalized stream discharges.

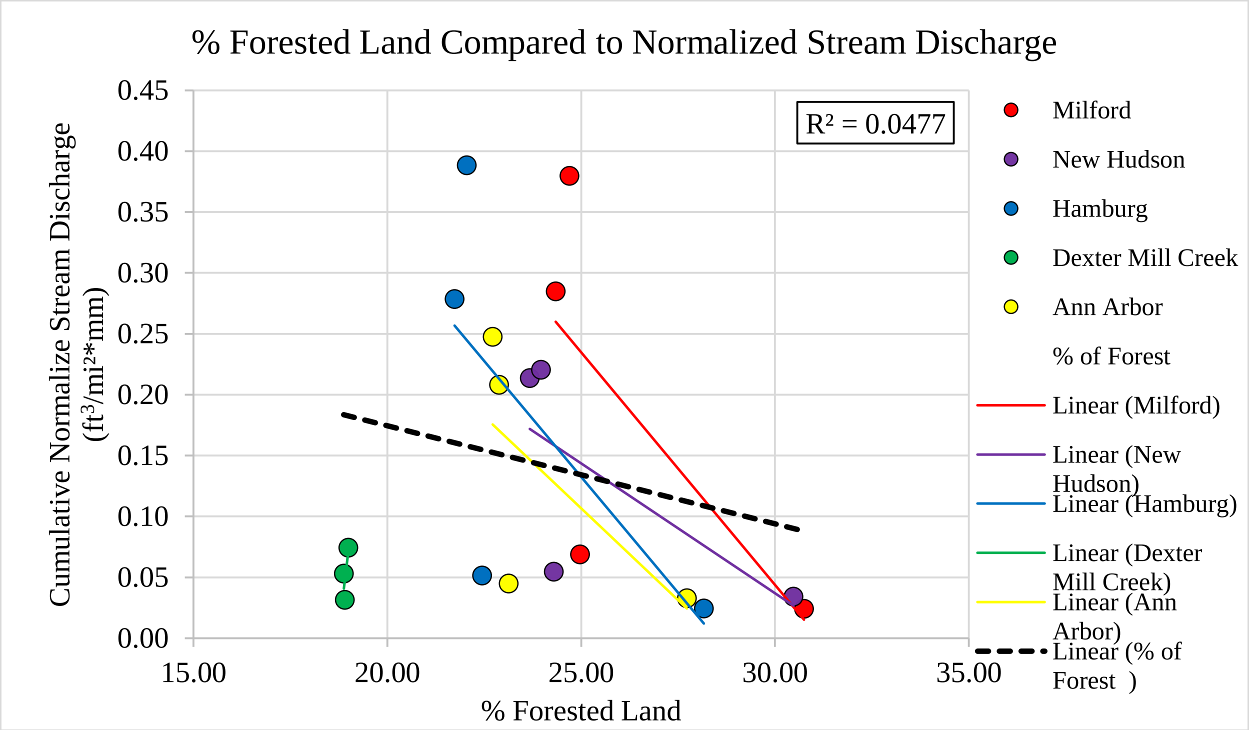


Figure 11. Percent Forest within the Huron River Watershed per Square Mile Compared to Normalized Stream Discharge

Summary

Results from analyzing stream discharge show that both daily and maximum stream discharge have been increasing over the past 20 years. Maximum stream discharge has also consistently been positively skewed, falling outside of the cluster of recorded stream discharge during the summer months of 1992, 2001, 2006 and 2011. Stream discharge has also been affected by increasing developed regions within the watershed, as open space, low, medium and high intensity developed land has been on the rise throughout the study period. Trends of declining cropland, forest and agriculture have also affected the tributaries capacity to moderate stream discharge within its riverbed. This was also proven by increasing trends of normalized stream discharge values, over the study period, which showed a decrease in the capacity of the Huron River tributaries to sustain higher stream discharges. Consequently, a total coefficient of determination of urban, forest and agricultural land can explain 59% of increasing normalized stream discharge within the Huron River watershed. Therefore, stream discharge can be a factor in affecting the variability of stream characteristics within the Huron River and the potential for volatile stream discharge causing a higher frequency of flooding.

Precipitation

The total amount of annual precipitation observed during the summer months of June, July and August within the study period has not increased meaningfully. This is seen from 113.64mm of rainfall recorded for the watershed in 2001, 59.75mm for 2006, while 196.64mm of precipitation was recorded for 2011 (Table 13). Total precipitation from 1992 to 2011 also showed that Milford and Dexter Mill Creek subwatersheds had the highest calculated precipitation from recorded events, while New Hudson and Ann Arbor showed the lowest total calculated recorded precipitation throughout the study period.

When compared to the area of each subwatershed, it is noted that the subwatersheds with the smaller areas such as Milford and Dexter Mill Creek have more precipitation. Ann Arbor has the largest area of all subwatersheds at 296 mi^2, however, only recorded 89.22mm total precipitation throughout the study period. Hamburg also recorded 95.94mm of rainfall despite with a larger subwatershed area of 164.5 mi^2.

Table 12

Precipitation for Subwatersheds, Huron River, Michigan during June, July, August from 1992 to 2011

Summer Precipitation Per Subwatershed						
Subwatershed	**Subwatershed Area (mi^2)**	**1992 (mm)**	**2001 (mm)**	**2006 (mm)**	**2011 (mm)**	**Subwatershed Total Precip (mm)**
Milford	114.5	74.42	21.47	3.68	12.72	112.29
New Hudson	40.5	45.15	21.62	4.71	12.72	84.20
Hamburg	164.5	55.78	24.26	2.97	12.92	95.94
Dexter Mill Creek	130.6	0.00	24.81	43.57	144.26	212.64
Ann Arbor	296.2	48.91	21.48	4.82	14.02	89.22
Annual Total		224.26	113.64	59.75	196.64	

These results indicate that although precipitation can be a factor in flooding, it is a very complicated process determined by many other factors, including the nature of the storm, spatial scales of aggregation, and measurement instrument errors, etc. Many variables are also influencing how precipitation interacts with stream discharge. One of them is seen well in the analysis of LULC, when observing urban, forested and agricultural regions from 1992 to 2011. As urban land per km^2 increases from an average of 8% to 16% (Table 11, pg. 47), even though experienced the smallest recorded precipitation, Ann Arbor and Hamburg, have very high values in normalized stream discharge. Therefore, the increase in the percentage of urban land can affect how precipitation runs overland, infiltrate and flow into tributaries of the Huron River. As these subwatersheds also had the highest change in the percent of forest, agriculture and grasses per km^2 from 1992 to 2011, this absence of vegetation due to developed regions can also affect how volatile stream discharge and how often stream variability occurs.

In observing the buffer of precipitation events, much of the precipitation was observed to have occurred one (1) day before or on the actual maximum stream discharge day (Appendix J). The highest chance of precipitation as well as the day with the most precipitation recorded also occurred one day before the maximum stream discharge date. An example of this pattern is Ann Arbor's subwatershed in 1992. One day before the maximum stream discharge day, the recorded precipitation is 41mm, much higher than the combined 3 days prior. On the actual maximum stream discharge date, 0.83mm was recorded. This pattern also stands true for the other subwatersheds, such as Dexter Mill Creek in 200, 2006 and 2011, Hamburg in 1992 and 2006, and Milford in 1992, 2006 and 2011 (Appendix J). Finally, it was observed that the four days buffer allowed for more precipitation to be accounted for the normalized discharge. However, because most of the precipitation was recorded on or 1 to 2 days before the maximum stream discharge event, a smaller buffer could have been tested in future analysis. This could remove the noises from precipitation event by tightening the buffer to include just the most important precipitation events that affected the extreme discharge events.

Comparing Normalized Stream Discharge to Precipitation

In observing precipitation compared to normalized stream discharge it was noted that although there were higher precipitation values recorded in 1992 and 2001, normalized precipitation was much lower in 1992 compared to 2011. This is seen from an increase of normalized discharge values from an average of 0.02 ft^3/mi^2*mm in 1992, to 0.06 ft3/mi^2*mm in 2001, 0.25 ft3/mi^2*mm in 2006 to 0.22 ft^3/mi^2*mm in 2011. These values show that even though there was more recorded precipitation in the early part of the study, precipitation was being better distributed before entering the tributaries of the Huron River. As the normalized stream discharge increased throughout the study period, LULC and precipitation combined became a greater factor in affecting stream discharge, and increased the chance that the Huron River will exhibit flashy characteristics from higher stream discharges.

Summary

In analyzing precipitation as a factor which affects the tributaries of the Huron River and their capacity to moderate flooding occurrences, interesting results were observed. Precipitation was observed to be recorded one day before, as well as on the day of maximum stream discharge events. This had an effect on the total amount of precipitation recorded for each subwatershed annually, throughout the study period. Precipitation within the subwatersheds saw a decreasing pattern between the summer months (June, July, August) of 1992 and 2001, but an increased from 2006 to 2011. It was noted that normalized stream discharge in every single subwatershed increased from 1992 to 2011. When precipitation occurred in lower quantities, stream discharge was still affected, and still gave way to the potential for the riverbed to experience flooding characteristics. This is particularly true in the much urbanized Ann Arbor subwatershed.

CHAPTER VI

DISCUSSION

This study demonstrates how to analyze spatial and temporal trends of data pertaining to the Huron River and assess how major variables including land use and land cover change, stream discharge and precipitation affect the magnitude of flooding within the Huron River.

LULCC - Huron River watershed

This study found that from 1992 to 2011, land use and land cover change has changed drastically. Forests and agricultural regions saw a marked decrease, while urbanized regions expanded significantly. This increase in developed regions along the tributaries of the Huron River is shown visually in digital maps of land use classification (Figure 6; Appendix A to G). Over 16% of the land is classified as developed regions in 2011, with much of the observations in change being seen in major cities along the river including metropolitan Detroit, Ann Arbor, Hamburg and Milford. Land use and land cover change throughout the time period showed much of the change was due to the conversion from agricultural and cultivated regions to urban categories. These changes were most prominent due to the decrease in farming activities and growth of centralized urban regions within the watershed. Due to the decrease in areas to grow crops as the demand for housing and developed infrastructure arose to meet the desires of population, the rate and area of impervious surfaces rose along with developed regions. These impervious surfaces from higher developed densities within the watershed can lead to increased and flashy runoff, as much of riparian vegetated regions act as buffers that slow down the concentration speed of the overland flow. Between 2001 and 2006, a small visual change in pixels was observed. This could be primarily due to relative smaller changes in lower density developed urban regions being converted higher density urban regions. These conversions lead to a higher percentage chance of impervious surfaces within the watershed. This higher density development also has a higher likelihood of directly modifying the actual riverbed to become smaller and straighter. Those changes are most well noted within the lower reaches of the watershed, where the river is seen to be narrowed and straightened, and in urban pockets of high population densities, such as Milford, South Lyon, Hamburg, Brighton, Ann Arbor, Ypsilanti and metropolitan Detroit.

Interestingly, water and wetland regions saw a brief increase in total percentage and between 1992 and 2001. Water regions increased from 13.7% in 1992 to 19% in 2011. This is probably due to an increase in awareness in conserving wetland areas. Many local, non-profit and government organizations such as the Huron River Watershed Council, paved the way in the early 1980’s to 2000’s in raising awareness on the quality and protection of wetland and water regions in and around the Huron River, which allowed a small but significant increase in waterbodies. These conservation efforts include public awareness, better mapping of water regions, and maintenance of wetlands in analyzing and the protection of water quality, some of which are discussed in relevant literature within this thesis. However the urbanization of the region became forefront in later years, causing a marginal decline and then stabilization of open water areas within the watershed.

LULCC - Subwatersheds

In analyzing each unique subwatershed within the Huron River boundary, the study found the highest total percent change occurred between 1992 and 2001. These increases may have been due to most of the developed regions expanding in this timeframe, as well as the nine (9) year gap between the first data timeframe, compared to later study timeframes of 2001, 2006 and 2011, which are consistently five (5) years apart. Analysis of data showed that forested areas, grasslands and agricultural regions were most likely were converted to developed spaces, ranging from open space to low intensity, to high intensity developed regions.

It was observed that the decline of forested regions in Lake Erie's subwatershed was due to high development rates within metropolitan Detroit areas. This holds true as much of Southeast Michigan's industries are located within and in close proximity to this watershed, which is associated with higher population rates and consequently more developed regions. These industries also make industrial use of the tributaries and its dammed lakes, which may account for higher waterbodies percentages within this subwatershed.

Areas of each subwatershed varied and have some relationship with their LULC. New Hudson's subwatershed was the smallest region at only 40.5 mi², so developed regions seem to be much more widespread. Ann Arbor has the highest area of 296 mi² with its developed regions being more centralized along the main tributary of the Huron River. It was also observed that the shape of the watershed also affected land use and land cover change. This was seen in Lake Erie's subwatershed, which is elongated and follows final stretch into Lake Erie. Due to this shape, much of the developed regions expanded along the river, leaving pasture, remnants of forest and sparse agricultural regions to cover only the most northern parts of this subwatershed. Shape and width of the Huron River watershed and its subwatersheds also play a role in the distribution of stream discharge.

In observing elevation and streamflow within the tributaries of the Huron River, it was also noted that there are many choke points along the stream. In the upper watershed, higher elevation merges into lower elevation regions only allows for one major tributary, in which multiple smaller streams empty into. The magnitude of water being funneled into a small area, along with competing impervious surfaces for development and commerce directly alongside the streambed, can definitely affect how stream discharge is directed and distributed effectively into the river. In the lower regions of the watershed, the Huron River is elongated in shape and straightened, with all 766 upper tributaries merging into 1 stream and emptying into the mouth of Lake Erie. This type of choke, along with increase impervious surfaces due to development, can also greatly affect stream discharge and dominance of flow.

Stream Discharge

By analyzing stream discharge data within the Huron River watershed, this study found that there was an increase in stream discharge over the past 20 years. Maximum stream discharge was also consistently positively skewed and higher stream discharges were found in the lower reaches of the Huron River. In the upper reaches of the watershed, the highest stream discharge recorded was 415 ft^3 from Milford's subwatershed in 2011, while Ann Arbor's subwateshed recorded its highest stream discharge of 2600 ft^3 in the same year. Some variables may be affecting the magnitude and frequency of the extreme stream discharge. It was also noted that a wider array of stream discharge values occurred more frequently within the lower reaches of the watershed as seen in the Ann Arbor watershed, with discharge values ranging from 400 ft^3 to 2590 ft^3. Stream discharge is also largely affected by urbanization, as much of the developed regions appeared and increased along the main tributary of the Huron River. Increases in developed regions also introduced higher amounts of impervious surfaces and altered channelization patterns. These higher stream discharges in the lower reaches of the watershed may also be due to higher density of populated areas as well as increased density and development of highways, industries, imperious surfaces.

High normalized stream discharges were observed within the Huron River watershed and its tributaries from 1992 to 2011. As higher normalized cumulative stream discharge values indicate a smaller capacity for the river to handle large streamflows and discharges, the increase in normalized discharge values from an average of 0.02 ft^3/mi^2*mm in 1992, to 0.06 ft3/mi^2*mm in 2001, 0.25 ft^3/mi^2*mm in 2006 to 0.22 ft^3/mi^2*mm in 2011 shows that precipitation affects the rate at which stream discharge flows through tributaries and causes extreme discharge events.

This study also showed that urban regions are influencing precipitation and stream discharges. Areas of higher urban percentages per square mile, where development increased approximately 10% from 1992 to 2011, exhibited higher flooding tendencies, which may be due to higher surface runoff from increased watershed imperviousness. As urban land increases, the chance that precipitation will affect the rivers' capacity to sustain stream discharge decreases, which with relevant literature also shows a higher chance of flooding tendencies. As some watersheds were smaller in area than others, a high normalized stream discharge value may have meant that more water is passing through a smaller area, which is most common for regions in the upper watershed regions such as Milford and New Hudson which had high normalized stream discharge values in 2011 of 0.28 ft^3/mi^2*mm and 0.21 ft3/mi^2*mm respectively. However, even though subwatersheds such as Ann Arbor and Hamburg were not as small as its upper regions, due to the extremely developed nature of these subwatersheds, even small quantities of precipitation showed that stream discharge was still affected immensely, and still gave way to the potential for the riverbed to experience flooding characteristics.

Consequently, as agriculture, pasture and cultivated cropland decreased within the Huron River watershed, normalized stream discharge from precipitation values increased, causing a higher probability that precipitation is affecting stream discharge. This may be due to the absence of riparian and marine vegetation, as well as a shift from farming and agriculture to more industry and anthropogenic practices. Other direct results may be from recorded precipitation most likely running overland as surface flow and being directed into storm drains and channelized tributaries, causing increased stream discharge. Therefore, increased stream discharge due to precipitation and urbanization is a high likelihood a factor in the potential of rivers within the Huron River watershed to exhibit flashy characteristics and can be a potential factor in stream variability.

Precipitation

Precipitation throughout the study was a major factor in affecting stream discharge within the tributaries of the Huron River. Results showed that total precipitation decreased between 1992 and 2006, but then increased from 2006 to 2011. There is also a higher likelihood that precipitation is contributing to maximum recorded stream discharges. Pronounced and continuous precipitation is also affected and distributed by changes in LULC, and in turn, affected stream discharges within the tributaries of the Huron River. Recorded precipitation occurring on only 1 day before and on the actual maximum stream discharge date indicates that instead of vegetation intercepting rainfall, precipitation is instead being channeled over impervious surfaces and directly into tributaries. In most cases within the Huron River watershed, total recorded precipitation was much higher one day before maximum stream discharge events occurred than the entire three days buffer combined. These results are especially crucial observations in the lower regions of the watershed, where, though there is a larger subwatershed area and less precipitation being recorded, the extent and density of the developed regions is still causing high normalized stream discharge values. Subsequently, much higher stream discharges are being recorded.

Cumulative normalized stream discharge was also observed to have increased steadily throughout the study period for every single subwatershed. Due to this rising trend in normalized stream discharge from 1992 to 2011, it is worrisome that increased urban regions and decreased forest, grasses and cropland may all be factors in affecting stream discharge and are variables in affecting the frequency of flooding within cities throughout the region. As normalized stream discharge values continue to follow a rising pattern, this indicates that tributaries within the watershed are becoming more volatile, and unable to distribute its water efficiently and effectively. This can lead to flooding, not only in the lower regions of the watershed where the LULC is primarily urban, but also in the upper regions of the watershed, where vegetation and wetlands are slowly but surely being replaced for commerce, industry and residential areas. The maintenance headwaters of any river is crucial for any sustainable river, as increasing precipitation and stream discharge affecting the river upstream with have a very high probability of affecting concurrent subwatersheds.

Although precipitation was seen to increase throughout summer of the study period, further study may be needed to analyze if precipitation have been fluctuating seasonally and annually throughout the entire watershed.

CHAPTER VII

CONCLUSION

The Huron River is no stranger to the consequences of increasing urbanization and development within its watershed. Over the past 20 years, the river has been subject to degradation from point and non-point sources pollution, flooding from impervious surfaces and channelization, and the growth of population along its riverbed. Within this study, relevant literature and data analysis showed that many factors affect the capacity for the Huron River to accommodate its stream discharge, consequently causing many regions along its path to exhibit flashy characteristics.

One of the major factors in which the Huron River has begun to show instability is through change in land use and land cover. Research showed that almost 20% of the watershed has been reclassified to developed regions, including low, medium and high intensity development from 1992 to 2011. Much of this growth has also occurred within close proximity to the riverbed. Most of the forested and agricultural regions decreased due to increase in urban area. A few waterbodies within the watershed may have also been increased. Much of the land cover dynamics has occurred downstream, close to the mouth of the river and this correlates disturbingly to increased maximum stream discharges seen in the lower reaches of the watershed.

Over the study period, maximum stream discharge for the years of 1992, 2001, 2006 and 2011 consistently fell outside of the normal cluster of stream discharges recorded and analyzed, which led to the notion that other factors may be affecting stream discharges and the rate and capacity at which the Huron River tributaries were distributing its water downstream. Daily and maximum stream discharges also saw a trend of increasing intensity, and when analyzed to precipitation, normalized stream discharges rose from 0.02 ft3/mi²*mm in 1992 to 0.25

ft3/mi^2*mm in 2011. Subsequently, these values correlated well to increases in developed regions as well as in regions of decreased agricultural, forested and grassland areas.

Finally, summer precipitation within the months of June, July and August for the Huron River was shown to have decreased between 1992 and 2006, and then increased steadily into 2011. Precipitation has also showed a trend of massive rainfall being documented just before a recorded summer maximum stream discharge date, especially one day before the recorded event. Land use and land cover change also affected precipitation and its normalized stream discharge values within each subwatershed. Normalized stream discharge is noted to be increasing steadily over the past 20 years within every single subwatershed of the Huron River, which is in turn affecting stream discharge, especially in urbanized regions and areas of decreased forest and agriculture. In areas of declining agriculture and forest, especially in the largest and most developed subwatersheds such as Hamburg and Ann Arbor, precipitation also showed a high contribution in affecting stream discharge as vegetation disappears and more water is being diverted over impervious surfaces.

Limitations

There were some limitations, which presented themselves throughout the research period and analysis of data. These errors may have subsequently affected the results seen within the study. In utilizing land use and land cover from the United States National Land Cover Database, the extended timeframe between digital maps of 1992 and 2001 of over 9 years showed that a longer time period can show more changes much easier, compared to the digital land cover maps of 2001, 2006 and 2011, which are only 5 years part. There were also uncertainties in the area estimation in the land use as digital LULC maps of 1992 are known to be classified differently compared to

2001, 2006 and 2011. This limitation can be remediated by further study of analysis using raw remote sensing imagery of concurrent years, using a uniform land cover method such as supervised classification with a change detection analysis.

One internal difficulty is the classification of wetland regions into water. The reasoning behind this reclassification is due to many, but not all, wetlands within the Huron River watershed, being 'wet, marsh-like' regions, located alongside the riverbed or encompassing lakes, ponds and other waterbodies within the river basin. However, some wetlands can be completely dry with dense vegetation. With the conservation of wetland areas in the early 1990's as well as improved technology to document water regions, waterbodies increased by a significant portion throughout the study period. This may have introduced uncertainties when analyzing results and the full extent of pasture or grassland regions affecting stream discharge, as well as wetland regions may also be classified as such.

In observing precipitation for this study only for the summer months of June, July and August, and for only for the years of 1992, 2001, 2006 and 2011, much of the rainfall recorded annually would not have been analyzed. Though precipitation throughout the summer months of this study decreased from 1992 to 2006, rainfall, snowmelt and spring thaw for the other 9 months could have definitely played a factor in the increase in hydric regions within the Huron River watershed.

In developing areas of urban sprawl, the increase in residential areas would have caused an increase in large ponds; both for flood control and aesthetics. In determining pixels of change in LULC within the digital maps of the NLCD, the 30m by 30m pixels may have registered these ponds as an increase in water and hydric regions.

In comparing data in each watershed for both stream discharge and precipitation, a particular data record was absent in the retrieval of data. In 1992, daily stream discharge values were not recoded for the months of June, July and August. Therefore, a maximum stream discharge event could not be obtained, and precipitation could not be derived for this year. This absence of data may have been due to human error, instrument error, or lack of a discharge or precipitation event occurring. Due to an uncalculated normalized stream discharge value, this point was not plotted and analyzed when observing normalized stream discharge to urban, forest and agricultural percentages.

There are many stream gauges within the Huron River that have been installed since 2011 in an attempt to track stream discharge and other water quality factors within the watershed and its tributaries. However, because many of these stream gauges were only installed within the last 5 years, the data is not old or concurrent enough to provide more data records for analysis. This problem especially holds true at the mouth of the Huron River, where the oldest stream gauge within the study area was only installed in 2013, and therefore did not provide relevant data of the final portion of the Huron River.

As this research was an exploratory study to determine trends within the tributaries of the Huron River, statistical analyses such as Analysis of Variance, Pearson's r and Skewness ratios could have been utilized to further analyze the data which can be applied as further research. When analyzing my coefficient of determination, the variables within this study, urban, forest, agriculture and grasses only explained 59% of affecting increasing stream discharge. This indicated that at least 41% of factors are left unexplained. Determining other factors which affect how the Huron River handl extreme discharges can also lend understanding in how to mitigate against increasing frequencies of flooding.

Further Recommendations

In furthering research into the health of the Huron River as humans occupy much of its floodplain with the seen accompanying urbanization, continuous digital maps of land use and land cover can be created by supervised classifications of remote sensing imagery. Future land use and land cover changes can be investigated pertaining to natural changes as well as forced change such as the federal protection of land cover or conservation efforts.

The installation of new stream gauges within the Huron River will provide stream discharge as well as other water quality data such as conductivity, temperature pH, turbidity and nutrients to the public. This data will become crucial in understanding how urbanization affects streambeds, tributaries and nutrient loading, vegetation densities and water quality within the watershed. Analyzing stream health within the Huron River watershed with more variables allows the opportunity to delve deeper into understanding each unique section of the river, eliminate potential noise factors and apply other scientific methods in analyzing flooding trends and patterns within the watershed.

As this study observed precipitation during the summer months of June, July and August for only 4 years, analyzing long term precipitation values, not only monthly, but also for a wider number of years may allow for a higher statistically relevant result to be made in connecting LULC and precipitation. Long term moving averages of precipitation may also yield statistically relevant results pertaining to affecting stream discharges within the Huron River.

As the Huron River watershed becomes increasingly urbanized, agriculture is still a prominent feature within the floodplain and still affects many of the river's tributaries. In monitoring the location of cultivated crops in approximation to topography, river flow, and nutrient influx due to irrigation, we can better maintain the river's water quality and quantity. They are in good health currently, but need to be actively monitored for areas of degradation and flooding potential. Further research on water quality can use data to map and predict changes in stream temperatures, nutrient influxes, due to variations in main agricultural regions, stream discharges and precipitation.

Mitigation

Finally, one of the most effective methods in lessening the frequency and magnitude of flood events within the Huron River, or eliminating them completely, is through the use of mitigation tactics. Better land use planning and design can allow for good water quality, and can control increased rates of surface runoff. Spatial planning systems and storm water management practices for better flood storage and dispersion can be put into effect for the reduction of peak streamflows due to volatile flows and high precipitation events.

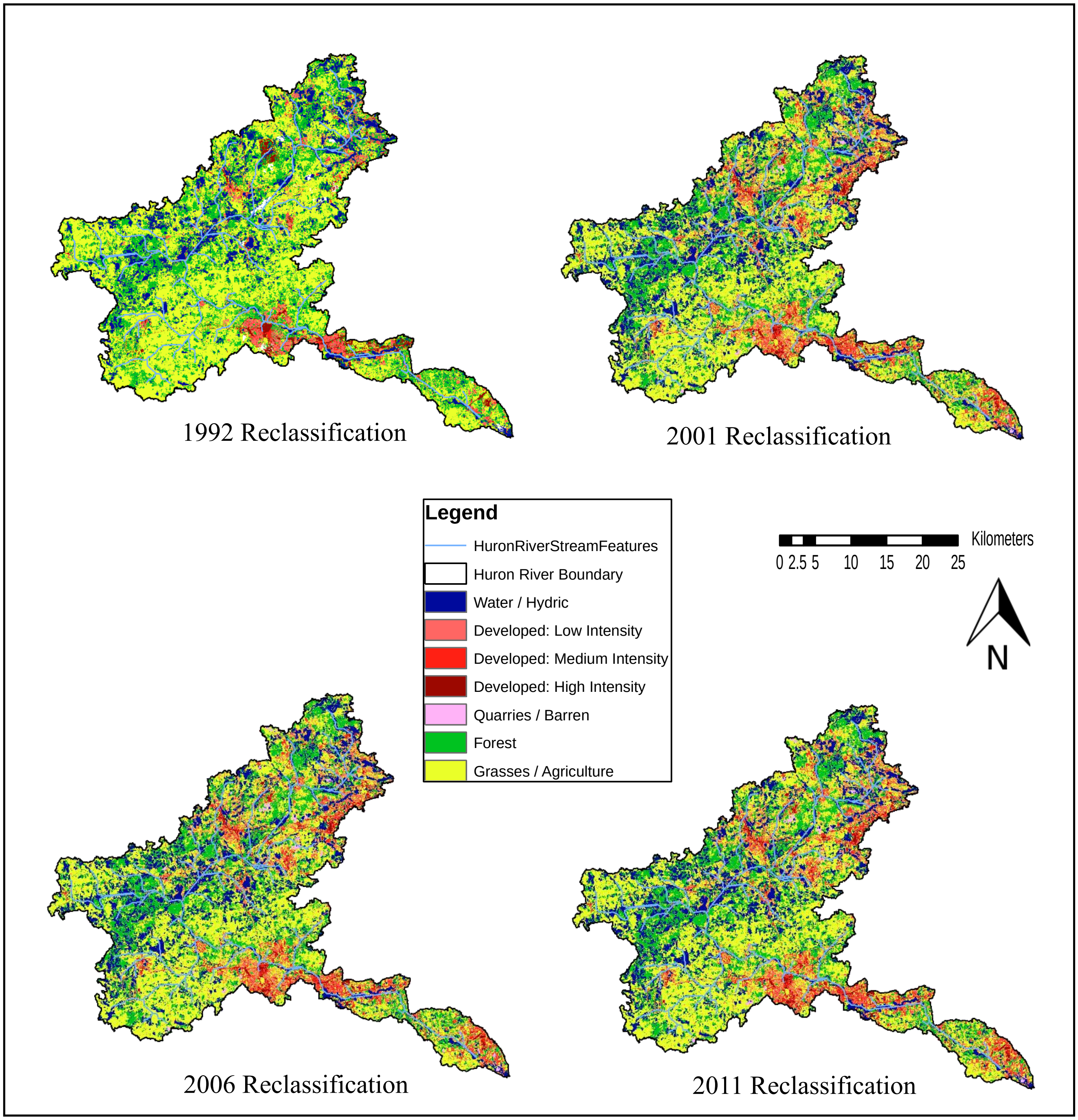
Changing and updating flood polices can allow for more effective public awareness and the reduction of flood damages. One such method can be the mapping of the floodplain and documenting the types of land cover within it. Increased location accuracy of developed regions residing within the Huron River floodplain prone to flooding can also aid in lessening damages extreme discharge events. Another method is the removal of residential areas and impervious surfaces within the floodplain to allow better distribution of stream discharge. Ripping up pavement, and the planting of vegetation such as buffer strips, trees and grasses can allow better infiltration, interception, increase lag time, and subsequently minimize extremely high peak flows.

Finally, research into flood mapping and warnings can be useful in mitigating against the effects of climate change. As nature is unpredicatable, extreme discharges can sometimes be higher than expected or planned for. Within the Huron River watershed, which has had multiple flooding occurances in the past, upgraded flood warnings can allow for a lower damages, lower costs, and lower changes of loss of life. Some methods to upgraded flood warnings can include forecasts, proper gauging points of impending flooding events and flood risk maps. Flood risk maps will be able to influence local planners within flood prone regions of the watershed in building new developments. These maps can also inform the public of flood risks on buying certain properties.

Even with the enforcement of these methods, flooding is a natural phenomenon that cannot be totally eliminated. However, this study examined the spatial and temporal trends within the Huron River and identified which factors greatly affected extreme discharges, caused volatile flows and increased the probability for flooding. Decisions made from understanding how urban forest, agriculture and grassland affect stream discharge and the frequency of flooding, allows for the next step in increasing the sustainability and water quality of the Huron River, and applying sound research to its surrounding Michigan rivers.

APPENDIX A

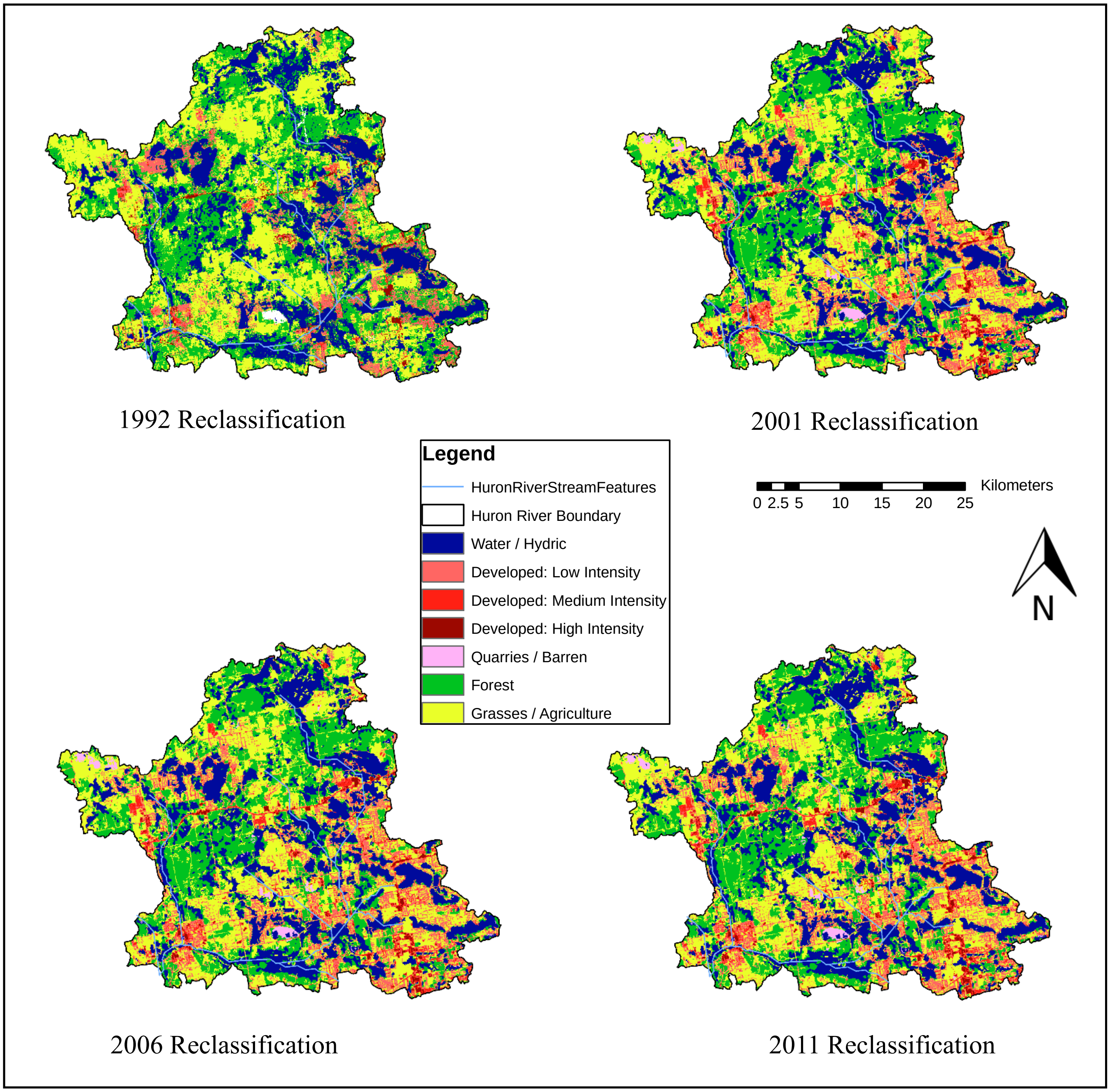
Maps of Land Use & Land Cover Change from NLCD for the Huron River Watershed: 1992-2011



Maps of Land Use & Land Cover Change for the Huron River Watershed: 1992-2011

APPENDIX B

Maps of Land Use & Land Cover Change for Milford Subwatershed, Huron River Watershed: 1992-2011


1992 Reclassification

2001 Reclassification

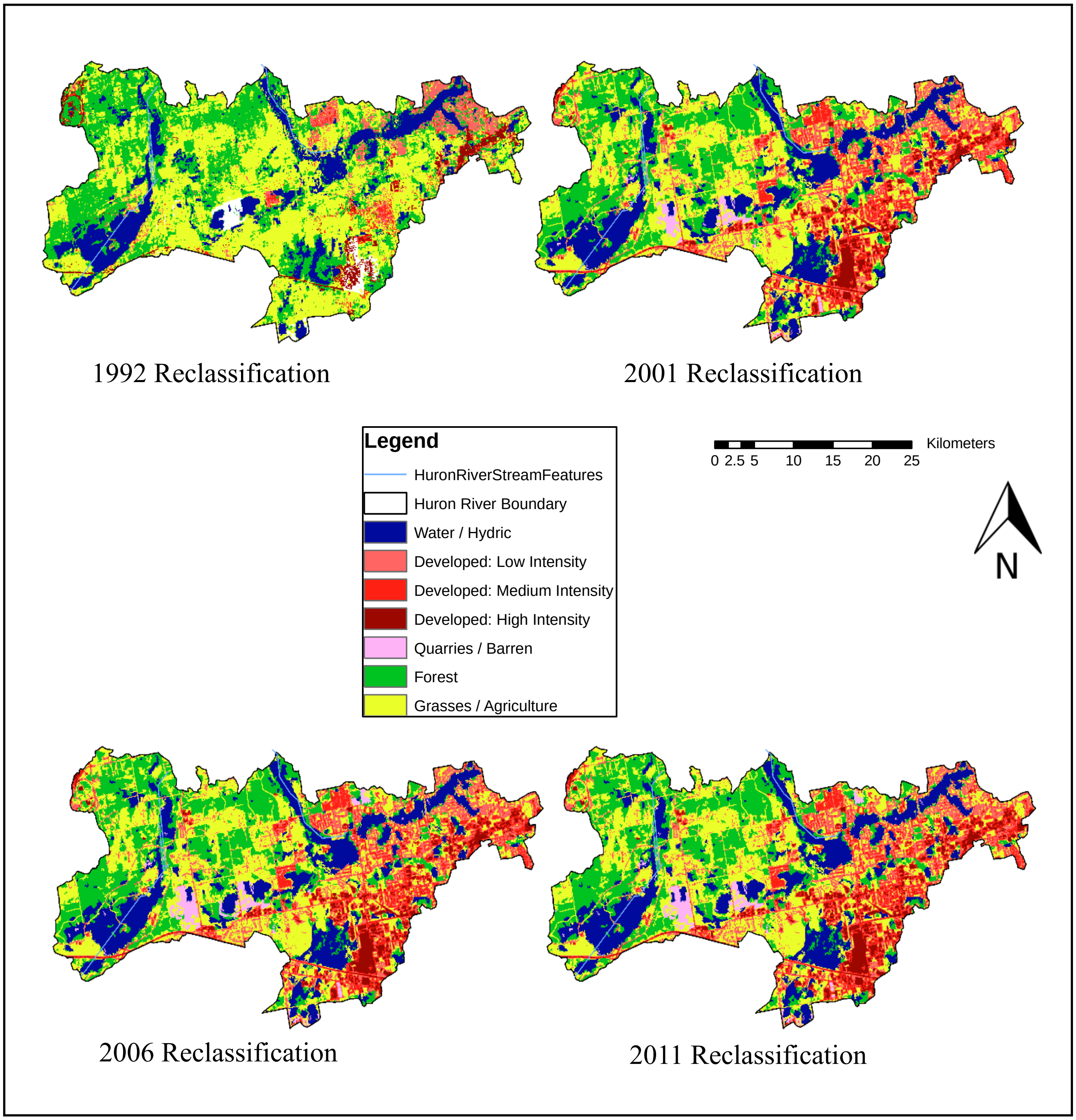
2006 Reclassification

2011 Reclassification

Maps of Land Use & Land Cover Change for Milford Subwatershed, Huron River Watershed: 1992-2011

APPENDIX C

Maps of Land Use & Land Cover Change for New Hudson Subwatershed, Huron River Watershed: 1992-2011


1992 Reclassification

2001 Reclassification

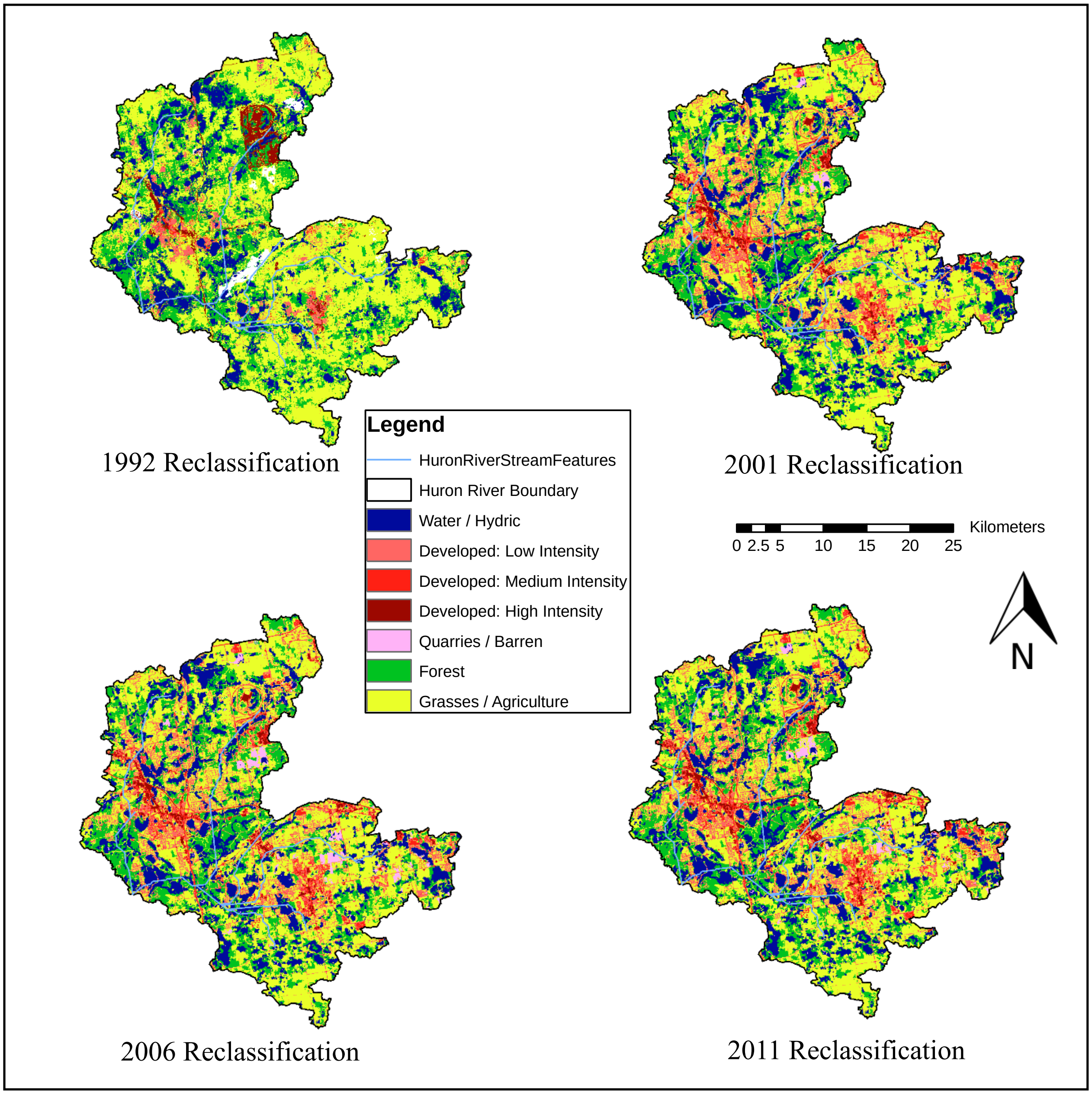
2006 Reclassification

2011 Reclassification

Maps of Land Use & Land Cover Change for New Hudson Subwatershed, Huron River Watershed: 1992-2011

APPENDIX D

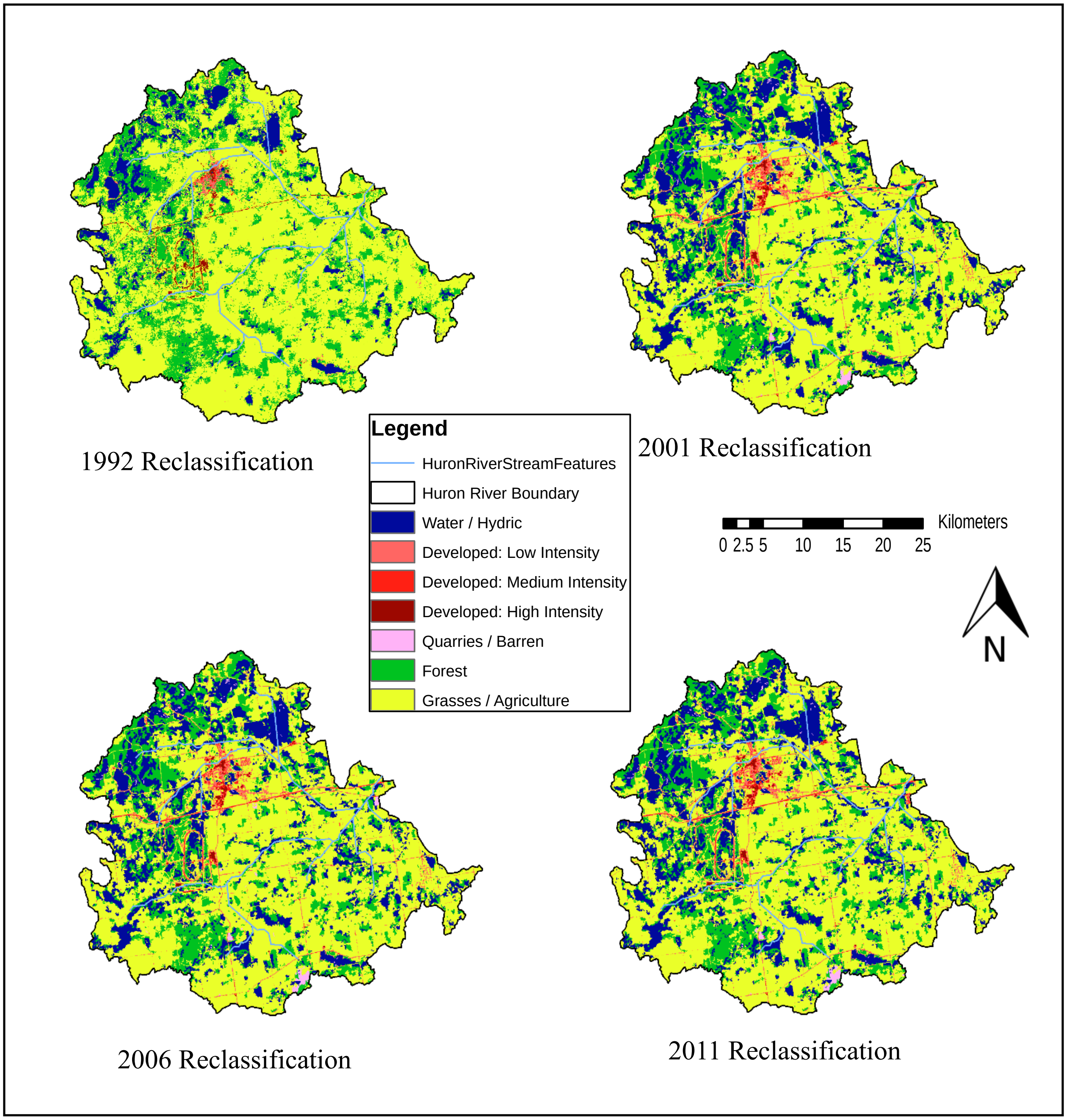
Maps of Land Use & Land Cover Change for Hamburg Subwatershed, Huron River Watershed: 1992 - 2011



Maps of Land Use & Land Cover Change for Hamburg Subwatershed, Huron River Watershed: 1992 - 2011

APPENDIX E

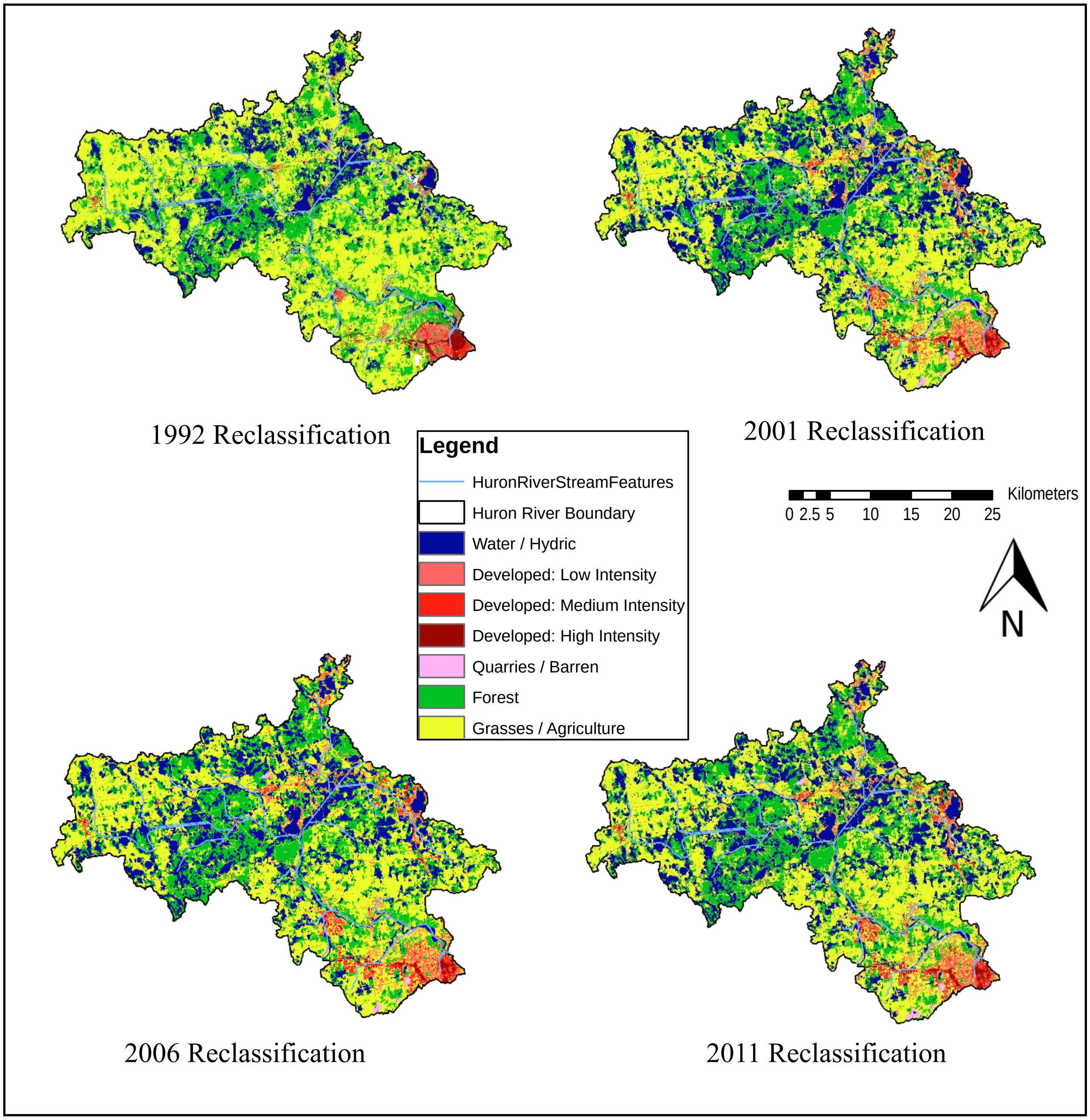
Maps of Land Use & Land Cover Change for Dexter Mill-Creek Subwatershed, Huron River Watershed: 1992 – 2011



Maps of Land Use & Land Cover Change for Dexter Mill-Creek Subwatershed, Huron River Watershed: 1992 – 2011

APPENDIX F

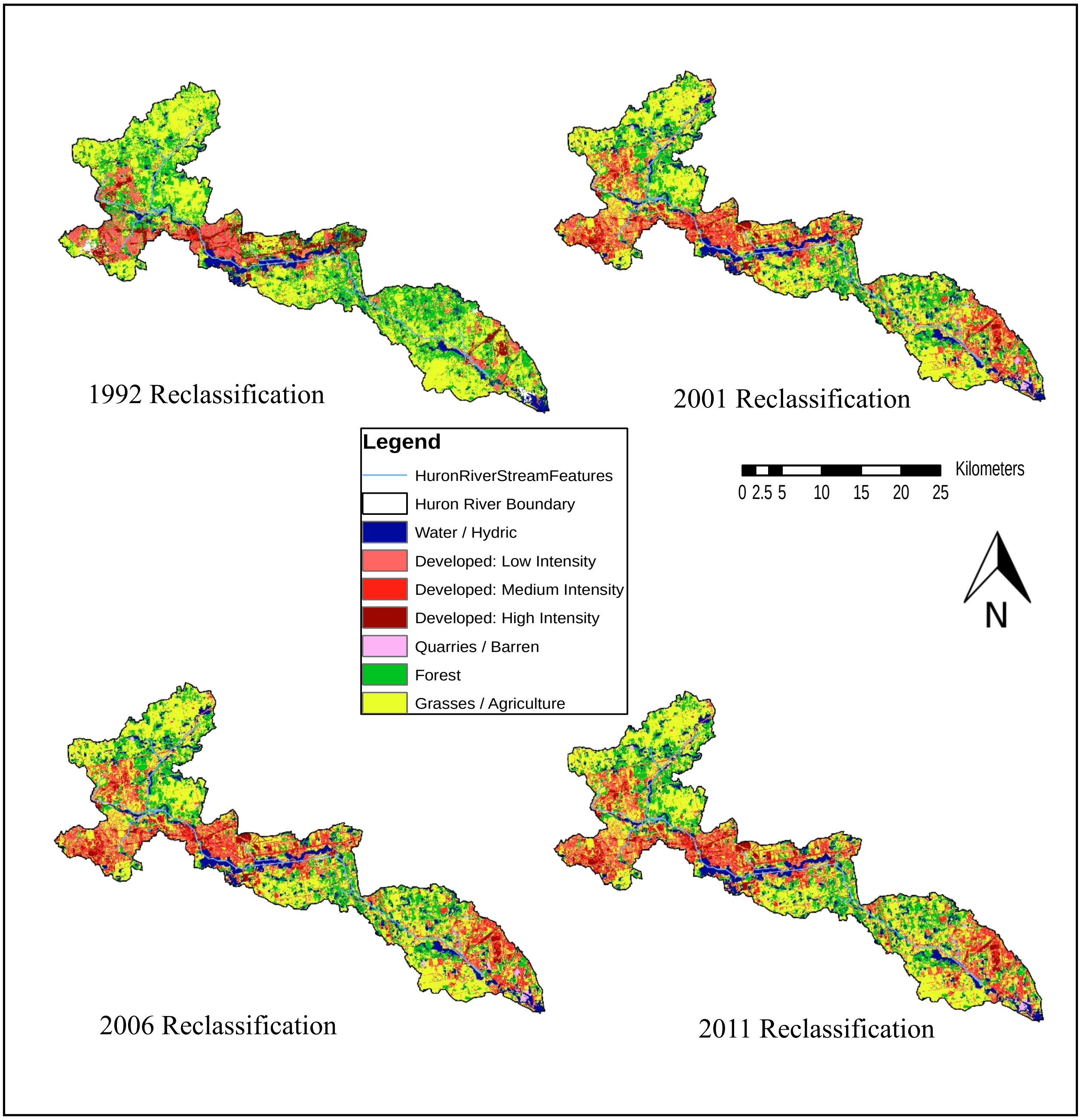
Maps of Land Use & Land Cover Change for Ann Arbor Subwatershed, Huron River Watershed: 1992 - 2011



Maps of Land Use & Land Cover Change for Ann Arbor Subwatershed, Huron River Watershed: 1992 - 2011

APPENDIX G

Maps of Land Use & Land Cover Change for Into Lake Erie Subwatershed, Huron River Watershed: 1992 - 2011



Maps of Land Use & Land Cover Change for Into Lake Erie Subwatershed, Huron River Watershed: 1992 - 2011

APPENDIX H

Table of Daily Stream Discharge 1992, 2001, 2006, 2011 (June, July, August) for the Huron River Watershed

Discharge ft3/sec					
Date	Milford	New Hudson	Hamburg	Ann Arbor	Dexter Mill Creek
6/1/1992	76	82	189	339	
6/2/1992	69	81	192	326	
6/3/1992	66	82	189	311	
6/4/1992	64	86	185	254	
6/5/1992	65	84	189	307	
6/6/1992	67	82	193	371	
6/7/1992	71	86	193	401	
6/8/1992	79	89	195	418	
6/9/1992	70	86	191	321	
6/10/1992	59	78	184	303	
6/11/1992	54	71	173	235	
6/12/1992	51	65	161	232	
6/13/1992	49	61	150	232	
6/14/1992	50	60	138	227	
6/15/1992	49	54	126	224	
6/16/1992	47	50	115	242	
6/17/1992	50	48	106	232	
6/18/1992	76	76	120	256	
6/19/1992	78	88	147	365	
6/20/1992	69	83	160	335	
6/21/1992	61	75	160	246	
6/22/1992	55	68	148	236	
6/23/1992	52	68	138	257	
6/24/1992	57	72	142	259	
6/25/1992	52	67	143	258	
6/26/1992	49	66	143	203	
6/27/1992	45	61	135	196	
6/28/1992	41	56	126	205	
6/29/1992	41	52	116	200	
6/30/1992	45	53	110	264	
7/1/1992	46	51	106	246	
7/2/1992	45	49	103	174	
7/3/1992	43	47	99	174	
7/4/1992	40	44	92	186	
7/5/1992	35	43	89	186	
7/6/1992	34	39	85	144	
7/7/1992	35	37	83	136	
7/8/1992	35	39	81	141	
7/9/1992	37	42	85	147	
7/10/1992	38	42	86	148	
7/11/1992	38	42	85	147	
7/12/1992	42	46	86	169	
7/13/1992	67	74	104	271	
7/14/1992	126	128	167	330	
7/15/1992	169	161	278	427	
7/16/1992	161	167	339	383	
7/17/1992	146	172	371	470	
7/18/1992	158	175	388	604	
7/19/1992	156	183	399	702	
7/20/1992	147	170	399	594	
7/21/1992	138	161	387	565	
7/22/1992	128	150	363	477	
7/23/1992	123	146	341	516	
7/24/1992	121	140	324	555	
7/25/1992	110	132	302	448	
7/26/1992	112	131	280	502	
7/27/1992	105	127	262	451	
7/28/1992	97	115	244	338	
7/29/1992	91	114	234	342	
7/30/1992	84	113	227	374	
7/31/1992	141	147	274	624	
8/1/1992	169	158	323	720	
8/2/1992	154	162	345	527	
8/3/1992	146	164	354	610	
8/4/1992	146	159	353	664	
8/5/1992	139	154	346	581	
8/6/1992	130	147	332	434	
8/7/1992	121	140	315	472	
8/8/1992	130	143	307	603	
8/9/1992	128	145	299	519	
8/10/1992	115	138	288	409	
8/11/1992	109	131	276	408	
8/12/1992	101	123	256	398	
8/13/1992	117	135	246	412	
8/14/1992	110	132	249	401	
8/15/1992	97	123	243	386	
8/16/1992	88	108	225	358	
8/17/1992	80	98	203	318	
8/18/1992	78	93	191	319	
8/19/1992	82	96	194	318	
8/20/1992	77	91	189	309	
8/21/1992	74	84	175	302	
8/22/1992	75	82	160	226	
8/23/1992	73	82	148	268	
8/24/1992	71	83	141	262	
8/25/1992	68	83	143	261	
8/26/1992	64	80	148	293	
8/27/1992	82	105	154	319	
8/28/1992	129	149	220	531	
8/29/1992	138	157	278	483	
8/30/1992	116	154	295	381	
8/31/1992	101	146	290	420	
6/1/2001	182	216	436	907	123
6/2/2001	192	226	432	1080	181
6/3/2001	206	237	429	1200	240
6/4/2001	197	238	425	1110	185
6/5/2001	184	224	426	846	144
6/6/2001	174	213	422	838	132
6/7/2001	166	206	412	933	127
6/8/2001	158	195	395	859	107

Discharge ft3/sec					
Date	Milford	New Hudson	Hamburg	Ann Arbor	Dexter Mill Creek
6/9/2001	150	181	375	782	92
6/10/2001	139	176	350	740	81
6/11/2001	134	171	333	704	74
6/12/2001	124	163	317	674	69
6/13/2001	105	154	302	604	64
6/14/2001	93	139	284	587	57
6/15/2001	87	127	270	616	54
6/16/2001	104	135	268	574	90
6/17/2001	104	132	261	558	67
6/18/2001	101	129	246	554	57
6/19/2001	95	124	233	571	56
6/20/2001	91	126	218	555	59
6/21/2001	86	124	210	568	59
6/22/2001	106	134	223	557	136
6/23/2001	104	132	230	539	113
6/24/2001	96	127	225	518	96
6/25/2001	100	123	214	505	78
6/26/2001	91	118	201	514	63
6/27/2001	81	111	189	536	54
6/28/2001	74	103	177	490	49
6/29/2001	72	96	165	431	46
6/30/2001	72	91	154	256	45
7/1/2001	68	86	143	358	43
7/2/2001	64	74	130	484	40
7/3/2001	61	71	119	381	40
7/4/2001	59	68	112	331	40
7/5/2001	53	65	105	239	38
7/6/2001	48	57	97	190	36
7/7/2001	45	50	90	206	36
7/8/2001	42	49	86	189	37
7/9/2001	38	43	81	164	36
7/10/2001	37	43	76	193	33
7/11/2001	35	39	71	201	31
7/12/2001	34	36	66	184	31
7/13/2001	34	34	62	140	30
7/14/2001	33	33	58	97	29
7/15/2001	32	31	54	89	28
7/16/2001	30	31	52	78	28
7/17/2001	28	33	51	78	27
7/18/2001	28	35	52	93	29
7/19/2001	27	36	60	77	28
7/20/2001	25	35	62	62	27
7/21/2001	24	34	62	55	27
7/22/2001	23	34	60	111	28
7/23/2001	23	33	59	47	27
7/24/2001	25	33	59	71	26
7/25/2001	25	36	59	88	29
7/26/2001	29	38	61	88	33
7/27/2001	30	33	61	67	28
7/28/2001	27	32	60	60	26

Discharge ft3/sec					
Date	Milford	New Hudson	Hamburg	Ann Arbor	Dexter Mill Creek
7/29/2001	34	48	68	100	26
7/30/2001	54	102	85	123	30
7/31/2001	60	93	112	107	33
8/1/2001	53	87	128	93	29
8/2/2001	48	82	126	104	28
8/3/2001	46	81	122	148	32
8/4/2001	41	75	117	124	28
8/5/2001	36	70	109	122	26
8/6/2001	31	64	101	113	25
8/7/2001	25	59	95	110	24
8/8/2001	24	55	93	100	23
8/9/2001	23	51	89	121	22
8/10/2001	24	53	88	123	25
8/11/2001	22	48	85	112	23
8/12/2001	21	45	82	100	23
8/13/2001	21	43	81	96	23
8/14/2001	21	40	78	86	22
8/15/2001	23	38	76	78	21
8/16/2001	28	44	77	176	25
8/17/2001	33	49	85	101	32
8/18/2001	31	53	90	120	28
8/19/2001	56	72	101	197	47
8/20/2001	71	86	121	165	37
8/21/2001	59	85	138	126	31
8/22/2001	58	87	150	190	34
8/23/2001	62	91	160	210	43
8/24/2001	60	88	164	203	34
8/25/2001	54	82	161	205	31
8/26/2001	52	84	158	250	34
8/27/2001	56	83	158	294	37
8/28/2001	51	80	156	260	36
8/29/2001	46	74	149	247	32
8/30/2001	44	66	141	226	29
8/31/2001	39	64	134	212	27
6/1/2006	90	131	369	748	71
6/2/2006	83	118	317	500	65
6/3/2006	92	113	283	506	62
6/4/2006	98	114	271	533	64
6/5/2006	94	112	259	535	58
6/6/2006	89	108	244	495	52
6/7/2006	87	107	232	497	52
6/8/2006	81	104	231	438	53
6/9/2006	77	100	222	404	48
6/10/2006	70	91	209	389	45
6/11/2006	64	81	193	369	42
6/12/2006	60	75	177	352	41
6/13/2006	58	67	163	338	40
6/14/2006	56	64	154	255	39
6/15/2006	53	58	146	249	37
6/16/2006	51	53	139	226	35

Discharge ft3/sec					
Date	Milford	New Hudson	Hamburg	Ann Arbor	Dexter Mill Creek
6/17/2006	54	55	133	184	33
6/18/2006	54	56	128	193	32
6/19/2006	64	71	132	220	39
6/20/2006	59	75	136	225	35
6/21/2006	79	88	148	310	39
6/22/2006	125	126	191	468	178
6/23/2006	138	143	219	507	141
6/24/2006	130	145	234	425	96
6/25/2006	119	141	241	376	64
6/26/2006	110	132	239	350	52
6/27/2006	156	139	233	347	55
6/28/2006	160	158	232	352	71
6/29/2006	130	161	236	363	69
6/30/2006	105	142	239	349	55
7/1/2006	86	121	237	359	46
7/2/2006	83	107	223	350	41
7/3/2006	79	102	206	299	40
7/4/2006	76	100	195	321	64
7/5/2006	69	88	183	334	72
7/6/2006	64	80	169	287	49
7/7/2006	60	72	157	268	40
7/8/2006	56	68	146	145	36
7/9/2006	52	64	136	133	34
7/10/2006	50	65	129	150	32
7/11/2006	50	62	125	178	31
7/12/2006	92	90	131	210	40
7/13/2006	87	96	149	203	37
7/14/2006	65	91	163	198	33
7/15/2006	64	88	167	202	36
7/16/2006	66	80	163	228	32
7/17/2006	57	75	155	286	30
7/18/2006	58	77	151	330	45
7/19/2006	56	72	149	261	45
7/20/2006	70	80	147	255	38
7/21/2006	75	90	149	117	34
7/22/2006	65	86	154	124	32
7/23/2006	60	78	152	136	30
7/24/2006	62	71	142	143	29
7/25/2006	55	69	133	145	28
7/26/2006	47	67	127	326	31
7/27/2006	60	71	127	224	50
7/28/2006	69	85	129	281	46
7/29/2006	59	80	134	264	39
7/30/2006	48	74	136	270	37
7/31/2006	41	65	134	135	40
8/1/2006	44	56	126	90	32
8/2/2006	47	51	115	122	29
8/3/2006	61	60	112	164	33
8/4/2006	68	69	118	256	41
8/5/2006	59	65	127	238	33

Discharge ft3/sec					
Date	Milford	New Hudson	Hamburg	Ann Arbor	Dexter Mill Creek
8/6/2006	52	57	128	101	29
8/7/2006	45	52	123	117	27
8/8/2006	45	47	116	117	26
8/9/2006	44	42	109	130	25
8/10/2006	43	42	102	123	25
8/11/2006	44	38	96	124	24
8/12/2006	48	34	90	117	23
8/13/2006	46	32	84	113	23
8/14/2006	44	32	79	104	22
8/15/2006	44	33	75	104	23
8/16/2006	43	34	72	95	22
8/17/2006	38	34	71	86	22
8/18/2006	31	32	70	60	22
8/19/2006	40	42	77	171	38
8/20/2006	46	46	87	156	38
8/21/2006	41	39	92	124	29
8/22/2006	45	38	91	122	26
8/23/2006	44	39	89	153	24
8/24/2006	48	47	90	118	28
8/25/2006	58	57	102	199	38
8/26/2006	51	57	114	171	32
8/27/2006	46	56	120	190	33
8/28/2006	50	58	125	248	38
8/29/2006	69	78	143	360	92
8/30/2006	63	74	158	307	87
8/31/2006	41	61	160	268	62
6/1/2011	415	421	1150	2590	365
6/2/2011	362	394	1040	2360	276
6/3/2011	321	359	928	1980	205
6/4/2011	291	335	817	1830	160
6/5/2011	264	317	721	1680	139
6/6/2011	240	290	646	1360	123
6/7/2011	220	267	588	1240	112
6/8/2011	200	245	537	1060	104
6/9/2011	181	228	485	889	97
6/10/2011	170	216	443	958	97
6/11/2011	169	210	417	946	109
6/12/2011	152	199	389	882	99
6/13/2011	138	181	361	773	92
6/14/2011	112	164	331	674	87
6/15/2011	108	143	301	636	82
6/16/2011	110	137	276	493	85
6/17/2011	105	136	258	541	87
6/18/2011	98	132	245	603	77
6/19/2011	85	124	235	571	72
6/20/2011	80	109	222	543	69
6/21/2011	81	104	207	529	71
6/22/2011	96	104	198	526	69
6/23/2011	102	111	201	441	73
6/24/2011	103	116	206	385	78

Discharge ft3/sec					
Date	Milford	New Hudson	Hamburg	Ann Arbor	Dexter Mill Creek
6/25/2011	102	117	207	390	74
6/26/2011	101	117	204	389	66
6/27/2011	100	111	200	383	62
6/28/2011	96	109	194	373	60
6/29/2011	90	107	186	351	56
6/30/2011	86	105	177	343	53
7/1/2011	79	101	170	325	51
7/2/2011	77	95	163	324	49
7/3/2011	78	92	156	321	54
7/4/2011	73	88	150	305	51
7/5/2011	67	82	142	290	47
7/6/2011	64	80	136	221	46
7/7/2011	61	78	131	218	44
7/8/2011	59	73	128	204	42
7/9/2011	56	71	123	197	40
7/10/2011	53	65	118	188	39
7/11/2011	57	65	114	212	41
7/12/2011	59	69	115	213	46
7/13/2011	55	66	116	208	41
7/14/2011	52	61	113	145	38
7/15/2011	51	59	110	133	37
7/16/2011	50	54	105	129	36
7/17/2011	50	52	101	124	35
7/18/2011	62	53	98	128	36
7/19/2011	80	63	102	139	40
7/20/2011	65	65	112	130	37
7/21/2011	58	62	117	126	36
7/22/2011	55	60	116	129	34
7/23/2011	55	57	114	148	35
7/24/2011	52	57	111	148	37
7/25/2011	50	55	109	132	35
7/26/2011	48	49	104	124	33
7/27/2011	49	46	98	176	36
7/28/2011	184	121	142	1070	694
7/29/2011	247	211	231	1690	996
7/30/2011	266	254	307	1770	913
7/31/2011	240	264	357	1400	658
8/1/2011	187	253	385	1020	444
8/2/2011	163	227	391	882	329
8/3/2011	180	233	392	935	265
8/4/2011	178	226	377	824	203
8/5/2011	156	216	361	708	148
8/6/2011	137	196	344	588	122
8/7/2011	130	179	326	573	109
8/8/2011	122	168	304	565	100
8/9/2011	178	225	326	1630	466
8/10/2011	222	244	365	1600	427
8/11/2011	216	252	397	1220	284
8/12/2011	189	248	417	973	216
8/13/2011	169	238	422	790	155
8/14/2011	176	234	424	742	135
8/15/2011	172	226	406	718	122
8/16/2011	149	211	387	678	106
8/17/2011	129	186	367	631	95
8/18/2011	118	167	345	591	97
8/19/2011	111	153	321	505	93
8/20/2011	118	147	306	484	84
8/21/2011	136	166	309	504	89
8/22/2011	122	160	302	509	81
8/23/2011	111	145	289	474	73
8/24/2011	123	151	285	522	90
8/25/2011	135	163	291	514	98
8/26/2011	121	157	291	474	86
8/27/2011	112	148	285	414	75
8/28/2011	105	132	269	348	67
8/29/2011	99	118	249	352	62
8/30/2011	95	109	229	346	58
8/31/2011	93	106	211	334	56

APPENDIX I

Table of Maximum Stream Discharges from USGS from 1992, 2001, 2006, 2011 for the Huron River Watershed

Maximum Discharge Per Year Annually										
Year	Date	Milford	Date	New Hudson	Date	Hamburg	Date	Ann Arbor	Date	Dexter Mill Creek
2011	6/1/2011	415	6/1/2011	421	6/1/2011	1150	6/1/2011	2590	7/29/2011	996
2006	6/28/2006	160	6/29/2006	161	6/1/2006	369	6/1/2006	748	6/22/2006	178
2001	6/3/2001	206	6/4/2001	238	6/1/2001	436	6/2/2001	1200	6/3/2001	240
1992	7/15/1992	169	7/19/1992	183	7/19/1992	399	8/1/1992	720		0

APPENDIX J

Recorded Precipitation from NOAA on Maximum Stream Discharge Date with 4 Day Buffer

Year	Subwatershed	4 Days before Max Stream Discharge Date	3 Days before Max Stream Discharge Date	2 Days before Max Stream Discharge Date	1 Day before Max Stream Discharge Date	Max Stream Discharge Day	Total Precip (mm)
2011	Milford	0.98	5.29	5.49	0.00	0.97	12.72
	New Hudson	0.98	5.29	5.49	0.00	0.97	12.72
	Hamburg	0.91	4.76	6.05	0.00	1.20	12.92
	Dexter Mill Creek	0.00	0.00	0.00	107.64	36.62	144.26
	Ann Arbor	0.48	8.49	4.92	0.00	0.13	14.02
2006	Milford	0.00	0.00	0.00	0.90	2.78	3.68
	New Hudson	0.00	0.00	0.90	2.78	1.03	4.71
	Hamburg	0.00	0.00	0.00	2.90	0.08	2.97
	Dexter Mill Creek	0.00	8.44	3.24	6.40	25.49	43.57
	Ann Arbor	0.00	0.00	1.47	2.63	0.72	4.82
2001	Milford	0.23	0.00	1.73	6.99	12.52	21.47
	New Hudson	0.00	2.13	7.70	11.35	0.44	21.62
	Hamburg	12.34	10.37	0.15	0.00	1.40	24.26
	Dexter Mill Creek	0.08	2.87	6.61	10.37	4.87	24.81
	Ann Arbor	1.54	0.08	2.87	6.61	10.37	21.48
1992	Milford	0.00	16.82	14.37	33.61	9.62	74.42
	New Hudson	9.62	8.81	8.87	11.15	6.70	45.15
	Hamburg	14.40	12.63	8.92	9.99	9.83	55.78
	Dexter Mill Creek						0.00
	Ann Arbor	0.05	1.72	5.30	41.00	0.83	48.91

APPENDIX K

Calculated Normalized Stream Discharge Based on Area of Subwatersheds

Year	Subwatershed	Discharge (ft^3)	Individual Area (mi^2)	Cumulative Area (mi^2)	Cumulative Normalize Discharge (Ft^3/ mi^2)
2011	Milford	415	114.5	114.5	3.62
	New Hudson	421	40.5	155	2.72
	Hamburg	1150	164.5	319.5	3.60
	Dexter Mill	996	130.6	130.6	7.66
	Ann Arbor	2590	296.2	746.3	3.47
2006	Milford	160	114.5	114.5	1.40
	New Hudson	161	40.5	155	1.04
	Hamburg	369	164.5	319.5	1.15
	Dexter Mill	178.0	130.6	130.6	1.37
	Ann Arbor	748.0	296.2	746.3	1.00
2001	Milford	169	114.5	114.5	1.48
	New Hudson	183	40.5	155	1.18
	Hamburg	399	164.5	319.5	1.25
	Dexter Mill	240.0	130.6	130.6	1.85
	Ann Arbor	720.0	296.2	746.3	0.96
1992	Milford	206	114.5	114.5	1.80
	New Hudson	238	40.5	155	1.54
	Hamburg	436	164.5	319.5	1.36
	Dexter Mill		130.6	130.6	
	Ann Arbor	1200.0	296.2	746.3	1.61

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