An Evaluation of Wetland Functions with Specific Emphasis on the Role of Wetlands in Flood Control in the Red River Valley of Manitoba

by

Kristine Juliano

A thesis submitted to the Faculty of Graduate Studies
in partial fulfillment of the requirements
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FACULTY OF GRADUATE STUDIES
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ABSTRACT

In the past, wetlands have been viewed as unproductive wastelands whose only value was in their ability to be drained and put to 'better' use. Agricultural practices, urbanization and industrial development have all contributed to the destruction of wetland areas all over the world. Today, Canadian soil is home to 24% of the world's remaining wetlands.

Due to scientific studies that have identified wetland functions, there has been a gradual shift in society's perception of the role that wetlands play in the environment. This is because many of the functions that wetlands perform are considered to be valuable. This recent public awareness has led to questioning regarding how wetlands should be managed; that is, is wetland removal in the best interest of society, or should the protection of wetlands be a priority? Obviously, this is not an easy question to answer since all wetlands are slightly different from each other, and each perform functions in different capacities. What is obvious, however, is that all wetland functions should be understood and considered holistically when making such a decision. Wetland research has been strong in the last couple of decades, however, the role that wetlands play in low frequency flooding events has not received the attention it deserves.

The research in this thesis focuses on considering wetland functions in a holistic manner when making resource decisions. To accomplish this, all wetland functions must be fully understood; this includes the role of wetlands in flood control. This function is given special attention in Chapter Three: A Case Study, where one watershed from the Red River Valley was studied; the Rat River Watershed. It was found that a reduction in total flood volume would be possible with an expansion of wetland areas. The reduction,

however, was found to be quite modest for low frequency flooding events. It is important to note that these results are limited by several factors: data strongly limited the model, and the sub-routines within the model, that could be used for the analysis. This conclusion is also based on data from only one large flood, 1997. Additionally, the results from this study generalize the impacts of wetlands on flood control for the entire Red River Basin based on only one watershed within it.

It can be concluded from this research that the protection of wetlands for the sole purpose of flood control in the Red River Valley may not be the best option, since they are of limited value during low frequency floods. This does not mean to say that wetlands should not be protected in the Valley. Rather, attention should be given to the fact that wetlands can reduce total flood volume; this could be of tremendous value on a smaller, community scale. This value, coupled with the many other valuable services that wetlands offer, clearly indicate that wetlands are a valuable resource that deserve special attention.

ACKNOWLEDGEMENTS

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CHAPTER 1: INTRODUCTION

1.0 PREAMBLE

Wetlands currently comprise approximately 6 percent of the surface of the earth (Williams 1990). Historically, they have been regarded by many individuals as wastelands and as areas that could be drained and put to 'better' use. There has been a substantial world-wide decline of wetlands as these areas have been drained for the purpose of agricultural production and other purposes. Today, twenty-four percent of the world's remaining wetlands exist within Canada (North American Wetlands Conservation Council 1992). This accounts for approximately fourteen percent of Canadian land (Cox 1996).

Over the last few decades there has been a gradual shift in the public's perception of wetlands and the role that they play in both rural and urban environments. Scientific studies regarding the identification and functions of wetlands have contributed to a greater appreciation of the various roles that wetlands play. Some of the many benefits with which wetlands have been accredited with, include: water purification and the cycling of nutrients, ground water recharge, habitat for wildlife, and recreational opportunities for individuals.

Research studies have identified the functions and the numerous and wide ranging benefits that wetlands can offer society. The role that wetlands play in low frequency flooding events, however, is one function where further research is necessary. With depleted wetland areas due to agricultural pressures, some organizations have strongly supported the idea that wetlands could provide relief from flooding events. This issue has become prevalent in the last couple of years due to the flood that was experienced in the Red River Valley in 1997. This flood resulted in significant economic damage to both public and private property in Canada and the United States. While some organizations support the idea that increased wetland areas would have resulted in less flooding in the valley, others support the idea that wetlands could not have made such a difference in flow volumes.

Understanding all functions and assessment strategies of wetlands is crucial. It is of the utmost importance that decision makers recognize and fully comprehend the many important functions that wetlands perform. Because wetlands are relatively small, and generally quite dispersed over a landscape, they have often been misunderstood. Wetlands, however, need to be considered holistically.

1.1 ISSUE STATEMENT

With increased interest in some of the roles that wetlands play, it is important that all wetland functions and values be fully understood in order for decision makers to come to knowledgeable choices regarding wetland preservation, restoration or construction. The role that wetlands play in flood control is poorly understood and is one where farther research is necessary. An investigation of this function will be performed using one representative sub-watershed, the Rat River, within the Red River Valley of Manitoba (Figure 1).

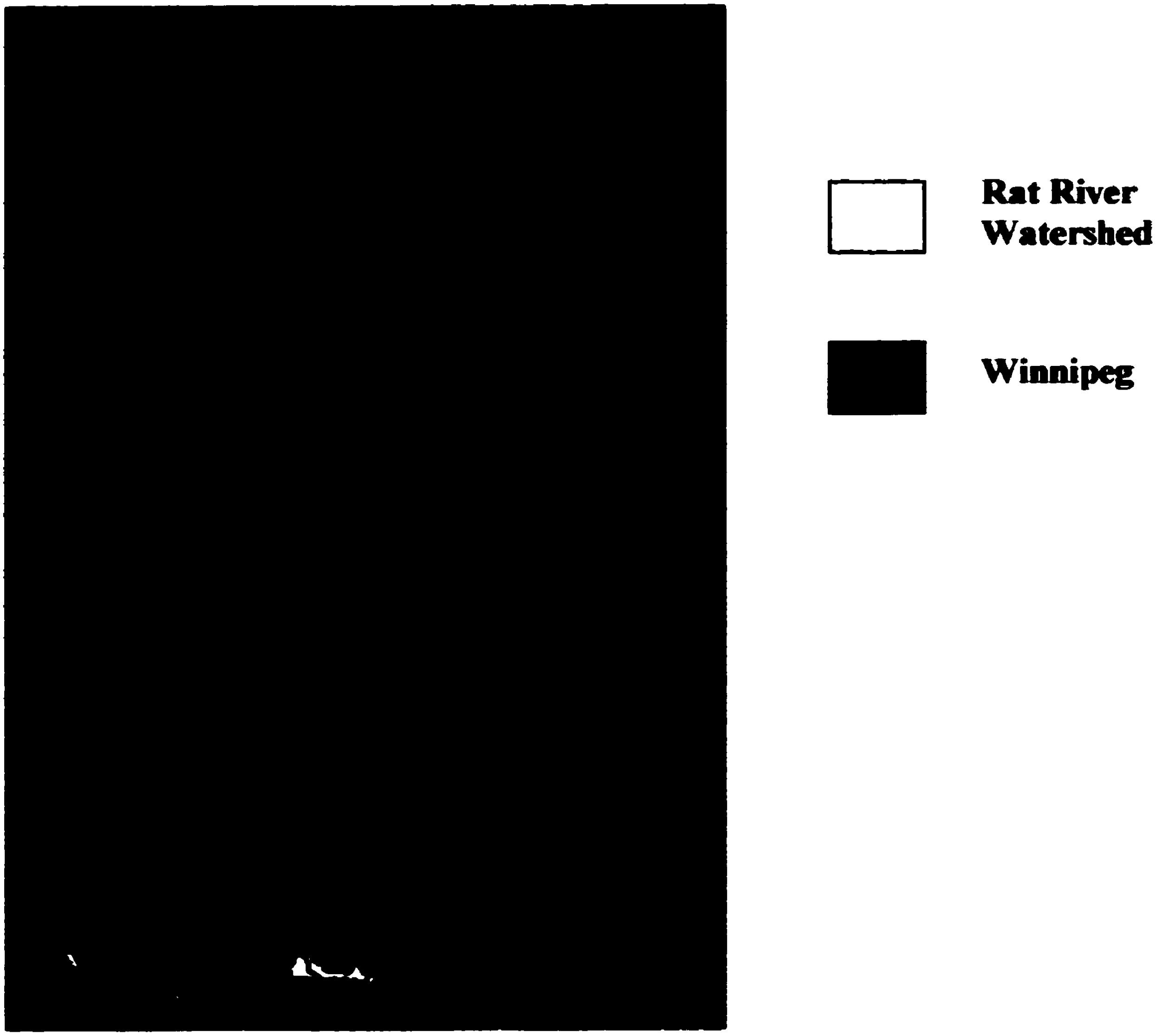

Figure 1. The Rat River Watershed in relation to Lake Manitoba, Lake Winnipeg, and the city of Winnipeg.

1.2 OBJECTIVES

- To provide a holistic review of wetland functions and Canada's wetland assessment strategy.
- To present a detailed case study of one wetland function; the role of wetlands in flood control.
- To provide recommendations for short-term surface water storage evaluation and wetland assessment.

1.3 METHODS

To meet the first objective of this research, a thorough literature review was completed. This is included within Chapter Two, which focuses on wetland decline and the need to protect remaining wetlands due to the value that society has placed upon them. These values are closely linked to the many functions that wetlands have been proven to provide. Recent increased interest in wetland decline, however, has prompted questions regarding wetland functions.

A review of government regulations within Canada was also completed. Distinctions were made between federal and provincial legislation. Chapter Two also considers wetland properties and looks specifically at how wetlands are classified and distributed within Canada. An evaluation of Canada's wetland assessment strategy has shown that wetlands should be considered holistically, both in terms of their functions and in terms of their surrounding ecosystems. This is quite difficult, however, since one wetland function supports a great deal of controversy; the role of wetlands in flood control.

To meet the second and third objectives of this research this function is further investigated in the case study contained in Chapter Three of this report. The case study specifically focuses on the role of wetlands in flood control using a representative watershed, the Rat River. This was accomplished through the construction and use of a digital elevation model (DEM) and a hydrological model. This watershed was selected for use in this project, as it is very similar to the rest of the Red River Basin. It also had the necessary data to allow such an analysis to be completed; this data is discussed in more detail later in this document.

Procedures for the development of the DEM are attached in Appendix A. This involved the substantial research of different methods to create digital surfaces. A Geographical Information System (GIS) called ArcView was used to create the DEM. The hydrological model chosen for this project was the Hydrologic Engineering Centre's Hydrologic Modeling System (HEC-HMS). Research into various models was done to aid in the process of determining which model would best serve this project, given the data that was available. The specific methodology associated with this case study can be found in Chapter Four.

1.4 ORGANIZATION OF THE STUDY

This project considers all wetland functions while specifically focusing on the role that wetlands play in flood control. Chapter Two is a literature review that examines how wetlands are classified in Canada, wetland functions and values, and Canada's wetland assessment strategy. Chapter Three specifically investigates the role that wetlands play in controlling floods in the Red River Valley of Manitoba. Chapter Four consists of a discussion of the case study, and draws conclusions, and gives recommendations for further evaluation of hydrologic functions in wetlands, and future wetland assessment strategies. Appendices are located at the end of this document.

CHAPTER 2: REVIEW OF RELATED LITERATURE

2.0 INTRODUCTION

2.0.1 Wetland Properties

Wetlands represent a very complex portion of the ecosystem. They are not climatically based and as a result they can be found in nearly every climatic zone on earth including, the land at and between the equator and the poles (Williams 1990). Generally, wetlands cover small areas of land and they are found scattered throughout a landscape. Features such as these have perpetuated the notion that wetlands are wastelands and therefore worthless.

Wetlands are typically classified as distinct entities since they are neither completely aquatic nor completely terrestrial; wetlands often represent a physical interface between the aquatic and terrestrial ecosystems resulting in a functional overlap (Figure 2a) (National Research Council 1995). Wetland areas can also be found isolated

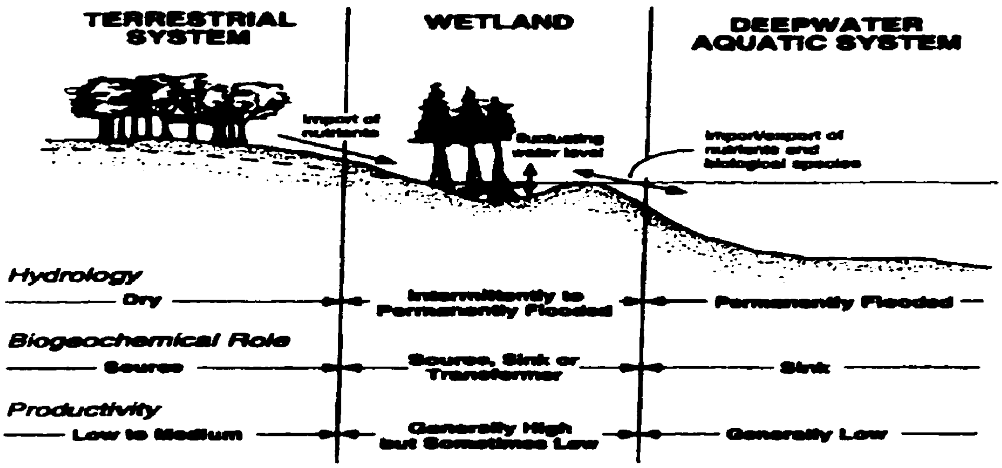

Figure 2a. Wetlands as a physical interface between aquatic and terrestrial systems (after National Research Council, 1995).

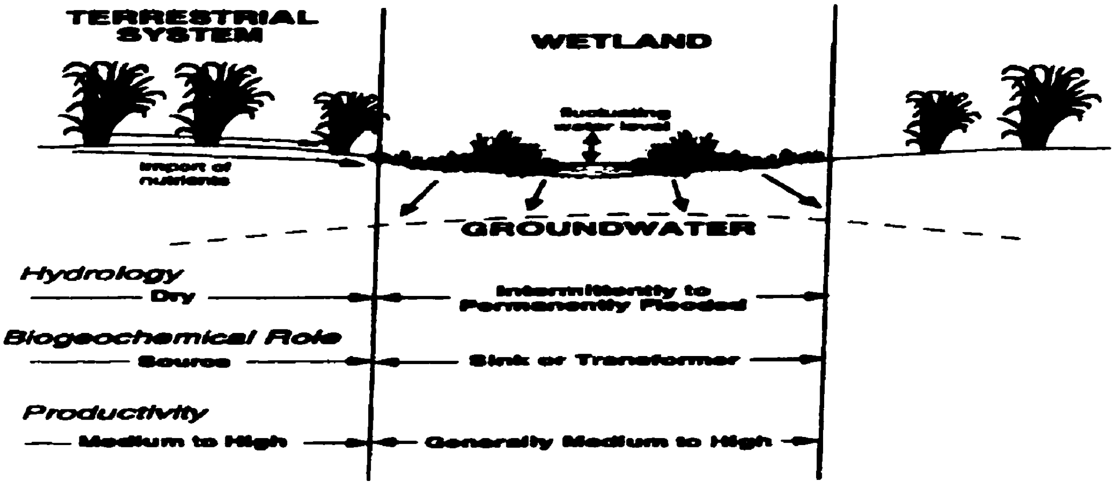

Figure 2b. Wetlands isolated from other water bodies (after National Research Council, 1995).

from aquatic systems (Figure 2b). They can share the vascular flora of terrestrial ecosystems, however, the flora are usually of a different species. Despite this physical interface, and the structural and functional overlap with both terrestrial and aquatic systems, wetlands show a uniqueness from these other ecosystems and deserve recognition as a distinctive class (National Research Council 1995).

The aquatic and terrestrial overlap often complicates the procedure of determining wetland boundaries. In fact, the process of identifying and determining wetland boundaries constitutes the majority of the technical and legal work often associated with wetlands (Luce 1995). Watershed modification, average annual precipitation and evapo-transpiration all contribute to wetland expansion and contraction over time, making wetland boundaries difficult and sometimes impossible to determine (Kent 1994). An additional complication comes from the fact that there is not one universal definition for wetlands. This is due to individual wetland uniqueness in terms of their hydrology, soils, vegetation, size, shape, and location within a watershed (Kent 1994). This results in functional attributes that are unique to a particular wetland area, making it difficult to assign one common wetland definition to all wetlands. Nonetheless, it is often helpful to understand the various definitions before assigning the one that best meets the needs of the project at hand.

2.0.2 Wetland Definitions

There are numerous definitions of wetlands that can be found in the literature; some are vague while others are quite specific. Some of these definitions include: "an area of wet soil that is inundated or saturated under normal circumstances and would support a prevalence of hydrophytic plants" (Ward and Elliot 1995), and "the occurrence of water in bodies that do not constitute permanent watercourses, such as lakes or rivers" (Percy 1993). A reference definition given by the National Research Council (1995) includes:

> ...an ecosystem that depends on constant or recurrent, shallow inundation or saturation at or near the surface of the substrate. The minimum essential characteristics of a wetland are recurrent, sustained inundation or saturation at or near the surface and the presence of physical, chemical, and biological features reflective or recurrent, sustained inundation or saturation. Common diagnostic features of wetlands are hydric soils and hydrophytic vegetation. These features will be present except where specific physicochemical, biotic or anthropogenic factors have removed them or prevented their development.

For the purposes of this study, however, a wetland will be defined as an area of land "that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation, and various kinds of biological activities which are adapted to a wet environment" (National Wetlands Working Group 1987). This Canadian definition is simple, yet it takes into account the essential features for which wetlands have become known.

2.0.3 Wetland Hydrology

"Wetland hydrology is the single greatest impetus driving wetlands formation" (Tammi 1994). Additionally, hydrologic conditions influence and determine many of the characteristics of a wetland. The size of a wetland and the species that are found within it, are both determined by its water status (Mitsch and Gosselink 1993). Wetland soils and nutrients are also influenced by hydrologic conditions (Kadlec and Knight 1996).

Water enters and exits a wetlands' system through a variety of processes. Surface runoff, groundwater discharge, precipitation, and stream-flow are means through which water enters a wetland (Figure 3). Alternatively, wetlands lose water through groundwater recharge, evapo-transpiration, and stream-flow (Figure 3). Both the inflow

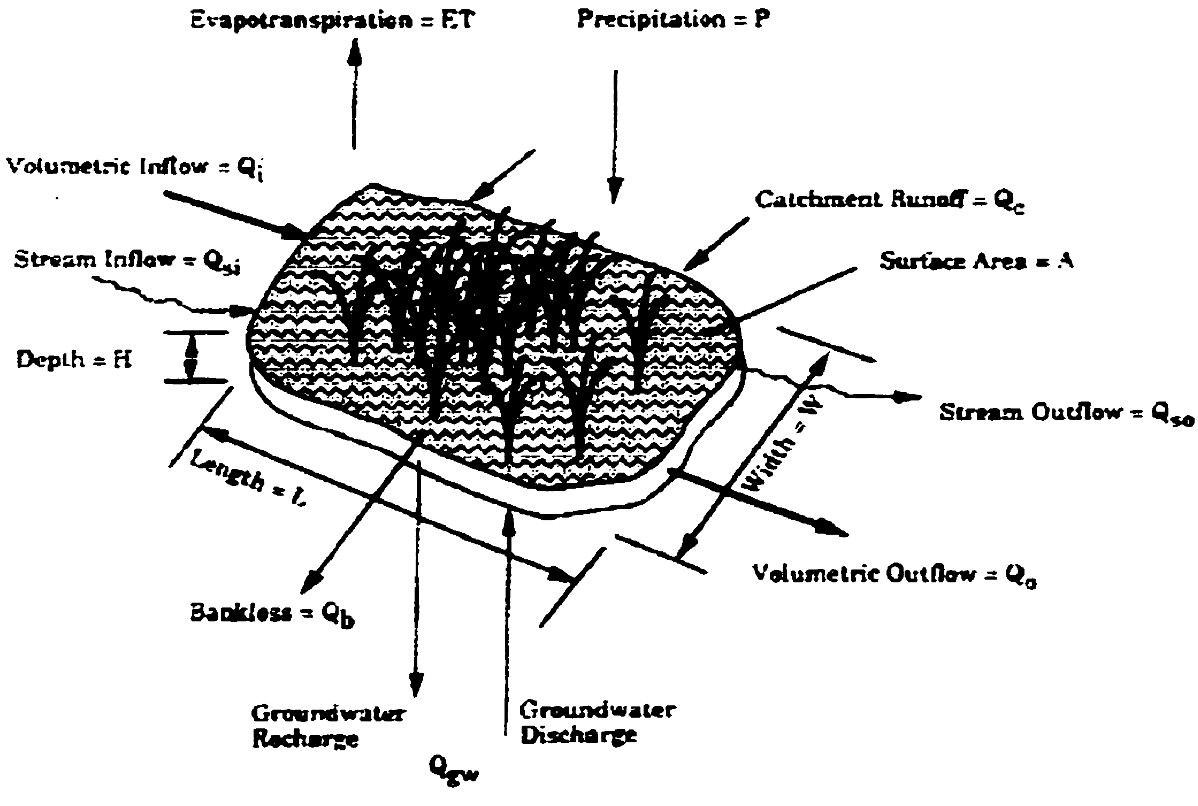

Figure 3. Wetland input/output components (after Kadlec and Knight 1996).

and the outflow from a wetland are quite variable. For example, inflow from surface runoff would occur after a rainfall event, or during and after the spring melt. Thus, inflow from a rainfall event is dependent on climatic circumstances, which is often unpredictable, while spring melting is seasonal. Likewise, outflow from evapo-transpiration is dependent upon the sun and is therefore on a diurnal cycle. The volume of water that a wetland stores is directly related to the balance between these inflows and outflows, and the wetland basin characteristics (Kadlec and Knight 1996). This will be discussed in more detail in the Case Study in Chapter Three within this document.

Wetland areas commonly have fluctuating water levels depending on the geomorphic setting, water source, and the hydrodynamics of the system itself (National Research Council 1995). These factors interact with each other, which contributes to the uniqueness of a specific wetland area. Both abiotic and biotic characteristics of a wetland are controlled by the hydrology of that wetland, and vice versa (National Research Council 1995).

2.1 WETLAND FUNCTIONS AND VALUES

2.1.1 Overview

In the last several decades an enhanced awareness of wetland functions and values has occurred. This awareness has been attributed to an increased appreciation of the positive environmental and ecological functions that wetlands support and the values that society places on these functions (Williams 1990a). It is sometimes difficult, however, to distinguish between these functions and values; in fact, functions are frequently viewed as values. This is, however, an important distinction to make (ibid.), since not all wetland functions are valued by society. The value that society places on a particular function may depend on many factors. These values also have the potential to change over time since they are essentially based upon society's perception of a wetland function (National Research Council 1995). Richardson (1994) defines the value of a wetland as "an estimate, usually subjective, of the worth, merit, quality, or importance of a [wetland] or portion thereof". Reimold (1994) reinforces this idea in his definition; he considers values to be "sociological, subjective terms, which are particularly malleable". Values are clearly anthropogenic in nature. Functions, on the other hand, have been described as "the basic processes at work in wetland environments" (Williams 1990a). Thus, although functions and values are distinct from one another, they are intricately connected; values would not exist without functions.

Wetland functions can be divided into a multitude of different categories. For simplicity, however, they are generally categorized into three main groups. These include: hydrologic functions, bio-geo-chemical functions, and habitat and food web functions (National Research Council 1995). These three functions are all fundamentally linked to each another. Within each one of the broad categories listed above, wetland functions are divided farther, into more specific roles. Because wetland values are strongly linked to these specific functions, each function has one or more values that is associated with it.

2.1.2 Hydrologic Functions

There are several hydrologic functions that are associated with wetlands. Many of the hydrologic functions that wetlands perform, however, are less well known (Ward and Elliot 1995). Some roles are poorly understood due to the difficulty in adequately characterizing a wetland area; this requires time and money, and is often technically challenging (Cole et al. 1997). For example, determining a wetland's hydro-period (the water level of a wetland over a period of time) is "a major technical challenge ... for sites on which there are no hydrologic data, or for which hydrologic data cover only a short interval (National Research Council 1995). This is a very important feature of a wetland to understand since a hydro-period is closely integrated with other aspects of the wetland water budget such as rainfall, evapo-transpiration and ground water seepage (ibid.). This is also closely related to the hydrologic functions of wetlands. Knowing the hydro-period of a wetland can aid in the understanding of some functions at a particular wetland site. This in turn, aids in the understanding of the value that society may place on a specific wetland.

Some wetlands are the source of ground water recharge (National Research Council 1995). This function is dependent, however, on the physical characteristics of the particular wetland area. The geological setting, soil type, and the hydraulic conductivity of the area of interest, all play a significant role in whether a particular wetland is capable of recharging an aquifer (Williams 1990a). Wetland areas that are a source of ground water recharge are a value to society; they supply water for the aquifer which in turn, supplies water for both domestic and industrial consumption.

The long term storage of surface water is also considered to be a function that wetlands perform (National Research Council 1995). These particular wetlands are characterized by some type of topographical relief allowing water to pool over extended periods of time. This is a valuable function to society as it allows for the maintenance of fish habitats during dry periods, and it provides habitat for many birds and mammals; this potentially allows for recreational activities, such as hunting and fishing, to occur.

Another hydrologic function that wetlands have been found to foster is the discharge and recharge of streams located in close proximity to the wetland area (Richardson 1994). Streams provide habitat and food for a wide variety of plant and animal species. This is of potential value to society as maintenance of these species may provide many recreational opportunities. Additionally, streams and rivers can provide water for industrial or agricultural purposes.

The reduction of downstream flood peaks due to a wetland's short-term surface water storage capability has also been accredited as one of their functions (National Research Council 1995). The idea is that wetlands temporarily store run off water, which reduces channel stage and channel velocity. This results in flood waters reaching main channels at different times, which ultimately results in the protection of downstream communities. This could be of tremendous value to communities as it potentially reduces property damage due to flood waters. Whether this would hold true given the volume of spring runoff in the Red River Valley during low frequency floods is further investigated in Chapter Three of this document.

2.1.3 Bio-Geo-Chemical Functions

Wetlands are also responsible for many *bio-geo-chemical functions*. Wetlands aid in the transformation and cycling of chemical elements through the system allowing nutrient stocks to be well maintained (National Research Council 1995). Through the processes of development and growth of wetland plants, nutrients and chemicals are absorbed by both the portion of the plant that exists above and within the soil (Kadlec and Knight 1996). Alternately, when a plant dies it decomposes and becomes part of the 'litter' where some of these chemicals are returned to the water, keeping it nutrient rich, while other chemicals are absorbed or retained by the soil (ibid.) (Figure 4). Additionally, some chemicals are released into the atmosphere, thus leaving the wetland cycle completely. These chemicals can include nitrates, ammonium, and sulfur.

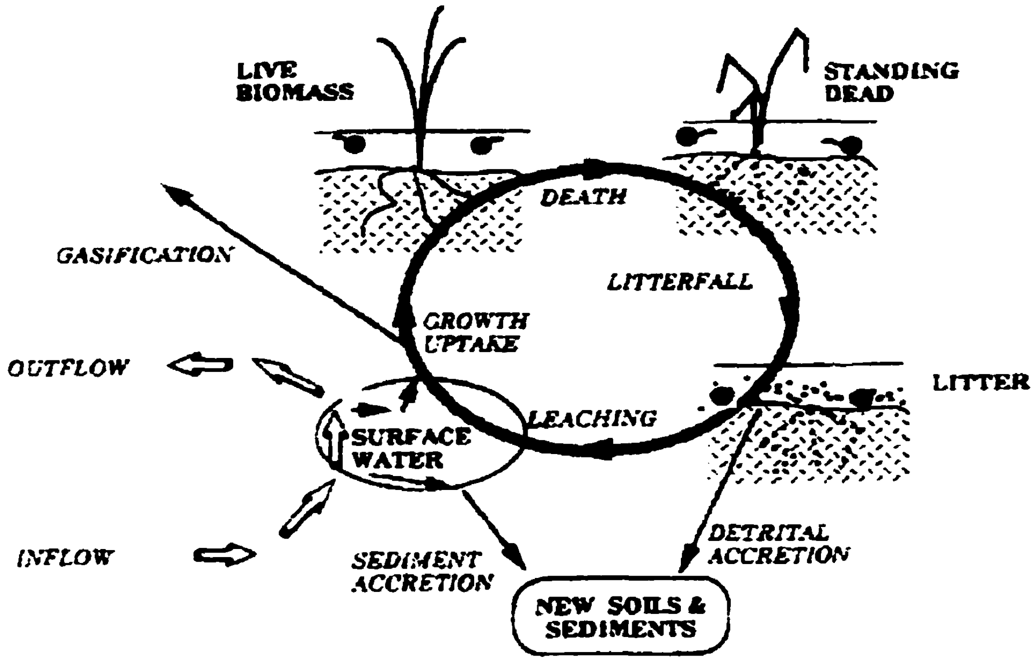

Figure 4. A wetland's bio-geo-chemical cycle (after Kadlec and Knight 1996).

Through this process wetlands are able to retain and remove harmful dissolved substances in the water column. This is an important function, as it allows for the trapping and removal of such pollutants as phosphorus and nitrogen (Williams 1990). Both of these chemicals are heavily used in agricultural fertilizers and can lead to rapid plant and algae growth when they reach streams, rivers and lakes. The removal of such pollutants thus assists in the enhancement of water quality; when water passes through a wetland, its velocity is reduced allowing for bio-chemical interactions to take place between the water, plants, and soil. This allows for the natural removal of nutrients, pathogens and pollutants (Coughanowr 1998). It is the trapping of sediments and the removal of nutrients that has the greatest impact on improving water quality (Kantrud et al. 1989).

The accelerated eutrophication of lakes is often the result of an overload of phosphorus and nitrogen and this has many consequences; among them is the inability of a lake to support a healthy aquatic environment, leading to the loss of marine organisms. Wetlands are also able to remove toxic residues such as pesticides, herbicides and heavy metals (William 1990). It is important to note, however, that a wetland's ability to effectively remove pollutants from the water column fluctuates depending on its hydrology and biota at a particular time (Davis et al. 1981). The ability of a wetland to perform this function is very valuable for society; wetlands help improve the quality of drinking water and preserve the presence of aquatic life in healthy environments. This allows for continued recreational enjoyment by society.

Some wetlands are also responsible for the accumulation of peat and inorganic sediments (National Research Council 1995). The formation of peat results after the accumulation of many years of deposits from wetland 'litter' and compaction., under anaerobic conditions. Peat formation is a relatively slow process; it generally accumulates at a rate of no more than 2 millimeters per year (Gosselink and Maltby 1990). Throughout the world peat wetlands are frequently mined for horticultural purposes and for fuel (Zoltai et al. 1988). Mining provides many economic benefits to those individuals in this industry. Peat wetlands that are not mined are also of significant value since they are able to aid in the maintenance of water quality (National Research Council 1995), thus supporting healthy ecosystems.

2.1.4 Habitat and Food Web Functions

Wetlands fall within the group of ecosystems that are among the most productive in the world (Williams 1990). Wetland vegetation plays a major role in transforming solar energy and nutrients into stored energy in plant tissues (Reimold 1994). This is because many wetland plants are autotrophs and are composed of green plant tissue, as opposed to woody tissue; as such, they are constant and efficient converters of solar energy into bio-mass (Williams 1990). This process results in a habitat where energy is in a concentrated form that can be consumed directly by grazing animals (Reimold 1994). Because wetlands provide an environment where photosynthesis can occur and where the recycling of nutrients can take place, they play a significant role in the support of food chains (Adams 1988). This is important for a large diversity of animals which depend on wetland areas for their survival.

Some vertebrates and invertebrates depend on wetlands for their entire life cycle while others only associate with these areas during particular stages of their life. The vegetation that is unique to wetlands, provides food and nesting grounds for many different migratory birds, including waterfowl. Depending on the geographic location of the wetland, it may be used temporarily by waterfowl during migration, or it may be used as a nesting site for a complete season. It has been well documented that the prairie pothole region of Canada and the United States provides primary nesting and breeding grounds for both ducks and geese (Williams 1990). This habitat is also used by birds considered to be more terrestrial in nature such as passerines, whom often use the perimeter of wetlands for nest sites.

Whether a wetland is permanent or temporary also influences which species will make use of it and for what duration of time. A temporary wetland that is saturated with water for only a couple of weeks out of the entire year, will have certain functions that may cease during the dry period (National Research Council 1995). For example, this type of wetland would not be able to support organisms such as fish that require inundation for an entire season. It is important to consider the length of time that a wetland is inundated when estimating wetland bio-diversity, however, wetlands that maintain water throughout the entire summer do not necessarily maintain a larger diversity of organisms. Thus, wetlands that become dry throughout the summer months still contribute significantly to bio-diversity. Reducing the number of wetlands in an area, however, frequently leads to a reduction in plant and animal diversity (National Research Council 1995).

The value of a wetland area as habitat can be determined by considering the following factors: diversity of vegetation, surrounding land use, spatial distribution of several wetlands, size, and water chemistry (Sather and Smith 1984 in Adams 1988). Because wetland areas are able to support a diversity of species, they are also of value to humans. The exploitation of species such as waterfowl, game birds, fur bearers and fish, has provided humans with many economic benefits. In addition to this, wetlands provide recreational enjoyment in the form of bird watching, hunting and fishing. Other wetlands are able to provide essential habitat for those species that are rare, threatened or endangered, such as the Whooping Crane. This aids in the survival of these species, giving further enjoyment and satisfaction to humans. Thus, the fact that wetlands provide essential habitat for many different mammals and birds is a valuable function that humans have taken advantage of for many years.

2.2 WETLAND DECLINE

Wetlands have historically been thought of as "unexploited wastelands" (Lynch-Stewart 1983). Although there are many functions of wetlands, as listed above, society does not always affix a value on those functions. The value of a wetland will often depend on the dynamic economic circumstances at the time (National Research Council 1995), its location, and what the wetland is perceived to be providing. That is, a wetland in one geographic location may offer the same benefits as one in another location, however, if those particular benefits are not recognized, or are not valued by society in that location, then they are perceived to be worthless. Wetland value in the past has been focused on their potential to be converted and used for more productive purposes such as agricultural uses, urbanization and industrial development.

Of all the reasons for wetland decline, the pressures posed to increase land acreage for agricultural purposes has been the major force behind wetland drainage (Williams 1990b). Additionally, government support programs have been in place that encourage farmers to drain wetlands (Rubec et al. *in* van Koot 1993). This perspective can also be seen in the legal history of the prairie provinces; statutes and 'common law' both ensured that the drainage of wetlands for agricultural production would require minimal effort (Percy 1993). Most of the wetland areas considered to be at risk are located on private land or are owned by provincial governments (Cox 1996). Over the years, increased consumer demand and increased cost of owning and operating agricultural land, has forced farmers to take full advantage of all potential areas on their property. This has resulted in the use and drainage of marginal lands, including wetlands.

Wetland losses and gains can also be attributed to natural processes. Formation, change, and degradation are all part of the dynamics of wetland systems (Gosselink and Maltby 1990). With the aid of human kind, these processes have been both accelerated (as seen in the examples above) and slowed. The creation, restoration, and enhancement of fresh water wetlands has been the main focus behind 'slowing down' the trend of wetland loss (Zentner 1994).

A review of a study done by Hanuta (1999) shows that the wetlands may have composed 18% of the land area in the Rat River Watershed, before agricultural development. Current land use data shows, however, that wetlands now compose only 3% of the land area. This is a significant reduction.

2.3 GOVERNMENT REGULATION

The Canadian Constitution clearly gives the provinces the vast majority of power with issues concerning wetland conservation and depletion (Percy 1993). The federal government may use their authority and enact general rules over wetlands only if those wetlands are "linked to specific areas of federal jurisdiction under the Constitution" (ibid.). This is due to the fact that provinces not only own the natural resources within their boundaries, but provinces also have jurisdictional power over property and civil rights within their province.

There are two pieces of federal legislation that indirectly concern wetlands; the Migratory Birds Convention Act and the Fisheries Act (Percy 1993). The Migratory Birds Convention Act has only one direct reference to wetlands and this concerns the prohibition of polluting any waters or surrounding land that migratory species might use. Percy (1993) states very strongly, however, that the Act is not concerned so much with the protection of habitat as it is with the physical protection of the migratory birds. The Fisheries Act, on the other hand, is much more direct in terms of its reference to wetlands, although this section of the Act is rarely enforced (Percy 1993). This Act prohibits any action that results in the harmful destruction, disruption or alteration of fish habitat. The federal government, however, is reluctant to enforce these powers for several reasons. First, this Act does not aid in the protection of wetlands that are not inhabited by fish; even those wetlands that do provide habitat may not support those fish species valued by society. Second, it is the provinces who hold jurisdiction over fish located within their province. Third, enforcement of a good portion of this Act has been entrusted to provincial officials.

Despite the fact that these two Acts of the federal government grant limited powers concerning wetlands, there are several other federal programs and initiatives in place which influence wetland depletion and conservation (Percy 1993). Some of these include: Federal Wildlife Policy, Federal Land Use Policy, Federal Policy on Wetland Conservation, the International Wetlands Convention, and the North American Waterfowl Management Plan. Although the federal government has effectively pursued the mandates of these programs and policies, most of the federal action has been restricted to the form of co-operative framework announcements (ibid.).

It appears that the majority of governmental influence on wetlands comes from the provincial governments. In Manitoba, for example, the *Water Rights Act* deals with wetland drainage in one broad category which encompasses all the different types of water bodies in the province, and it is the province who holds a vested interest. The Act states that the diversion of any type of surface water without a license is prohibited (Percy 1993). Thus, in order for a landowner to drain a wetland on their property, they must apply for a drainage license explaining their purpose. If the province feels that the land drainage would affect a significant area, then the application is forwarded to other appropriate departments for their feed-back. Although the process leading up to wetland drainage appears to be quite regulated, due to limited resources at the Water Resources Branch only those cases where individuals actually apply for licenses, or where individuals complain about unlicensed drainage activities, are reviewed (Percy 1993). That is, landowners generally only submit applications where land drainage will be substantial. Smaller operations are rarely penalized unless a complaint comes forward. Thus, some wetland decline can be accounted for in the fact that areas can often be drained without anyone being held accountable unless they are apprehended. It is therefore often to the farmer's advantage, in terms of time and money, to do precisely this. Resources for enforcement simply are not a government priority.

The Government of Manitoba's Water Policy # 6.6 states that "the protection of wetlands shall be a consideration in planning and developing drainage projects" (Province of Manitoba 1990). The government in 1990 adopted this policy, along with other water policies. Policy #6.6's intent was to "protect important wetlands from destruction and land development" (ibid). It was recognized that the majority of projects that resulted in wetland loss occurred on privately owned agricultural land. This document also recognized that the prevention of the destruction of wetlands can not be achieved through regulation alone; public education and incentives must be used in conjunction with such regulation.

2.4 WETLANDS IN CANADA

2.4.1 Wetland Classification

Wetlands can be either organic or mineral in nature (National Wetlands Working Group 1987). Organic wetlands are characterized by soils that exist on the accumulation of a minimum of 40 centimetres of peat. Alternatively, mineral wetlands are characterized by soils that, like organic wetlands, are saturated with excess water, however, due to climatic, edaphic or biotic reasons, little or no peat is produced (ibid.).

In Canada's Wetland Classification System (National Wetlands Working Group 1987) there are 3 hierarchical levels: class, form and type. There are five 'classes' including bogs, fens, swamps, marshes and shallow open water. Within each of these classes there are 'forms' that are specific to a particular ciass. The defining characteristics of wetland forms are: surface morphology and pattern, water type and the morphology of the underlying mineral soil. Wetland types are based upon the physiognomy of the vegetation cover; 'types' are not specific to classes or forms. This section of the document will focus on brief descriptions of each of the different wetland classes; refer to The Canadian Wetland Classification System (National Wetlands Working Group 1987) for more detailed information regarding wetland forms and types.

A *bog* is a wetland which is covered in peat where the water table is at or near the surface (National Wetlands Working Group 1987). The surface of bogs are characterized by acidic waters that are low in nutrients. These surfaces can be raised or level with the surrounding wetland area. The vegetation that is usually found is sphagnum moss and heath shrubbery; the area can be treed or treeless. Bogs are usually found in the northern regions of Canada and are the wetlands where peat harvesting and wetland drainage for the purpose of forestry frequently takes place in Canada (Bond et al. 1992).

Similar to bogs, *fens* are wetlands that are covered in peat; the water table however, is at or above the surface (National Wetlands Working Group 1987). The water in fens is characteristically high in nutrients, although these levels can be low to moderate. Decomposed sedge and brown moss peat is the dominating vegetation found in fens, however, grasses, reeds and shrubs may be present. Trees are sparse, if they occur at all. Like bogs, fens are found in the northern regions of Canada.

Swamps are characterized by standing or gently flowing nutrient-rich waters that persists for long periods of time (National Wetlands Working Group 1987). The water table is usually at or near the surface and the subsurface is continually waterlogged. Dense coniferous, or deciduous, forests and tall shrub thickets are usually present in addition to herbs and some mosses. Swamps are generally found in the southern temperate locations within Canada and they are frequently drained for forestry, agricultural and urban development purposes.

Marshes are wetlands that are characterized by the periodic, or permanent, inundation of nutrient rich water (National Wetlands Working Group 1987). Marsh waters are slow moving or stationary in nature with levels that often fluctuate seasonally. These waters can range from being fresh to quite saline with a high degree of oxygen saturation. Marshes can be recognized by their mosaic patterns in the landscape; they can be identified by numerous pools and channels with clumps of emergent vegetation. This vegetation is usually composed of sedges, grasses, rushes and reeds. They frequently border meadows and have a peripheral border of shrubs or trees. Marshes are found in close proximity to large temperate lakes, in tidal coastal areas, and in association with prairie ponds. Agriculture, dyking and urban development are the major forces that have had an impact on marshes.

Shallow open water wetlands are generally small water bodies that can be slow moving or standing in nature; they are frequently referred to as ponds, pools, shallow lakes, channels, oxbows, impoundments and reaches (National Wetlands Working Group 1987). To qualify as a shallow open water wetland, the water depth by mid summer must be no greater than 2 metres, and the water must cover a minimum of 75% of the original wetland surface area determined at the beginning of the summer season. This class of wetland is also characterized by either, shorelines that have experienced water erosion, or visible mudflats or floating vegetation mats. Very little vegetation exists in the open surface water. Agriculture, urban development and hydro-electric facilities have had the greatest impact on this class of wetland.

2.4.2 Wetland Distribution

The five wetland classes listed above can generally be found in similar regional areas since their characteristics are dependent upon the climate (Bond et al. 1992). The National Wetlands Working Group has identified twenty wetland regions in Canada; they are based upon a north-south temperature gradient, and an east-west precipitation gradient. These regions fall within seven geographic zones. These seven zones include: Arctic, Sub-Arctic, Boreal, Prairie, Temperate, Oceanic, and Mountain (Figure 5). Within each of these regions, similar vegetation exists (Zoltai 1988). The classes common to the Arctic, Sub-Arctic and Boreal regions are bogs and fens (Bond et al. 1988). The wetlands in the Prairie region are typically marshes and shallow open waters while the Temperate region wetlands are marshes, bogs and swamps. Marshes and bogs are characteristic of Oceanic regions while Mountain regions support bogs, swamps, and fens.

Figure 5. Canada's wetland regions. (Adapted from National Wetlands Working Group 1986 in Canada's Aquatic Environments 1999).

2.5 CANADA'S WETLAND ASSESSMENT STRATEGY

2.5.1 Introduction

The assessment of wetlands has become more and more important in recent years as awareness of the role that wetlands play in the environment has increased. The motivating factor behind research into assessing wetland functions has been the desire to predict the outcome of wetland alterations (National Research Council 1995). This is due in part to the realization that the drainage and conversion of wetlands for alternate purposes may not be in the best interest of society or the ecosystems involved. Recently, the results of wetland assessments has been used to 'rank' wetlands, allowing for the protection of those wetlands that offer the most value to society (ibid.). Thus, wetland values are very closely tied to wetland functions when considering their assessment results.

2.5.2 Functional Assessment Requirements

The National Research Council (1995) has outlined three requirements that are necessary for the functional assessment of wetlands. These include knowledge of a wetland's: functional capacity, predictors or indicators of those functions, and thresholds of the functions. The functional capacity of a wetland is its ability to perform a certain service (ie. to provide nesting habitat for waterfowl). An indicator of a function is a condition that can be observed that indicates whether a wetland can perform that function (ie. the presence of dense vegetation for waterfowl nesting). A threshold is the point at which a wetland can no longer perform that specific function (ie. the vegetation cover is less than a prescribed density deeming it unsuitable for nesting). These requirements are important concepts to understand and they seem to provide some of the theory behind wetland evaluation in Canada.

2.5.3 Evaluation Method

In an attempt to design a comprehensive method of assessing wetland functions and values and to aid in the understanding of wetland development concerns, Environment Canada and Wildlife Habitat Canada jointly undertook a multi-year project called 'Wetlands are not Wastelands'. The project was also initiated as a result of the realization that "an environment without wetlands is incomplete and a potential threat to our well-being" (Bond et al. 1992). In their final report they outline an extensive three stage evaluation process which is essentially designed to identify the benefits of a particular wetland and how those benefits are of value to society. These wetland values are then compared to the values of a proposed alternative. This aids developers, land-use planners, administrators, and the public in making informed wetland decisions.

This wetland evaluation guide is a three stage process designed in such a way that the completion of all three steps may not be necessary (Bond et al. 1992). It begins very generally, requiring information that would be readily available and proceeds into more complex questions. The first stage, called 'General Analysis', allows for the evaluation of wetland functions and the determination of the value that these functions offer society. These values are then compared to the values offered by a proposed project. The process is based on a system whereby numbers are assigned to individual questions which at the end of stage one, are tallied and compared to an overall rating scheme. This rating scheme then determines if a project should be accepted, rejected, or if more evaluation is necessary, in which case, Stage Two would be completed.

The process of Stage Two, called 'Detailed Analysis', is similar to Stage One, however, as the name suggests, it is significantly more detailed. It is more subjective and open to interpretation than the previous stage, however, its 'multiple value evaluation' is designed to be based upon rigorous investigations (Bond et al. 1992). Stage Three, called 'Specialized Analysis' requires the assistance of individuals with specific expertise in biology, resource economics and financial assessment. This is due to the necessity of placing monetary value on both non-marketable and marketable wetland functions. All benefits and costs associated with the project are understood at this level and the opportunity costs associated with wetland conversion are analyzed.

In 1998 Environment Canada released a report outlining the information and analysis that would be expected in the wetlands section of an Environmental Impact Assessment (Milko 1998). It clearly states the context within which the report should be written and asks for specific information concerning wetland functions, making direct reference to the report written by Bond et al. (1992).

2.6 CONCLUSIONS

For many years it has been documented that wetlands all over the world have been declining. Canada is no exception. Recent awareness of the functions that wetlands play in the environment has become of increasing interest to society and has lead to the questioning of whether wetland removal is in the best interest of individuals and the ecosystems involved.

This interest has also led to the examination of some of the functions that wetlands are accredited with performing. The concern stems from the idea that wetlands are slowly being destroyed and with them, the many functions that society depends upon. For the most part, a significant amount of research has been conducted concerning the various roles of wetlands. The role of wetlands during low frequency flooding events is one function, however, that has not been researched sufficiently. This function was brought to the forefront after the flooding that occurred in the Red River Valley of Manitoba during the spring of 1997.

As experienced in the rest of Canada, the Red River Valley has undergone a similar decline in the number of wetland areas. Permanent and temporary wetlands covered significant portions of the Valley during the nineteenth century (Krenz and Leitch 1993). As settlements in the Valley developed, well-drained land became scarce. This resulted in settlers turning toward poorly drained soils for their livelihood. Over time, this has led to our present day situation, where wetlands are not as plentiful as they used to be.

In the Red River Valley there is often the association of wetland decline with increased spring runoff. This idea was reinforced during the spring of 1997 when the valley experienced unusually high water levels. Severe flooding, however, has been occurring for many years, including those years prior to the surge of development in the valley. In fact, "the flood of 1776 was of vast proportions and part of the oral tradition of the region" (Bumsted 1997). Additionally, the flood of 1826 is the worst flood experienced in Manitoba, far surpassing the severity of the flood of 1997.

There are many opinions regarding the role of wetlands in flood control. One of the Sierra Club's suggested solutions to reducing the severity of the flooding that occurs in the Red River Valley, however, is wetland conservation and restoration (Sierra Club 1998). According to them, the restoration of those wetlands in the valley that have been drained, filled and destroyed "can help minimize peak river flows, and improve the health of the river system" (Sierra Club 1998). Sierra Club has suggested (1998) that "a program which begins to acquire or manage drained wetlands would help minimize future flooding". It is important to note, however that "very rarely has the importance and value of these natural mitigation strategies been quantified, and techniques for assessing the effectiveness and exact nature of their role have not been developed" (Williams 1990a).

The goal of this research is to investigate the role of wetlands in flood control in the Red River Valley of Manitoba and to bring attention to the importance of considering wetland functions in a holistic manner. As outlined by other individuals (Bond et al. 1992) wetlands perform many functions that are of value to society.

CHAPTER 3: CASE STUDY

3.0 INTRODUCTION

The devastation from the Red River Valley flood of 1997 can still be felt by many individuals in both Canada and the United States. The physical and economic damage to public and private property was substantial. This flood was particularly severe, but was by no means uncharacteristic of the Red River. High water levels and extreme flooding during spring runoff have been documented for many years.

There are many contributing factors that increase the likelihood of severe flooding during spring runoff. These can include: a high moisture content in the soil at the time of ground freezing during the fall, a large volume of precipitation experienced during the winter and spring months, ice jams, and a small number of days over which the winter snow pack melts. Given these uncontrollable factors, however, is there something economically feasible that can be done to reduce flooding in the Red River Valley?

The Prairie Provinces of Canada contains some of the richest agricultural lands in the world. Due to the high productivity of the soil, there has been a substantial increase, over the last century, in demand for this fertile land. With increased agricultural intensity many wetland areas have been converted to farmland (Adams 1988). By 1970 this had resulted in the conversion of 1.2 million hectares of wetlands to agricultural lands in the prairie provinces of Canada (Whitesell *in* Adams 1988, and Bellrose *in* Simpson-Lewis et al *in* Lynch-Stewart 1983). According to the Sierra Club (1998), there has been a reduction of 98% in the number of wetlands in the Red River Basin. It has been suggested that increasing the number and size of wetlands could result in a decrease in water levels during spring runoff periods (Sierra Club 1998). The Sierra Club suggests

(1998) that conserving the remaining wetland areas and restoring those that have been drained and filled, would result in reduced flooding. There are many opinions regarding this issue. Some individuals regard wetlands as storage reservoirs that can slow storm runoff. A wetland's response to such an event, however, would no doubt depend on many factors including antecedent conditions. Wetlands have been proven to provide many valuable services including bio-geo-chemical benefits and wildlife habitat, however, in the past, the role that wetlands play in alleviating flood impacts has not been clear. This is especially the case with floods of the magnitude experienced in 1997.

This Chapter serves to investigate the role that wetlands play in flood control. The limitations of this Case Study, however, must be recognized. The results and conclusions drawn in this study are based on one low frequency flood year, 1997. Additionally, the impacts of wetlands are generalized for the entire Red River Basin, based on those results from one representative watershed, the Rat River. The availability of data also limited the choice of the modeling tool, in addition to the sub-routines that could be used within the model.

The results generated from this study contribute to the correct estimation of the reduction of flood related damages, in that the findings can be used to assist in determining "possible actions to eliminate or reduce long-term risk to human life and property due to flooding" (International Red River Basin Task Force 1997). Additionally, these results will aid in the evaluation of whether changes to non-structural flood control measures are necessary. This study also contributes to the investigation of watershed land use changes in that the final results will help determine the extent to which "local and possibly regional effects on timing, magnitude, and volume of peak flows" (ibid. 1997) resulted from these changes.

3.1 METHODS

To investigate the hydrologic influence of wetlands on channel and overland flooding in the Red River Valley of Manitoba a digital elevation model (DEM) was used in conjunction with a hydrologic model. The current computer based hydraulic and hydrologic models that exist can predict channel and overland flows, in addition to flood events. These models, however, do not adequately quantify the impacts of wetlands on flood events. Additionally, the topography of the landscape defines how gravity will influence the flow of water in a watershed and thus plays a significant role in the hydrologic system. (Wolock and Price, 1994). The use of geographic information systems (GIS) to assist in hydrologic analysis is gaining recognition as an important means of incorporating detailed spatial data with hydrologic models. The utilization of a GIS allowed for a more comprehensive analysis of floodplain management to occur (Correia et al. 1998).

The local characteristics of the region within the Red River Valley of Manitoba were incorporated into this study through the selection of a representative watershed of southern Manitoba; the Rat River Watershed (Figure 1). Topographic data were collected for this area and a DEM was developed. The hydrologic model chosen for this analysis was the Hydrologic Engineering Centre's Hydrologic Modeling System (HEC-HMS). Both the DEM and the hydrologic models are described in more detail below.

A total of three scenarios for each of 1996 and 1997 were executed within the hydrologic model to predict the contribution of wetlands in flood reduction. The model was calibrated separately for each year, with the current area of wetlands being considered as a lumped parameter. In the first scenario, a 2% increase in wetland area was considered. The 2'nd and 3'rd scenarios involved a 5% and 10% increase in wetland area, respectively.

Wetland volume was determined through the combined use of the Prairie Farm Rehabilitation Administration's (PFRA) land–use data, the DEM and a past study done on the watershed by Ducks Unlimited. A feasibility study was performed by Ducks Unlimited in 1986 (Flavell and Sexton 1986) for the Rat River Watershed. Its purpose was to determine the feasibility of a waterfowl enhancement project in the watershed; the project was also considered for the additional capability of reducing flooding in the area. It was determined from this study that wetland depths in the burned-out peat areas "rarely exceed(ed) 40 cm" (Flavell and Sexton 1986). Using this information from this area, and the DEM it was determined that wetland depths were on *average* closer to 20cm in the entire watershed. This is the value that was used to determine wetland volume in the model.

3.2 STUDY SITE

The Rat River watershed is located approximately 30 kilometers south-east of Winnipeg and it flows into the Red River near a community called St. Agathe. The Rat River represents a typical river system within the Red River Basin. It drains an area of approximately 1550 km^2. Some of the watershed is used for agricultural purposes (Figure 6a), however, there still exists the large Rat River Swamp which is bisected by the river. Due to local fires the peat layer in this swamp has been reduced, but some peat is still present to various depths. During periods of high water levels, which occur during the spring, the Rat River overflows its banks resulting in the flow of water into Joubert Creek (Figure 6b). This creek also flows from east to west and it lies just to the north of the Rat River. It eventually joins the Rat River at a town called Ste. Pierre- Jolys. Many small communities exist throughout the watershed including: St. Pierre Jolys, St. Malo, and Grunthal. These communities and other smaller villages and farms are scattered throughout the watershed and account for a total population of approximately 3000 people. The western portion of the watershed, which is located closest to the Red River, is almost exclusively cropland. The central part of the watershed is a mix of trees, grassland, and cropland, while the eastern portion is characterized by treed and wetland areas. There are several Provincial Trunk highways, provincial two lane paved roads, and rail line routes that exist within the watershed.

Figure 6a. Cattle Grazing along the banks of the Rat River.

Figure 6b. Joubert Creek runs parallel with the Rat River. During spring run-off Joubert Creek often overflows its banks and flows into the Rat River.

3.3 DIGITAL ELEVATION MODELS

A digital elevation model is a continuous spatial representation of the surface of the earth. These models can be produced from a wide variety of information sources. Some of these sources include aerial photos, topographic maps and Global Positioning Systems. These data must be in a digital form in order to import it into a Geographic Information System (GIS) and it must be in a form that a GIS package can recognize. Once imported into a GIS, a spatial surface can be created. (See Appendix A for specific procedures used in developing the DEM).

After an extensive investigation into the digital data available for the Rat River Watershed, it was found that one continuous set of data did not exist that would cover the entire area of interest, at a scale that was deemed acceptable. This is because the best data available in the province of Manitoba follows the Red River, which flows from south to north. The Rat River Watershed, however, flows east to west. Thus, it was decided that two very different data sets would have to be combined and utilized. The Topographic Mapping Division of Manitoba's Department of Natural Resources provided both data sets. From easting 722,000 to 670,000, break-line data in an ASCII file format, at a scale of 1:60,000 was used. From easting 680,000 to 634,000 digital topographic data in a DXF format, at a scale of 1:30,000 was used. There was a 10,000 meter overlap of data between eastings 670,000 and 680,000. Both data sets were in the same datum, NAD83.

Ideally, it would have been best to use one continuous data set, where the format and scale were the same. This would have made the construction of the DEM significantly easier, as there would have been only one data set to deal with. Additionally, the DEM itself would have been developed from a more consistent set of spatially distributed points, and thus resulted in a more consistent DEM.

Because the elevation data available for the Rat River Watershed were not in a suitable format to be imported into ArcView, the GIS package selected for use in this project, both data sets required a significant amount of manipulation. It was also necessary to merge the two data sets.

Research has been conducted concerning the appropriate grid size for digital elevation models. Because processing time and space were a concern with this project, tests were done on small samples of data to determine if small grid sizes best reflected the features of the landscape. It is important to note that if the grid spacing in some areas is fine enough to pick up significant details, then in other places where variability is at a minimum, the grid will produce many unnecessary points that simply take up data storage space (Jones 1997). The final digital elevation model ultimately depends on three factors: the accuracy of the original data, the spacing of the original data points, and the grid cell size determined by the interpolator (Zhang and Montgomery 1994). That is, the DEM produced can not be any more accurate than the original survey data (Garbrecht and Martz 1996, and Montgomery 1996).

Using a sample from the original data set, it was found that decreasing the size of the cell exponentially increased the processing time, and the size of the final interpolated DEM (Table 1). Increasing the grid size of the sample allowed the results to be produced faster; the size of the file was also substantially smaller. Comparing the two tests, it was found that there was little difference between the resulting grids. It was ultimately decided that a 10-metre cell size would be adequate to reflect the variability of the landscape.

Table 1. A comparison of the two interpolation methods offered in the GIS package.

Method	**Grid Size** (metres)	**Time** (minutes)	**Space** (megabytes)
Spline	2	120	95
IDW	2	80	95
Spline	5	20	15
IDW	5	11	15

*Note that time and space are approximate, as the use of different options within each method produced slightly different results (results were generated using one 10km by 10km tile from within the watershed using a 64 megabyte ram, 350 megahertz computer system).

The GIS package used for the production of the DEM offered only two interpolation methods: Spline and Inverse Distance Weighting (IDW). Spline is a common interpolation technique that fits a minimum-curvature surface through the original input points. This is done such that the total curvature of the surface is minimized. With IDW it is assumed that the points closest to the cell being processed have the greatest influence on the interpolated value. Both methods were tested using a small sample of data. It was found that Spline produced more realistic results, however, due to the nature of the complete data set and a 'bug' within ArcView, it could not be utilized. This resulted in the use of IDW.

The final DEM of the entire watershed and surrounding area resulted in a file size of just over 200 megabytes. The area interpolated was slightly larger than the actual watershed; this was done on purpose. When a specific area is being interpolated there is often a certain degree of error that occurs around the edges of the interpolated area. Thus, edges of the DEM could be trimmed back to represent only the watershed itself; this would result in a final DEM with a size closer to 150 megabytes. The accuracy of the DEM, as stated above, is only as accurate as the original data set used to produce it. That is, because two data sets at different scales were used, the final product is only as accurate as the 1:60,000 data set. Figure 7 is an example of a 10km by 10km tile. In this example, the river is represented by the *series* of green dots. There is a difference in elevation of 20 metres from the highest surface to the lowest surface. In the DEM of the entire watershed there is a difference in elevation of 171 metres.

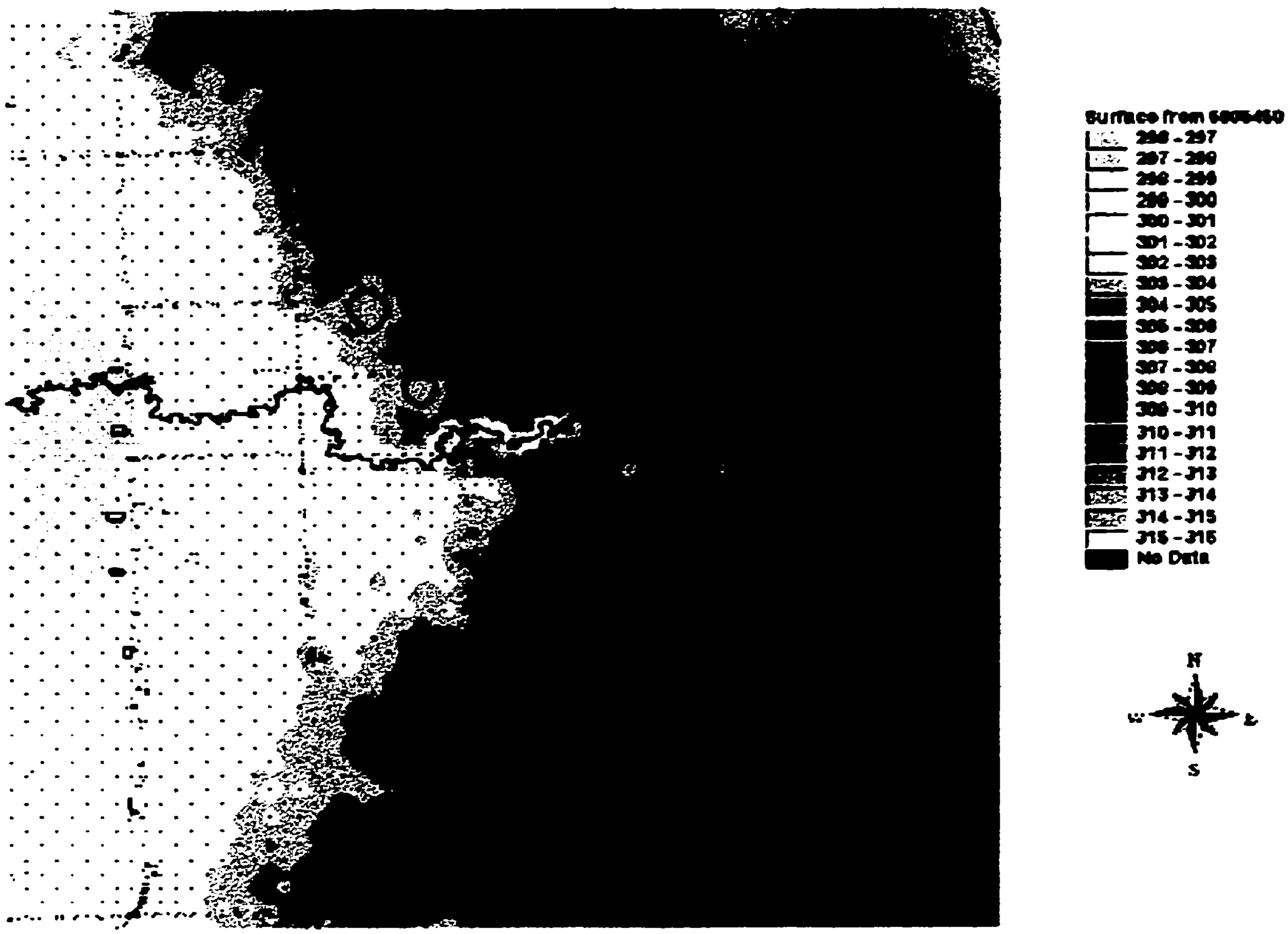

Figure 7. A 10km by 10km interpolated tile from within the Rat River Watershed, using IDW, and a 10m grid cell size. The green points on the surface represent the original data points within this tile. Each colour represents a different elevation which is measured in metres

Because a DEM is a continuous spatial representation of the earth's surface, it can provide additional detailed information about the topography of the landscape in projects such as this. The DEM produced of the Rat River Watershed was overlain with land-use data. The DEM, coupled with the land use data, provided additional topographic details, including the location and the available storage of wetlands in the watershed. This in turn was used as input data in the hydrologic model.

3.4 HYDROLOGIC MODELING OF WETLANDS: A BRIEF OVERVIEW

When selecting an appropriate model for the analysis of the impacts of wetlands on flood control there are many factors that should be considered. Understanding the hydrology of wetlands is very important and this involves understanding the characteristics of wetlands; this can aid in the model selection process. Some of the factors to take into account when modeling a wetland include (Hydrologic Engineering Centre 1988):

- the location of the wetland; whether it is directly connected to the water table or perched.
- where the wetland is located within the watershed.
- whether the wetland retains water for the entire year, or just during wet periods.
- the amount of vegetation in the wetland; this can effect evapo-transpiration to a great extent (this volume may be insignificant when considering floods such as that experienced in 1997).

Additionally, the following factors should also be taken into account:

- the storage and infiltration capabilities of the wetland.
- the spatial variation of the landscape.

Hydrologic models often have different modeling capabilities. Some of the components that models may have incorporated within them are, the capability to take into account: precipitation, snow accumulation and melt, evapo-transpiration, interception, infiltration, surface drainage and runoff, depression storage and routing, subsurface soil water flow and channel routing (Hydrologic Engineering Centre 1988). Given these many options, it is up to the modeler to determine which model meets their individual needs for their particular watershed; this decision is also based on data, or other, restrictions.

Compared with other basins in the world, the Red River Valley is quite unique in terms of its climate; during late fall the ground freezes, there is an accumulation of snow over the course of many winter months, and then a melt occurs during the spring. The length of the melt is different each year and depends on environmental characteristics. The Red River Valley is also unique in the fact that it is one of only eight rivers in the world that flows north. This can have an interesting effect on flooding conditions in the valley. This is due to the fact that snow often melts in the upstream reaches of the river prior to snowmelt in the downstream reaches. This results in water flowing north before the river ice has broken up or melted downstream.

Hydrologic models can be classified as either lumped or distributed. In lumped models a basin is considered to be homogeneous in terms of its spatial characteristics. That is, one location within a catchment is considered to have the same spatial characteristics, such as uniform rainfall, as another area in the catchment (Linsley et al. 1982). In distributed models, however, one larger catchment is divided into many smaller units. These smaller units are simulated separately and then combined to get a final catchment response. The advantage of using a distributed model is that the spatial variability of the watershed can be taken into account. Given sufficient input data these models can yield better results than lumped models.

Three hydrologic models were considered for this project: Hydrologic Simulation Program Fortran (HSPF), the Precipitation Runoff Modeling System (PRMS), the Hydrologic Engineering Centre Hydrologic Modeling System (HEC-HMS). These three models are briefly described below:

HSPF: This model was developed by the Environmental Protection Agency (Singh 1995). It is a lumped parameter, continuous model and is used to simulate both water quality and hydrologic processes in man-made and natural water systems. To simulate the processes of a watershed, this program incorporates the time history of climatic data with those parameters related to soil drainage characteristics and land use patterns. After a simulation has been run in HSPF the result is a time history of the quality and quantity of water that has been transported both over the land surface and through different soil zones. HSPF also has the capability of predicting runoff flow rates, stream sediment loads and concentrations of nutrients, pesticides and toxic chemicals.

Within HSPF there are 3 'application' modules and 5 'utility' modules. The application modules are used to simulate the hydrologic, hydraulic, and water quality characteristics of the watershed while the utility modules are used to access, manipulate and analyze the time-series data. Within the application modules, HSPF is able to simulate a variety of different processes including: water budget and runoff components, snow accumulation and melt, sediment production and removal, nitrogen and phosphorus fate and runoff, pesticide fate and runoff, and movement of tracer chemicals. It is also capable of modeling such things as heat balance processes for determining water temperatures, and hydraulic behaviour.

This model also makes use of an interactive program called ANNIE. Among its many capabilities, this program allows for data to be stored, updated, plotted and retrieved. Data is stored in a binary direct-access file called a Watershed Data Management (WDM).

HSPF prefers long time series records for precipitation and waste discharges. Additionally, for calibration purposes, lengthy records of stream flow and constituent concentrations are required. Some of the data requirements of this hydrologic model include: daily precipitation, evaporation, stream-flow, and solar radiation data, dew-point information and wind speed data.

There are many potential applications of this program including flood control planning and operations, river basin and watershed planning, and evaluation of urban and agricultural best management practices. It is unique in that it can simulate both water quality and water quantity problems. HSPF has had many applications from around the world.

PRMS: This model was developed by the United States Geological Survey (Singh 1995). It is a modular design, distributed parameter model. This model evaluates the effects of different combinations of precipitation, temperature, and land use on a watershed. PRMS can simulate watershed response on both a daily and a storm time scale. Its distributed modeling capabilities are accounted for in the modelers ability to partition the watershed into smaller units, called hydrologic response units (HRU's). Each HRU is considered to be homogeneous with respect to its hydrologic response. These units are determined based on such characteristics as slope, aspect, elevation, vegetation type, soil type, and precipitation distribution.

In the daily mode of PRMS, the daily accretion, depletion, storage and movement of water are calculated for each individual HRU. Each HRU's physical, hydrologic and climatic characteristics determine the rate and volumes of the processes listed above. Temperature, precipitation, and short-wave solar radiation are taken into account in the climatic component section of the program, while interception, soil moisture accounting, evapotranspiration, surface runoff, subsurface flow and ground water processes are taken into account in the land phase component section. There are separate components for channel reservoir calculations and snow component calculations.

PRMS also requires the use of the interactive program called ANNIE. This program provides the data management and analysis functions for PRMS. It allows the modeler to interactively create, verify, and update input data for the hydrologic model. Additionally, it provides statistical and graphical tools to aid in analyzing model input and output. All meteorological and hydrological data are placed in a file called a Watershed Data Management file (WDM). To populate the WDM file another program is generally used called In/Out Watershed Data Management (IOWDM). This program reads text files only.

Some of the model inputs include: daily precipitation, maximum and minimum air temperature, and solar radiation data. This model takes into account snowmelt and uses air temperature and solar radiation data to compute this process as well as those processes of evaporation, transpiration and sublimation.

PRMS also offers parameter-optimization and sensitivity analysis capabilities. The optimization subroutines allows for an automatic adjustment of parameters with the goal of obtaining a closer agreement between the predicted and observed runoff values. PRMS offers a large number of parameters for optimization and sensitivity analysis.

HEC-HMS: This model was developed by the U.S. Army Corps of Engineers (U. S. Army Corps of Engineers 1998). HEC-HMS essentially replaces HEC-1; it provides numerous options for simulating precipitation runoff processes. This new program offers the ability to perform continuous hydrograph simulations over long periods of time. It accomplishes this through the use of a 'single-reservoir soil-moisture representation'. It also computes spatially distributed run-off values using a 'grid cell' depiction of the watershed. The current version of this program does not have the capability to perform continuous moisture accounting or snow accumulation and melt simulation.

This model is broken down into three different components. These include: a basin model, a precipitation model, and a control specification section. Within the basin model choices can be made concerning loss methods, runoff transformation methods and routing methods. In this component the user can also select for the use of a diversion. The precipitation model allows for the incorporation of historical or hypothetical precipitation data. Control specifications are used to specify the start and end time and date for a simulation.

This model has the option to allow for the basin runoff to be 'quasi-distributed'. This can be accomplished through the use of the ' Modified Clark method'. What this does is superimpose grid cells on to the basin; rainfall and losses are then uniquely tracked for each cell. HEC-HMS also provides the ability for parameter optimization. The modeler is able to impose constraints on parameter values.

An interesting feature of HEC-HMS is that there are scripts available that are designed for use with the Geographic Information System, ArcView. These scripts allow the user to divide the entire watershed into smaller subbasins through the direct use of a DEM. This allows for the 'setup' within HMS to be significantly faster than if it is done manually. Of importance here, however, is the availability of data for each of the subbasins that these scripts produce.

This model was eventually selected for use in this project. There were several reasons for this decision. Although PRMS is a distributed model and therefore has the advantage of being very physically based, one cannot take advantage of this quality if the data set for the watershed of interest is not complete. As stated by Linsley et al. (1982) "unless the input rainfall and the catchment characteristics are known with comparable detail, the solution may be no better [for a distributed model] than that of a lumped model". This is the case for the Rat River. There simply is not a lot of available data. Although data has been collected for a number of years, it has not been consistently collected at each station. For example, only one (of four) of the daily surface water flow gage stations was operational in the watershed during 1997. PRMS is a significantly more complicated model and takes into account many more spatial variables than HEC-HMS. With this particular watershed, however, there is not a great deal of variability in terms of land use; it is quite homogeneous. The assumption is that using HEC-HMS may be as good as using PRMS with incomplete data. HEC-HMS is also run in Windows and therefore more user friendly.

3.5 DATA AVAILABILITY AND DESCRIPTION

Data have been collected from a variety of sources in Manitoba. All data were provided free of charge except for the climate data, which were purchased from Environment Canada. The data required for construction of the DEM are described in detail in section 3.3. The hydrologic data were collected from Manitoba's Department of Natural Resources, Water Resources Branch (Table 2). These data were requested for the following high flood years: 1950, 1974, 1979, 1986 (high flows for the Rat River watershed), 1996, and 1997. The data received include: snow survey data (Sandilands, Vassar, Stuartburn, and St. Pierre), start melt dates in the spring, daily discharge data (St. Malo, Sundown, Otterburne, and St. Pierre at Joubert Creek), and airborne gamma snow cover data (MB105, 106, 107, and 110).

Table 2. Summary of data available from Manitoba's Department of Natural Resources, Water Resources Branch.

Year	# of Stations with Snow Survey Data (snow depth and water content)	# of Flight Paths with Airborne Data (%soil moisture and snow water equivalents)	Start Melt Dates	# of Stations with Daily Surface Water Flows
1950	0	0	Yes	1
1974	4	0	Yes	4
1979	4	0	Yes	4
1986	4	0	Yes	4
1996	0	4	Yes	2
1997	4	4	Yes	1

Data collected from Environment Canada included: daily maximum temperature, daily minimum temperature, daily total rainfall, daily total snowfall, daily total precipitation, and solar radiation data (Table 3). The land use data (Figure 8) allowed for the current wetland area in the watershed to be estimated at 3% of the entire area.

Table 3. Summary of data available from Environment Canada. Pan evaporation data was extremely incomplete and therefor not included.

Year	Max. Daily Temp.	Min. Daily Temp.	Total Rainfall	Total Snowfall	Total Precipitation	Solar Radiation
1950	-	-	-	-	-	-
1974	-	-	-	-	-	Winnipeg Jan.-Dec.
1979	-	-	-	-	-	Winnipeg Jan.-Dec.
1986	Zhoda Jan.-Dec.	Zhoda Jan.-Dec.	Zhoda Jan.-Dec.	Zhoda Jan.-Dec.	Zhoda Jan.-Dec.	Winnipeg Jan.-Dec.
1996	-	-	St. Malo Jan.-Dec.	St. Malo Jan.-Dec.	St. Malo Jan.-Dec.	Winnipeg Jan.-Dec.
	St. Pierre Jan.-Dec.	St. Pierre Jan.-Dec.	St. Pierre Jan.-Dec.	St. Pierre Jan.-Dec.	St. Pierre Jan.-Dec.	
	Zhoda Jan-Dec.	Zhoda Jan.-Dec.	Zhoda Jan-Dec.	Zhoda Jan.-Dec.	Zhoda Jan.-Dec.	
1997	-	-	St. Malo Jan.-Dec.	St. Malo Jan.-Dec.	St. Malo Jan.-Dec.	Winnipeg Jan.1-17 May29-June1 Oct.3-Dec.31
	St. Pierre Jan.-Dec.	St. Pierre Jan.-Dec.	St. Pierre Jan.-Dec.	St. Pierre Jan.-Dec.	St. Pierre Jan.-Dec.	
	Zhoda Jan-Dec.	Zhoda Jan.-Dec.	Zhoda Jan.-Dec.	Zhoda Jan.-Dec.	Zhoda Jan.-Dec.	

This land-use data were provided in a GIS format by the PFRA. The data were divided into seven classes including: annual cropland, trees, water, grassland, wetlands, forage crops, and urban and transportation. The data for annual cropland and forage crop classes are from 1994. All other classes are from 1986.

Figure 8. Land-use data for the Rat River Watershed.

3.6 HYDROLOGICAL ANALYSIS OF THE RAT RIVER WATERSHED

It was initially decided that the hydrologic model would be calibrated for 1996 and that 1997 would be run, using these calibration results. After review of the hydrographs for each year, however, it was decided that HEC-HMS would be calibrated individually for each year. This was done due to the fact that the difference in flows between these two years was substantial. Thus the parameter calibration that was determined for 1996, was not appropriate for 1997. For calibration purposes, wetlands were treated as an integral part of the watershed. Wetlands were treated separately, however, during the 'scenarios', which are discussed in detail below. All environmental conditions were held constant throughout the scenarios to allow for predictions to be made concerning what influence wetlands have in terms of their ability to control flooding. It was also decided that results would be generated for each year for comparison reasons, with 1997 remaining the priority.

In HEC-HMS there is not a component that specifically considers wetlands and their interactions. Wetlands were therefore modeled using the 'diversion' option, offered in the program. A diversion operates by allowing a user-specified portion of the inflow to be diverted. When the model was calibrated for each year, the diversion option was not used as wetlands were considered to be an integral part of the watershed. From the land-use data, wetlands were determined to currently comprise 3% (27.62km^2) of the area of interest and this is the value that was considered to be present during calibration. In the 1'st scenario for each year, the land area considered to be wetland was 2% greater than that with which the model was calibrated; this resulted in a total of 46.06 km^2. In the 2'nd scenario, 5% additional land was dedicated to wetlands (total = 73.66 km^2) while in the 3'rd scenario, 10% additional land was considered to be wetland (total = 119.70 km^2). In a report recently submitted to the IJC concerning historical landscape reconstruction, wetlands are one of the land-use categories considered (Hanuta 1999). Comparing the area of interest within this report, with Hanuta's findings, it was found that wetlands may actually have historically comprised approximately 18% of the study area. This is slightly higher than any of the scenarios considered within this report. This higher value may be due to the fact that Hanuta's classification of wetlands is different from the definition used in this report; she includes marshes, swamps, muskeg, hay and weeds.

For each of the three scenarios in each year, two methods of diverting water were investigated. In the first case, all water from the watershed was considered to travel into the diversion (wetland) before it was considered as runoff. In the second case, water was not diverted until a certain flow was established in the watershed. Its important to note that the second case is quite hypothetical; wetlands do not behave in this fashion, but the idea behind modeling the wetlands like this was to allow for the analysis of the impact of flooding conditions on possible structural modifications within the watershed. This second case implies the construction of structural units which hydrologists would have the ability to control. Both of these cases resulted in the same volume of water being diverted for each scenario. There was a difference, however, in the timing of the diversion, which resulted in different impacts on the flood hydrograph.

3.6.1 Model Development

Data availability strongly restricted the model that could be used to investigate the role of wetlands in flood control. The data also restricted the options that could be used within the selected model. For example, due to data limitations concerning the availability of flow stations, only 920.80 km^2 of the total watershed size of 1550 km^2 was considered. The areas that were not used in the modeling process include: the area downstream of the last gage station (Otterburne) and the area upstream of the first gage station (Sundown). This second area was not considered because the flow was used as a boundary condition at Sundown. If the area had been considered, then precipitation data would have been used, and the flow data would not have been used, as its use would have resulted in accounting for the same factors twice. It was decided that flow data would give a better representation of the conditions present in this area, and that this additional area of the watershed would therefore not be included in the modeling process. The remaining watershed was divided into two basins, Joubert Basin (357.00 km^2) and the Rat Basin (563.80 km^2). There is a dam and reservoir that exists in the community called St. Malo. This was developed by the PFRA in 1958 for use as a water supply reservoir for both domestic use and stockwatering. Since that time the area has also been developed into a Provincial Park and used for recreational purposes. Because this dam and reservoir operate year round at the full supply level, it was not given special attention within the model. The basin schematic developed for this project can be seen in Figure 9.

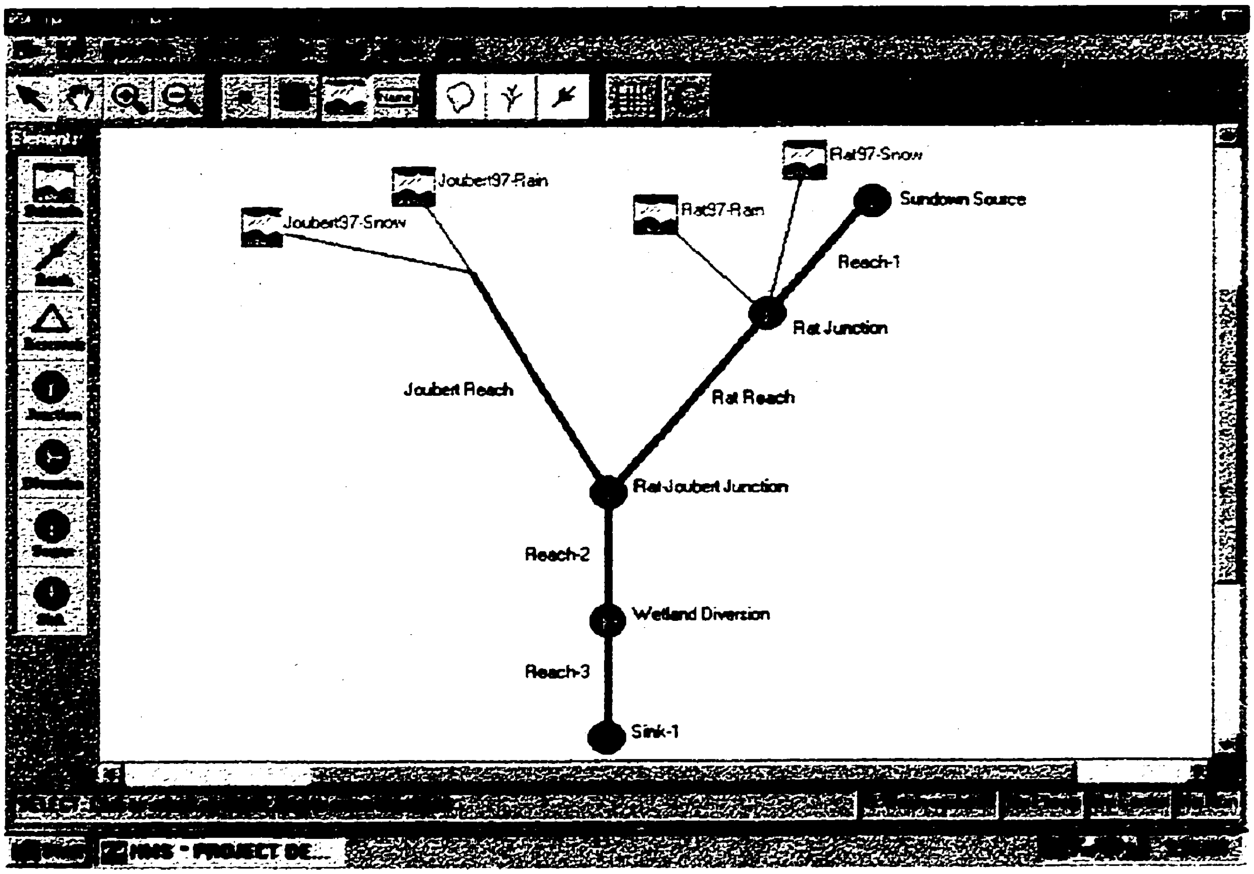

Figure 9. Basin Model for both 1996 and 1997.

HEC-HMS offers a variety of loss methods including: gridded SCS curve numbers, initial/constant, and Green and Ampt. The program also offers several runoff transformation methods: Clark, Snyder, SCS, and Kinematic Wave. Routing options include: Muskingum, Modified Puls, Kinematic Wave and Muskingum-Cunge methods. The loss and runoff transformation methods selected for this project were the SCS Curve number and method. This number was determined from the land-use data and from soil information within the watershed. The routing option selected was Kinematic Wave. The selection of these methods was due to data availability. The options selected resulted in the least number of estimations on the part of the modeler.

The current version of HEC-HMS does not take into account precipitation in the form of snow and it therefore does not consider snowmelt calculations. Because the timing and volume of snow melt plays a significant role in runoff generation each spring in the Red River Valley, a method was developed to estimate both of these parameters. For each year, snow depth and density data were given by Water Resources at the Department of Natural Resources, at a specific date. It was assumed that this value represented the total snow pack that had accumulated since the first snowfall in the fall of the previous year. From that date forward snowfall events were determined from Environment Canada data, and these events were added to this total snow pack. These additional values were assumed to have the same water density as the snow pack that had accumulated prior to this, as snow melt did not begin for several weeks after most of the new snow had fallen. To determine the date and the rate at which the snow melted, temperature data were used in conjunction with a mean temperature index. This index correlates mean daily temperatures with daily snowmelt (Gray 1973). Thus, a start melt date was determined and the snow melt calculation was performed according to temperatures on specific days.

Two flow stations were available for 1996, however, only one was available for 1997. As a result, flows were generated for a second flow station for 1997. This was accomplished by investigating the relationship between the two flow stations, Otterburne and Sundown, for 1996. The daily percent difference in flow was found between these two stations in 1996. This relationship was then established for 1997, resulting in values being established for Sundown. A large assumption was made when assigning these values to 1997; the relationship between Otterburne and Sundown was considered to be consistent from year to year.

3.6.2 Model Calibration

For both 1996 and 1997 the model was calibrated manually using the following parameters: SCS lag, and SCS curve numbers. Calibration results for 1996 can be seen in Figure 10a. For 1996, the computed peak discharge and computed total discharge volumes were found to be 48.5 cms and 98.7 x 10^6 m^3 respectively. The observed peak discharge and observed total discharge volume were 43.8 cms and 104.7 x 10^6 m^3.

For 1997 (Figure 10b), the computed peak discharge and computed total discharge volumes were found to be, 152.1 cms and 165.1 x 10^6 m^3 respectively. The observed peak discharge and observed total discharge volume were 173.0 cms and 175.9 x 10^6 m^3.

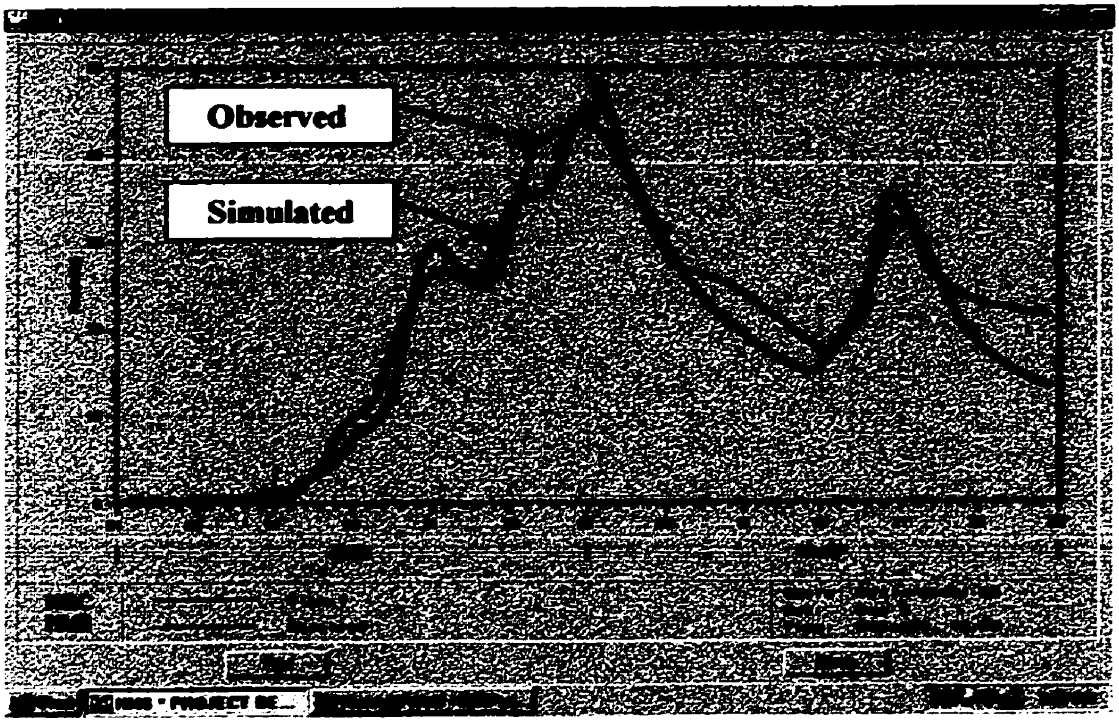

Figure 10a. 1996 Observed versus Simulated Runoff Hydrograph for the Rat River Watershed.

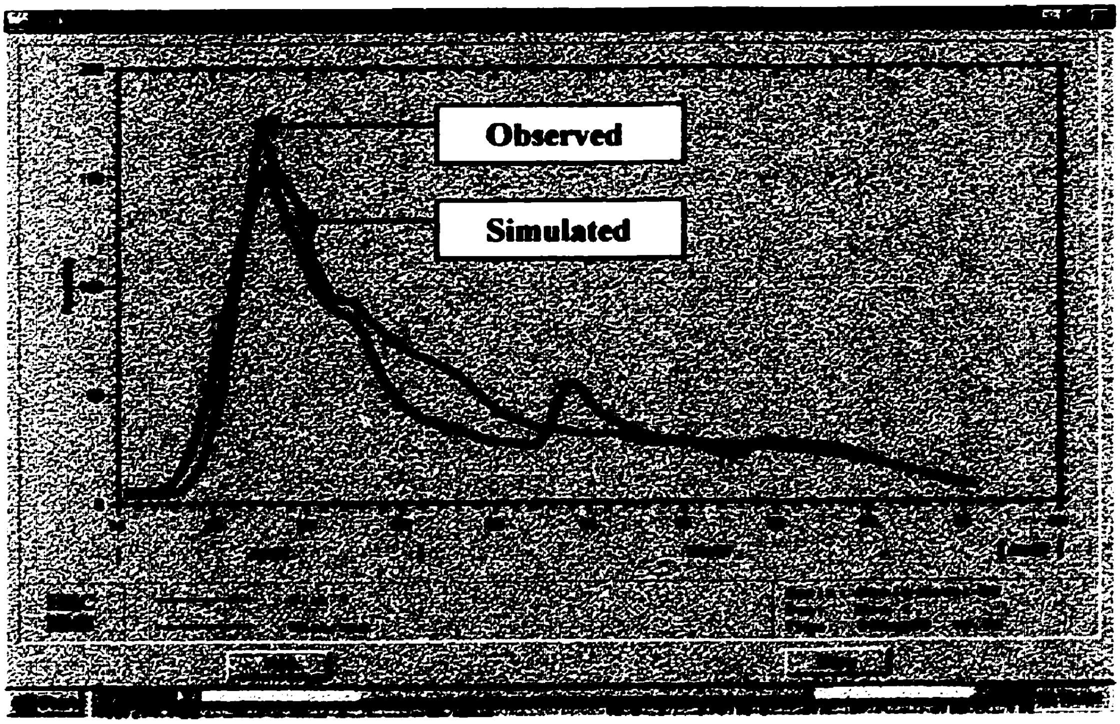

Figure 10b. 1997 Observed versus Simulated Runoff Hydrograph for the Rat River Watershed.

3.6.3 Model Analysis - 1996

To determine the influence of wetlands on flood control the different scenarios, as discussed in the previous section, were simulated. Analyzing 1996 first, some interesting results can be seen. Filling the diversion prior to letting any of the water flow into the sink resulted in a 'chipping' effect on the hydrograph (Figures 11a,b,c). That is, as the area of the wetland increased, the hydrograph's rising limb occurred over a shorter and shorter period of time. The hydrograph peak was not affected throughout these scenarios. In these three scenarios it is assumed that water for the wetland is diverted just upstream from the final flow gage.

Figure 11a represents a 2% increase in wetland cover. This resulted in a total wetland cover within the watershed of 46.04 km^2. With this amount of wetland area, the start date of spring flow was pushed back from approximately April 10 to April 18; it thus took approximately 8 days for the wetlands to fill to capacity. The peak of the hydrograph remained at 48.5 cms and the total wetland storage impact was found to be $3.7 \times 10^6 m^3$. In this scenario, the increase in wetland area by 2% resulted in a 3.7% total flood volume reduction (Table 4). The smaller graph above the main hydrograph represents the hydrograph for the diversion of water; it looks quite similar to the diversion on the main hydrograph since the diversion occurred a very short distance upstream from the final station.

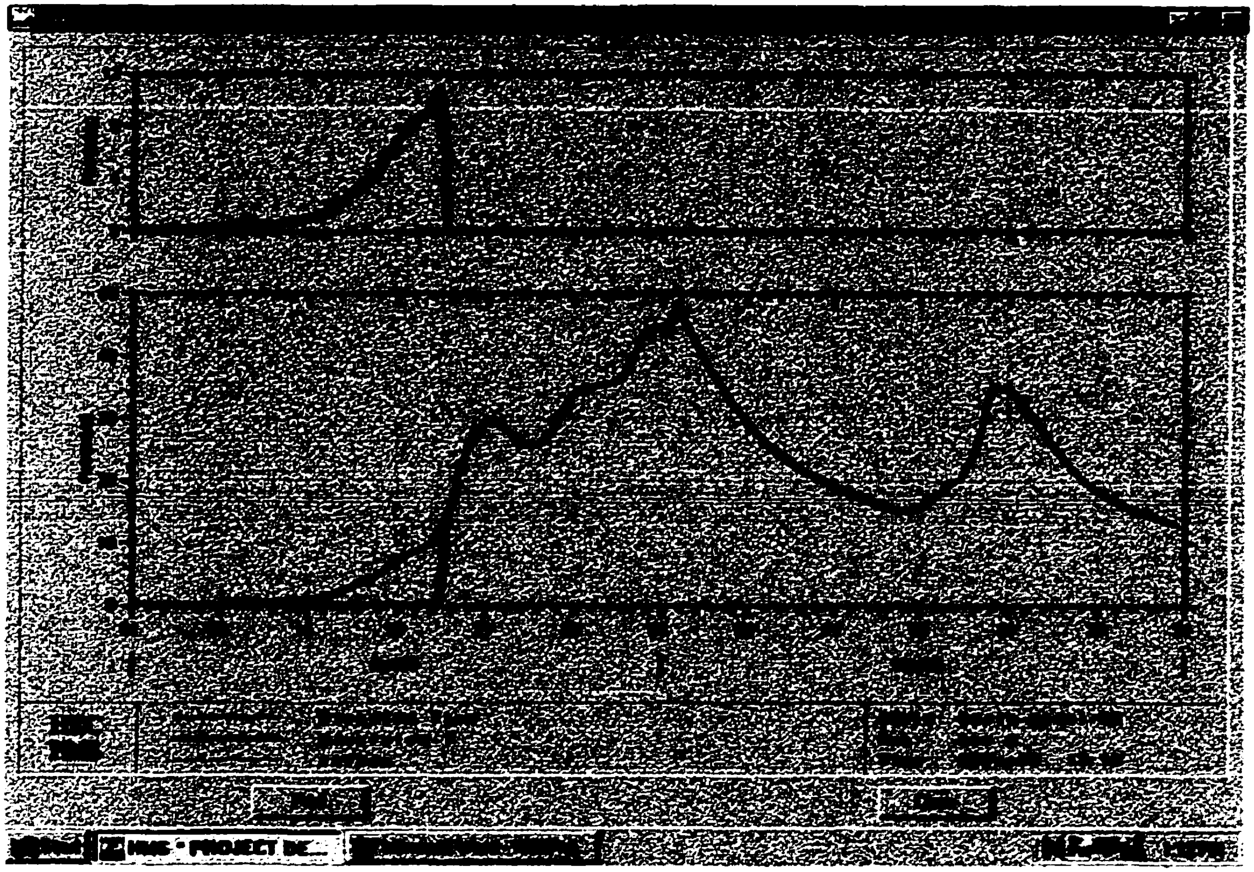

Figure 11a. 1996 Hydrograph for the Rat River Watershed with an additional 2% wetland area, where the diversion is filled prior to any flow entering the sink. The total wetland storage impact is 3.7×10^6 m^3.

Figure 11b represents a 5% increase in wetland cover. With this increase, the area of wetland in the watershed was 73.66 km^2. With this area of wetland, the start date of spring flow was pushed back even farther than the last scenario; it was found to be April 21. This is 3 days later than the previous scenario. Thus the wetlands took 11 days to reach their holding capacity. The hydrograph peak remained at 48.5 cms and the total wetland storage impact was found to be 9.2×10^6 m^3. This increase in wetland area resulted in a 9.3% total flood volume reduction (Table 4).

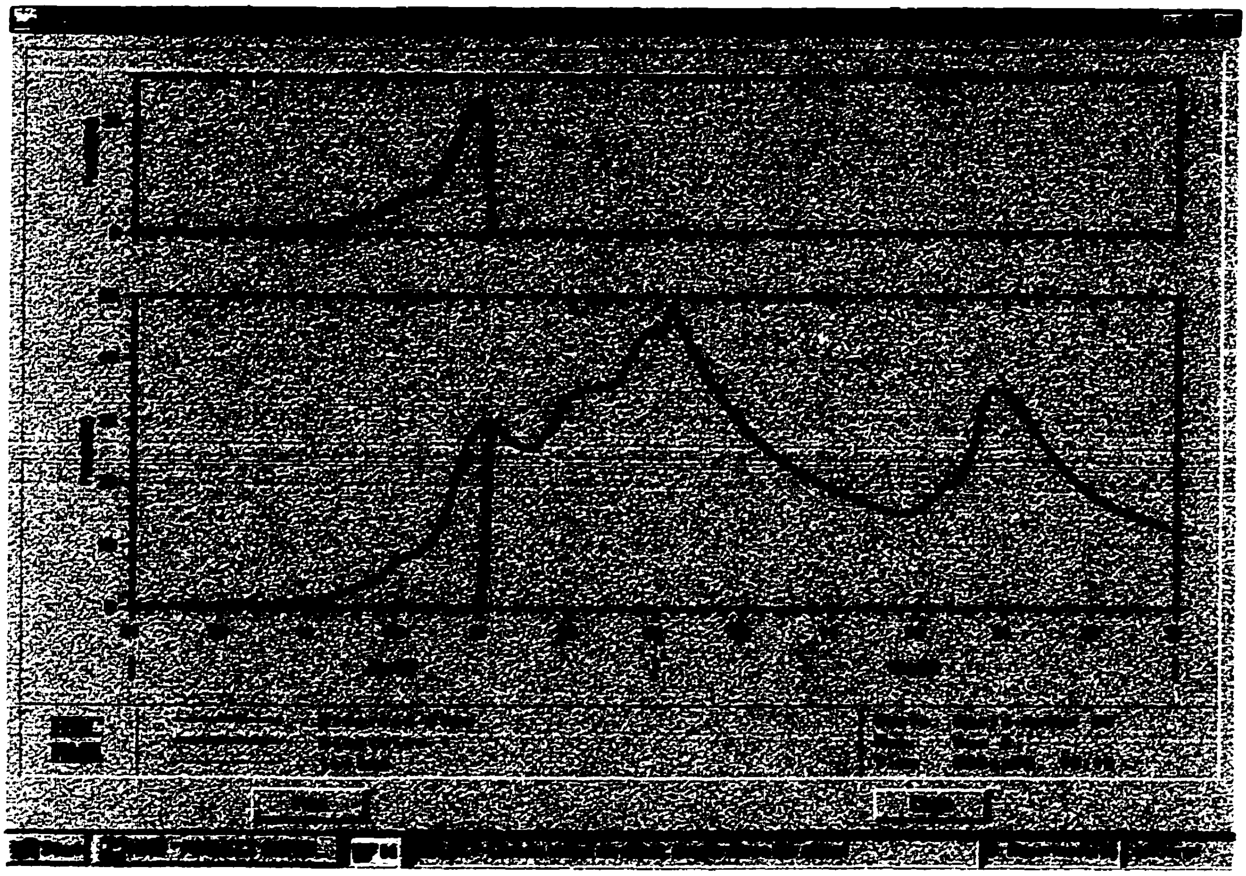

Figure 11b. 1996 Hydrograph for the Rat River Watershed with an additional 5% wetland area, where the diversion is filled prior to any flow entering the sink. The total wetland storage impact is 9.2×10^6 m^3.

In Figure 11c the effects of an additional 10% wetland area can be seen. This increase resulted in a final wetland area of 119.704 km^2 within the watershed. With this area of wetlands, the start of spring flow was found to be on April 25; this is 15 days later than if no additional wetlands had been added. The peak of the hydrograph remained at 48.5 cms and the total wetland storage impact was found to be 18.4×10^6 m^3. This increase in wetland area of 10% resulted in an 18.6% reduction in total flood volume (Table 4).

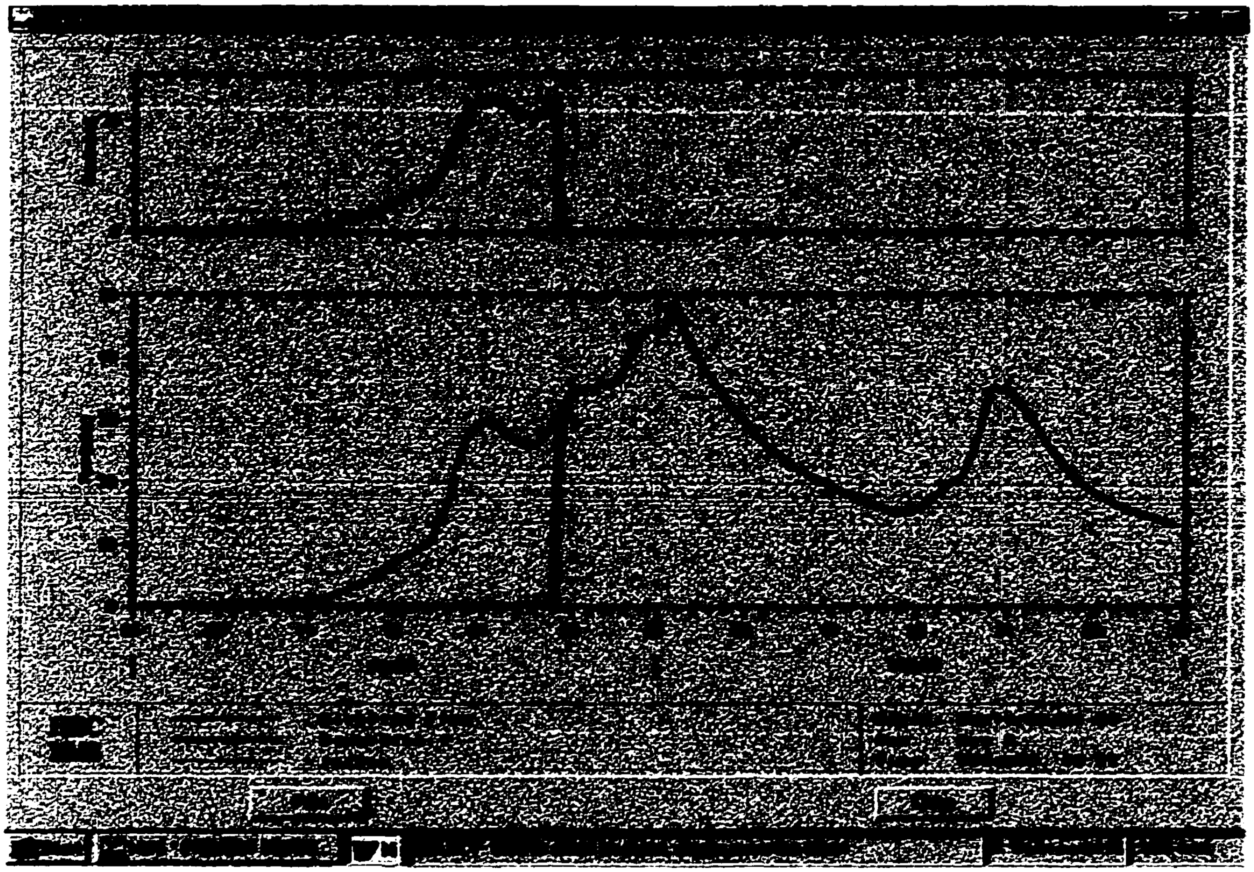

Figure 11c. 1996 Hydrograph for the Rat River Watershed with an additional 10% wetland area, where the diversion is filled prior to any flow entering the sink. The total wetland storage impact is 18.4 x 10^6 m^3.

In the following three scenarios water was diverted such that the peak of the hydrograph was reduced. These are hypothetical situations and it is important to note that wetlands do not behave in this manner. These three scenarios, however, allow for the analysis of possible structural modifications that could occur within the watershed. The results generated from these scenarios will be referred to as '*artificial storage*'.

The introduction of '*artificial storage*' gave slightly different results. Rather than a 'chipping' effect as seen in the previous 3 scenarios, the impact on the hydrograph peak was more significant (Figures 12a,b,c). The higher the 'storage area', the lower the peak flow. The flow at which diversion was begun was determined through a trial and error process that resulted in the start of the diversion occurring at different flow values for each scenario. That is, the flow value was the result of equating the volume under the peak of the graph to the wetland storage volume determined by the scenario. This was done to ensure that the maximum amount of water was diverted for each of these scenarios. Although this is not a realistic representation of a wetland response, these scenarios do show the potential impact that structural modifications could have on the watershed.

Figure 12a represents a 2% increase in storage area, resulting in 46.04 km^2 of storage available in the watershed. This additional storage area resulted in a reduced peak flow of approximately 37 cms, from 48.5 cms. The peak discharge date is also shifted from May 2 to May 4. It is on April 27, with a flow of approximately 35 cms, that the impact of the additional storage area is first seen. As the storage area reached capacity between May 3 and 4, the hydrograph peaked. The total artificial storage impact was 3.7×10^6 m^3. This increased storage resulted in a 3.7% total flood volume reduction.

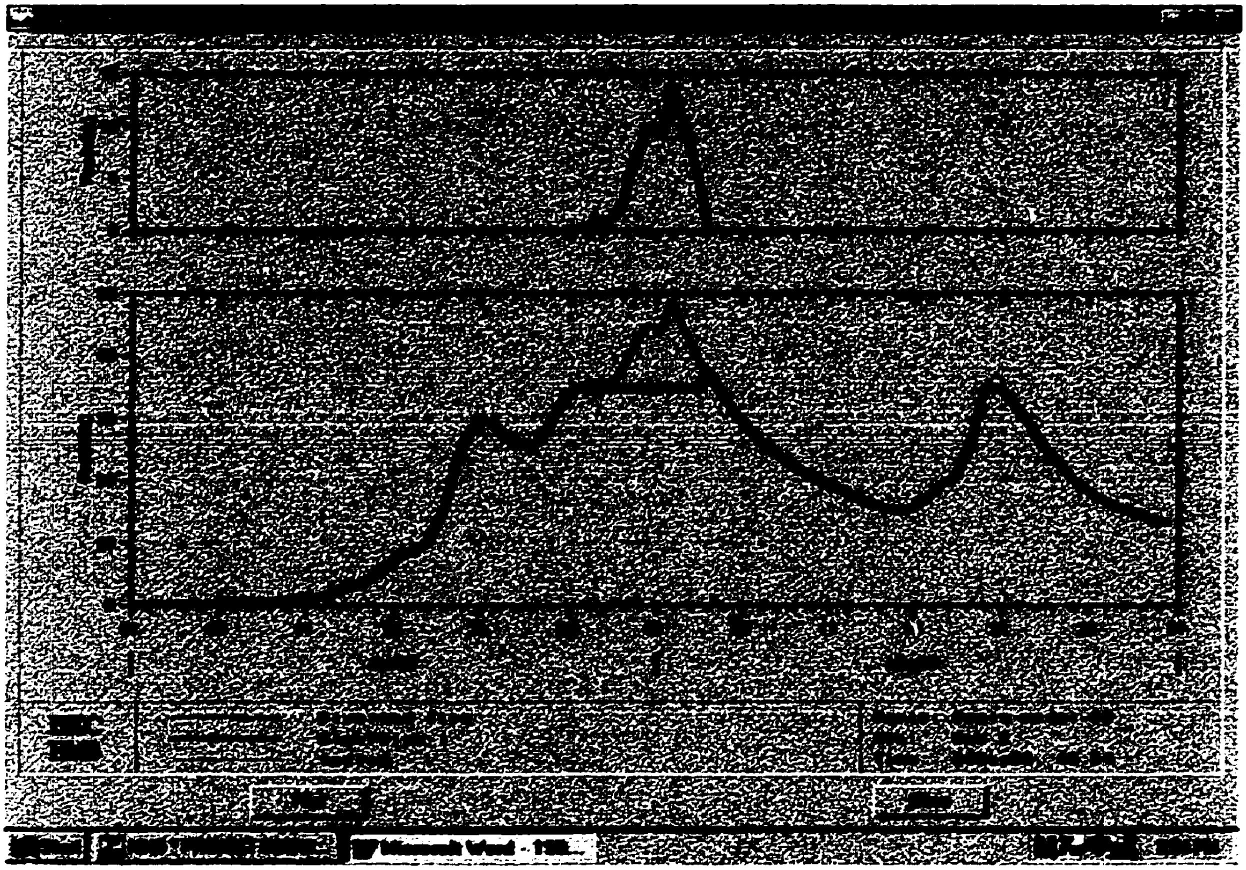

Figure 12a. 1996 Hydrograph for the Rat River Watershed with an additional 2 % 'storage area'. The total *artificial storage* impact is 3.7 x 10^6 m^3.

Figure 12b represents a 5% increase in storage area. This is the equivalent of having 73.66 km^2 of storage space available within the watershed. Like the previous scenario, this greater storage area resulted in a reduced peak flow from 48.5 cms to just over 34 cms. It is on April 20, with a flow of approximately 28 cms that the impact of this storage area is seen. The peak discharge date was shifted substantially from May 2 to May 20. This is due to the fact that by May 20 the storage area had reached filling capacity. The total *artificial storage* impact was 9.2 x 10^6 m^3. This increased storage resulted in a 9.3% total flood volume reduction (Table 4).

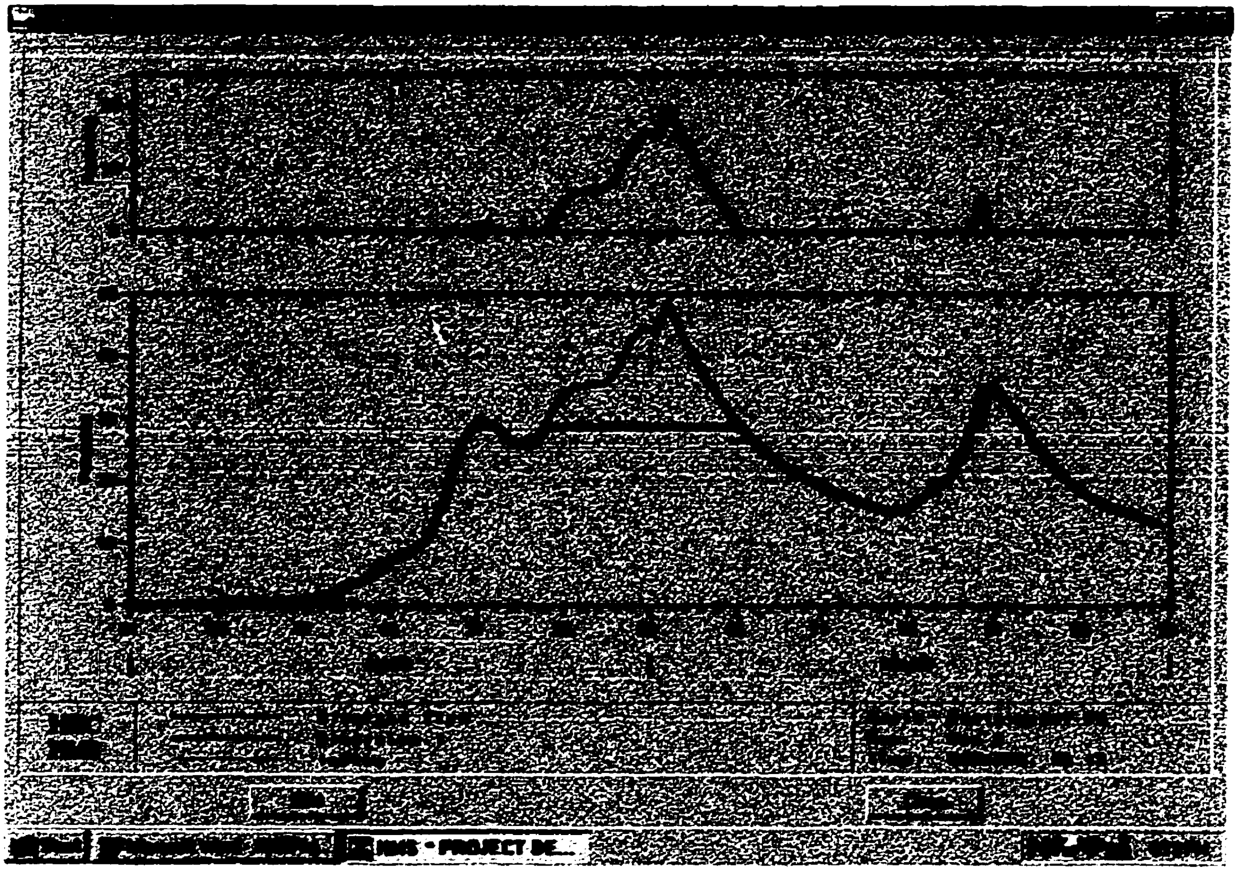

Figure 12b. 1996 Hydrograph for the Rat River Watershed with an additional 5 % 'storage area'. The total *artificial storage* impact is 9.2 x 10^6 m^3.

Figure 12c represents a 10% increase in storage area within the watershed; this results in an area of 119.704 km^2. This additional storage gives a reduced peak flow of approximately 34 cms, from 48.5 cms. It is on April 19, with a flow of approximately 23 cms that the impact of this storage area is first seen. The peak discharge date was shifted from May 2 to May 21; this is one day later than that which occurred for the 5% additional storage area. May 21 immediately follows the date at which the storage area reaches capacity. The total *artificial storage* impact was 18.4 x 10^6 m^3. This increased storage resulted in an 18.6% total flood volume reduction (Table 4).

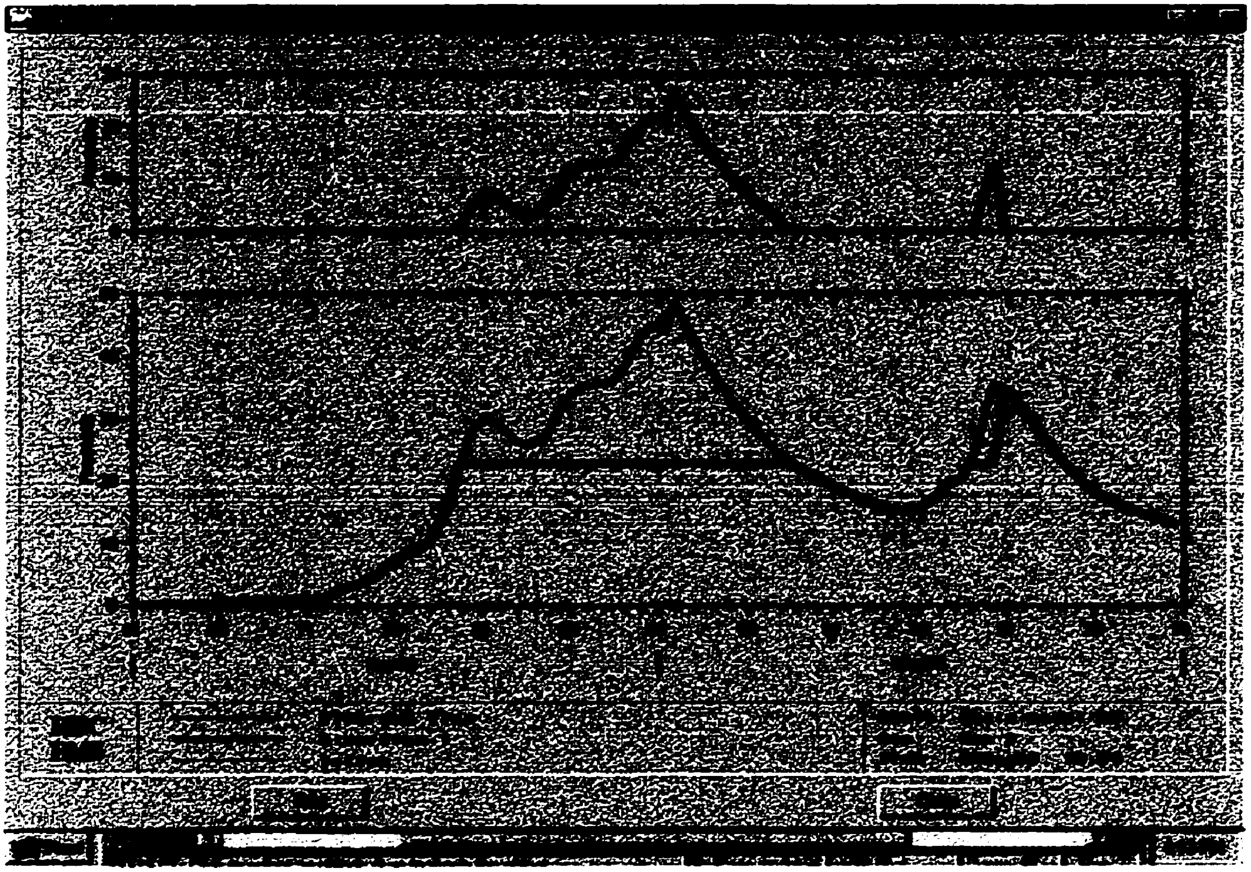

Figure 12c. 1996 Hydrograph for the Rat River Watershed with an additional 10 % 'storage area'. The total *artificial storage* impact is 18.4×10^6 m^3.

3.6.4 Model Analysis – 1997

Although different results from those of 1996 can be seen, the trend remains the same for 1997. Perhaps the largest and most important difference between the results from each year is the fact that 1997 provides even more modest flood volume reduction results than 1996. This is because 1997 was a low frequency flood event and, as such, the volume of flow was substantially greater.

In the first 3 scenarios for 1997, the filling of the diversion prior to allowing any of the water to flow into the sink, again resulted in a 'chipping' effect on the hydrograph (Figures 13a,b,c). That is, as the area of the wetland increased, the hydrograph's rising limb occurred over a shorter and shorter period of time. The hydrograph peak also remained the same throughout these scenarios, as it did for these same scenarios in 1996.

Figure 13a represents a 2% increase in wetland cover. This resulted in a total wetland cover within the watershed of 46.04 km^2. With this amount of wetland area, the start of spring flow was pushed back to April 19, from approximately April 18; thus, it took just over 1 day for the wetlands to fill to capacity. The peak of the hydrograph remained at approximately 152 cms, on April 23, with a total wetland storage impact at 3.7×10^6 m^3. In this scenario, the increase in wetland area of 2% resulted in a 2.2% total flood volume reduction (Table 4).

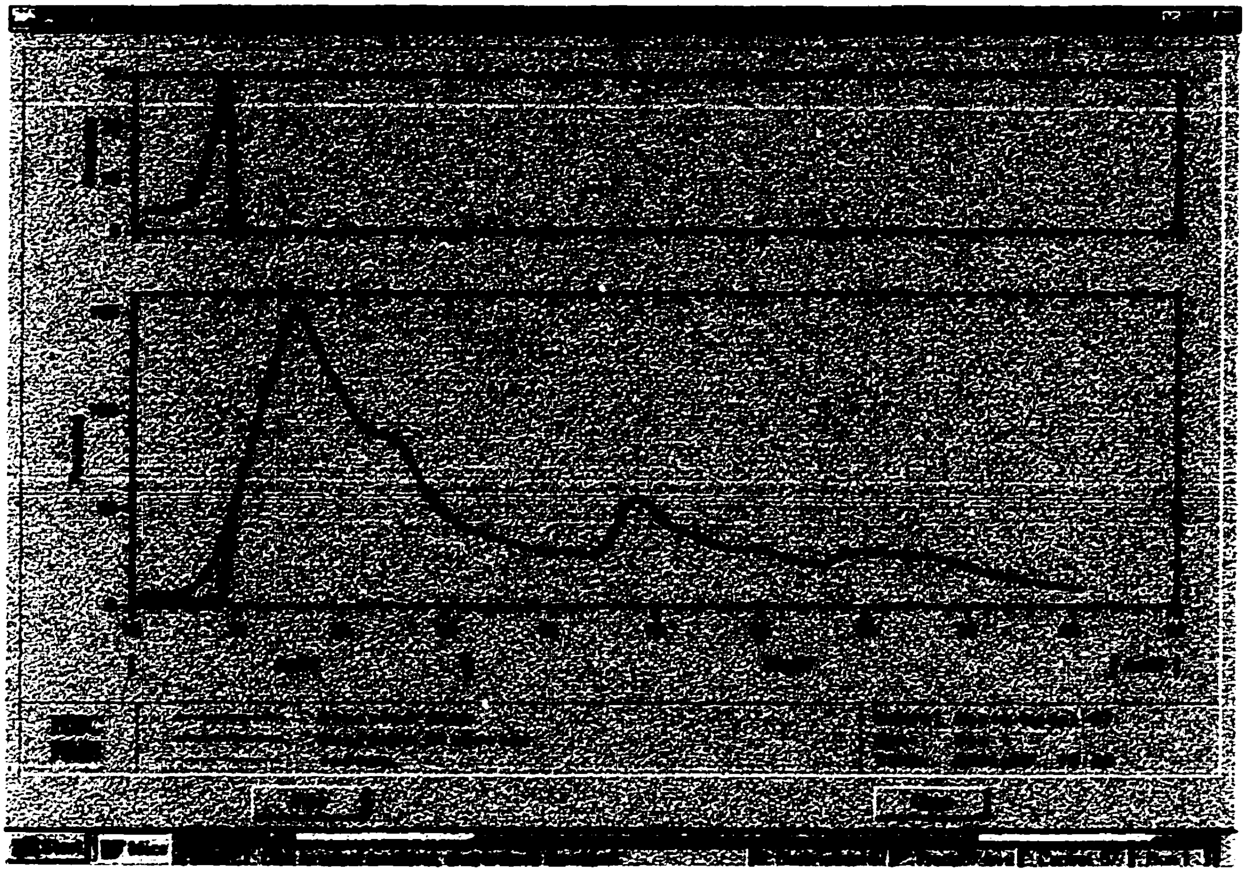

Figure 13a. 1997 Hydrograph for the Rat River Watershed with an additional 2% wetland area, where the diversion is filled prior to any flow entering the sink. The total wetland storage impact is 3.7×10^6 m^3.

Figure 13b represents a 5% increase in wetland area. This resulted in 73.66 km^2 of wetland cover within the watershed. With this area of wetland, the start flow date was pushed back to April 20 from approximately April 18; it thus took approximately 2 days for the wetlands to reach storage capacity. The peak of the hydrograph remained at 152 cms on April 23, and the total wetland storage impact was found to be 9.2×10^6 m^3. In this scenario the increase in wetland area of 5% resulted in a 5.6% total flood volume reduction (Table 4).

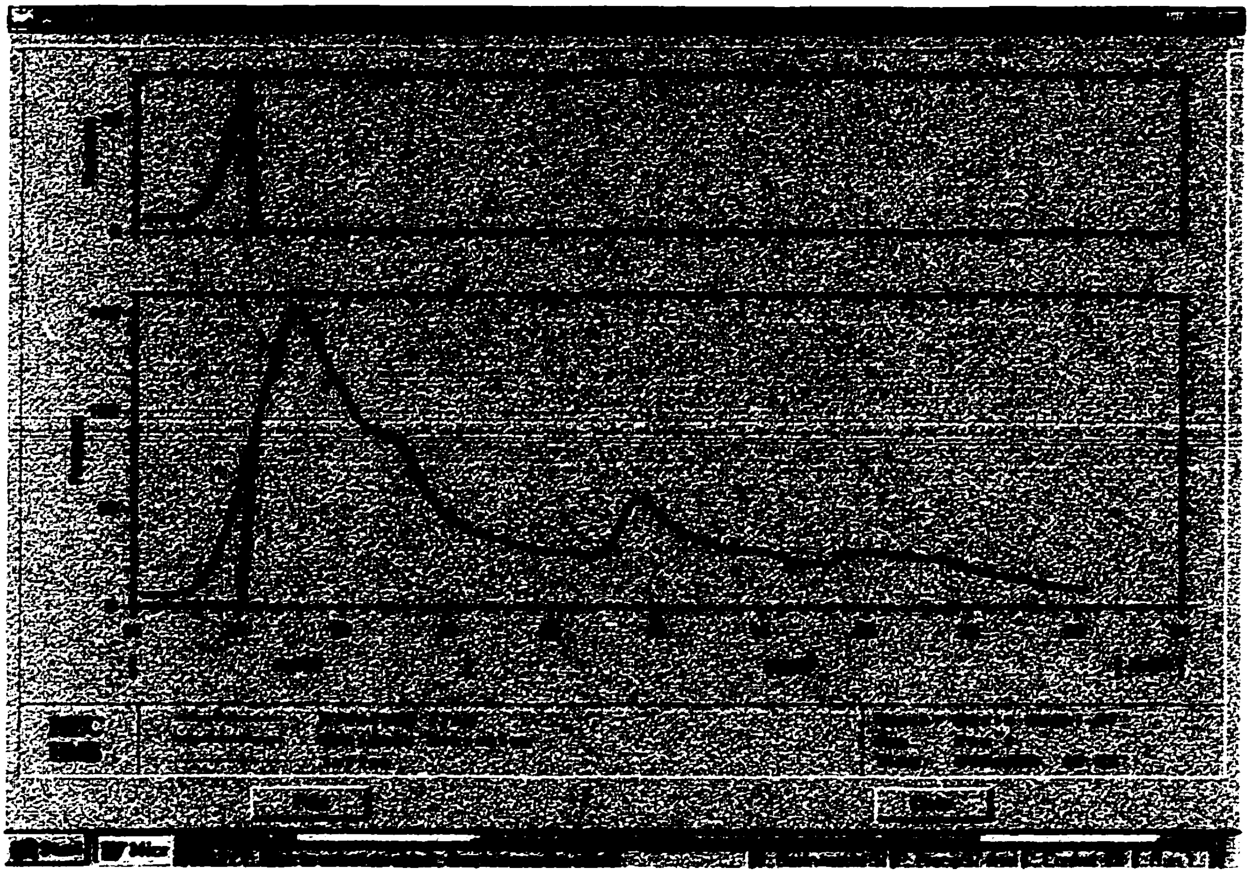

Figure 13b. 1997 Hydrograph for the Rat River Watershed with an additional 5% wetland area, where the diversion is filled prior to any flow entering the sink. The total wetland storage impact is 9.2×10^6 m^3.

Figure 13c represents a 10% increase in wetland area. This resulted in 119.704 km^2 of wetland cover within the watershed. With this area of wetland, the start flow date was pushed back to April 21 from approximately April 18; it thus took approximately 3 days for the wetlands to reach storage capacity. The peak of the hydrograph again remained at 152 cms, on April 23, and the total wetland storage impact was found to be 18.4×10^6 m^3. In this scenario the increase in wetland area of 10% resulted in an 11.1% total flood volume reduction (Table 4).

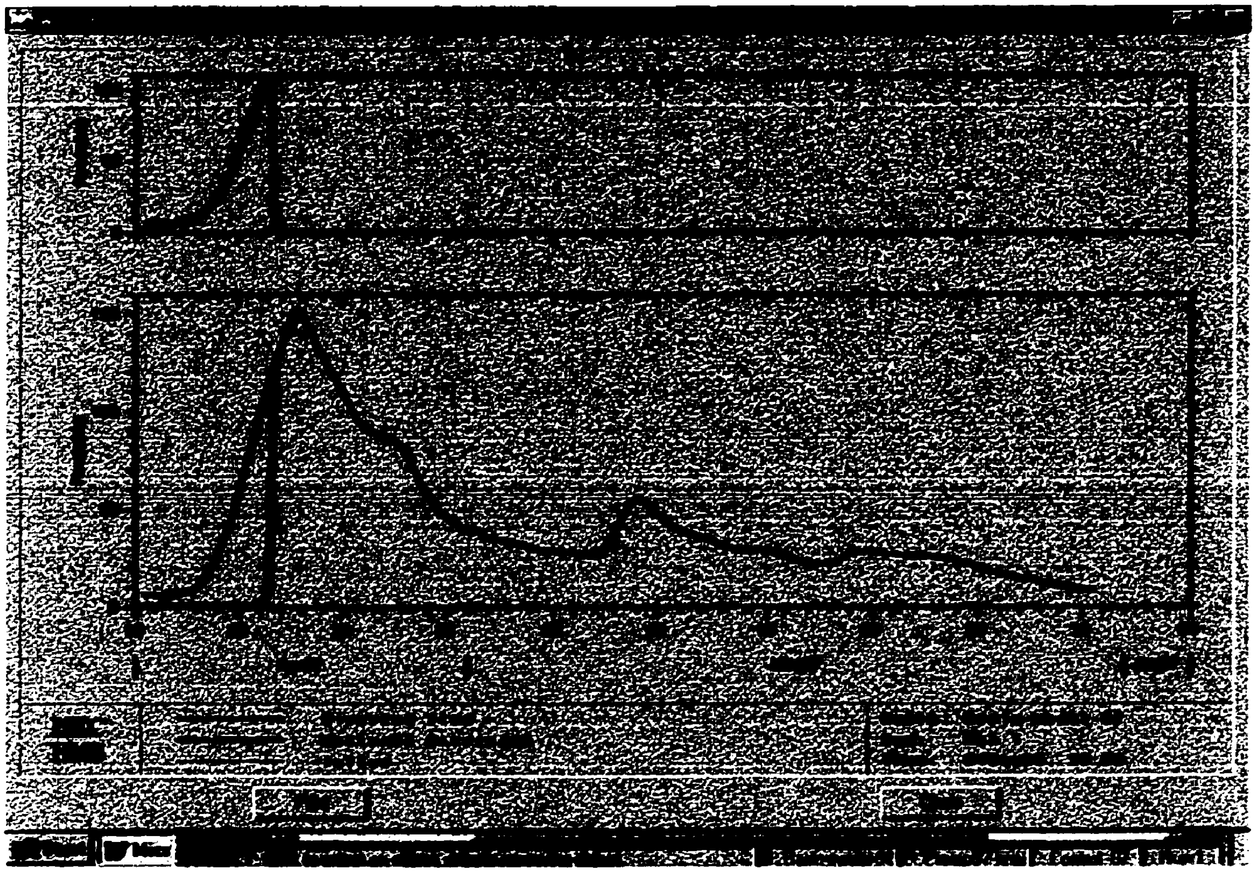

Figure 13c. 1997 Hydrograph for the Rat River Watershed with an additional 10% wetland area, where the diversion is filled prior to any flow entering the sink. The total wetland storage impact is 18.4 x 10^6 m^3.

In the following three scenarios water was diverted such that the peak of the hydrograph was reduced. These are again hypothetical situations and it is important to note that wetlands do not behave in this manner. These three scenarios, however, allow for the analysis of possible structural modifications that could occur in the watershed. The results generated from these scenarios will be referred to as '*artificial storage*'.

The introduction of '*artificial storage*' gave slightly different results. In 1996 a 'chipping' effect was not apparent in these scenarios. In 1997, however, this effect is seen for the first scenario (2% increase) due to the fact that the flow is considerably greater during this year. For the other 2 scenarios in 1997, however, the peak is reduced; it was found that the higher the 'storage area', the lower the peak flow. The flow at which diversion was begun was determined through a trial and error process that resulted in the start of the diversion occurring at different flows for each scenario. That is, the flow value was the result of equating the volume under the peak of the graph to the wetland storage volume determined by the scenario. This was done to ensure that the maximum amount of water was diverted for each of these scenarios. Although this is not a realistic representation of a wetland response, these scenarios do show the potential impact that structural modifications could have on the watershed.

Figure 14a represents a 2% increase in storage area, resulting in 46.04 km^2 of storage available in the watershed. In this case, the additional storage area did not result in a reduced peak flow; the hydrograph peak remained at approximately 152 cms, on April 23. The start of diversion occurred on April 21 at a flow of approximately 103 cms. The total *artificial storage* impact was 3.7×10^6 m^3. This increased storage resulted in a 3.7% total flood volume reduction (Table 4).

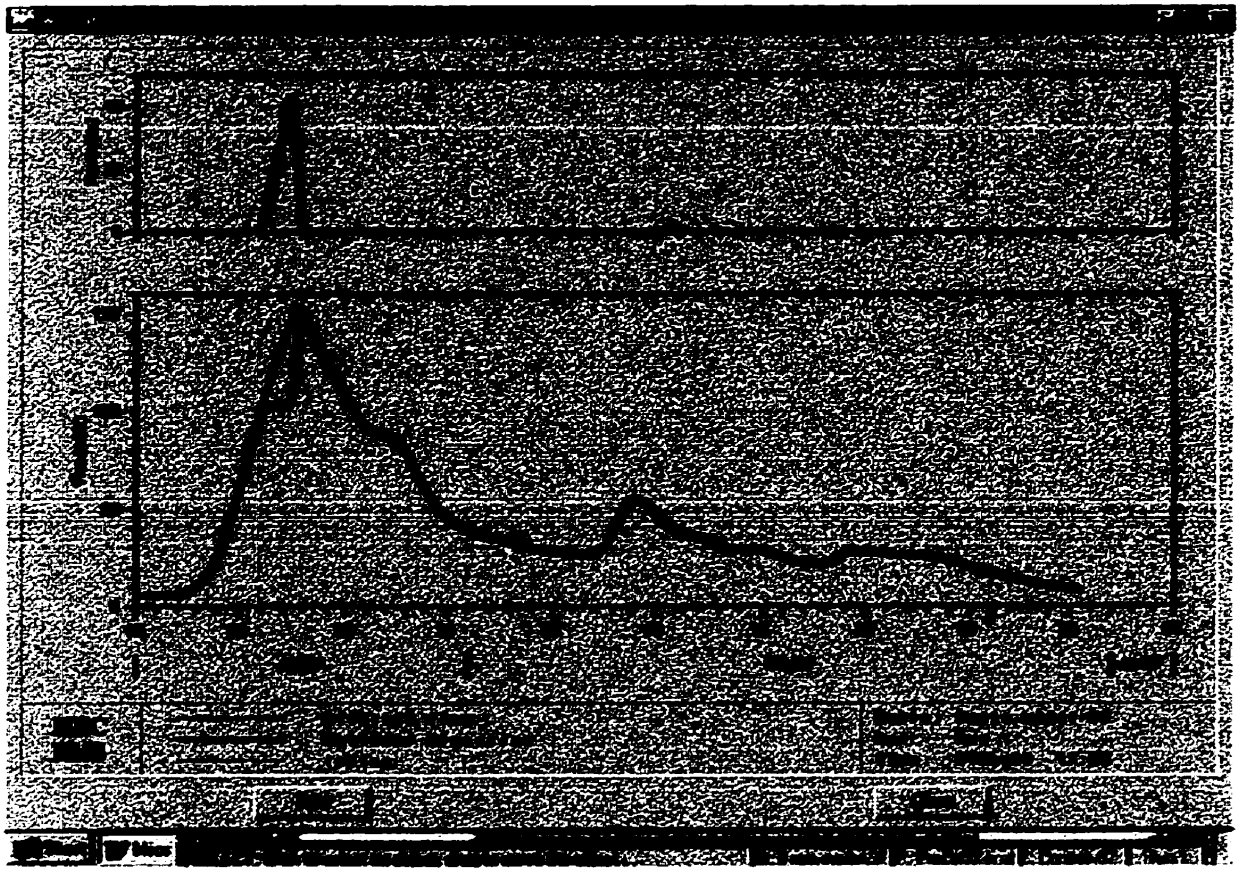

Figure 14a. 1997 Hydrograph for the Rat River Watershed with an additional 2% storage area. Total *artificial storage* impact is 3.7 x 10^6 m^3.

Figure 14b represents a 5% increase in storage area, resulting in 73.66 km^2 of storage available in the watershed. This additional storage gives a reduced peak flow of approximately 115 cms, from 152 cms. The peak discharge date was shifted from April 23 to between April 24 and 25. The start of diversion was on April 21 at approximately 100 cms. The diversion reaches maximum capacity on April 24 and this can be seen in the hydrograph by the increased flow just before the peak. The total *artificial storage* impact was 9.2 x 10^6 m^3. This increased storage resulted in a 5.6% total flood volume reduction (Table 4).

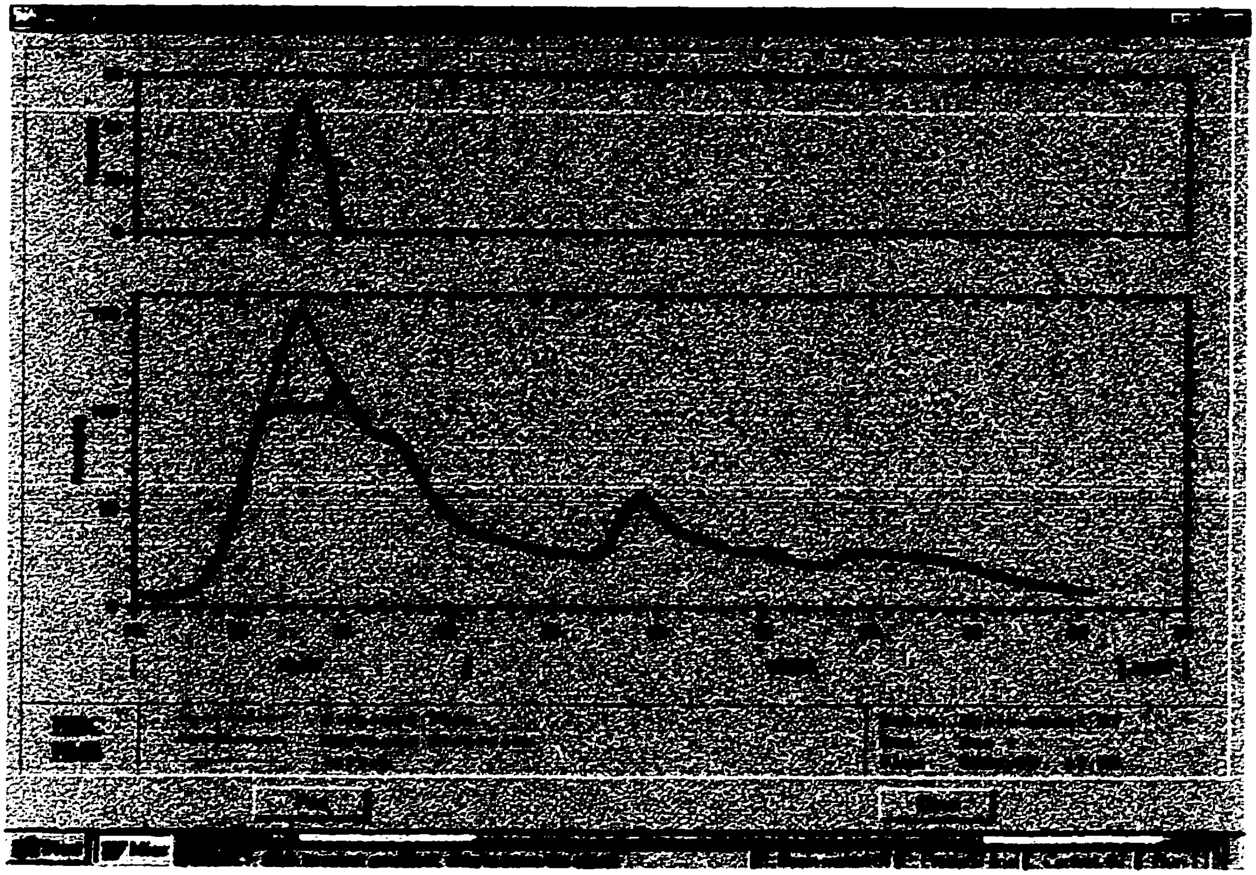

Figure 14b. 1997 Hydrograph for the Rat River Watershed with an additional 5% storage area. Total *artificial storage* impact is 9.2×10^6 m^3.

Figure 14c represents a 10% increase in storage area, resulting in 119.704 km^2 of storage available in the watershed. This additional storage gives a reduced peak flow of approximately 96 cms, from 152 cms. The peak discharge date was shifted from April 23 to between April 25 and 26. The start of diversion occurred on April 20 at a flow of approximately 85 cms. The diversion reaches maximum capacity just after April 25 and this can be seen in the hydrograph by the increased flow just before the peak. The total *artificial storage* impact was 18.4×10^6 m^3. This increased storage resulted in a 11.1% total flood volume reduction (Table 4).

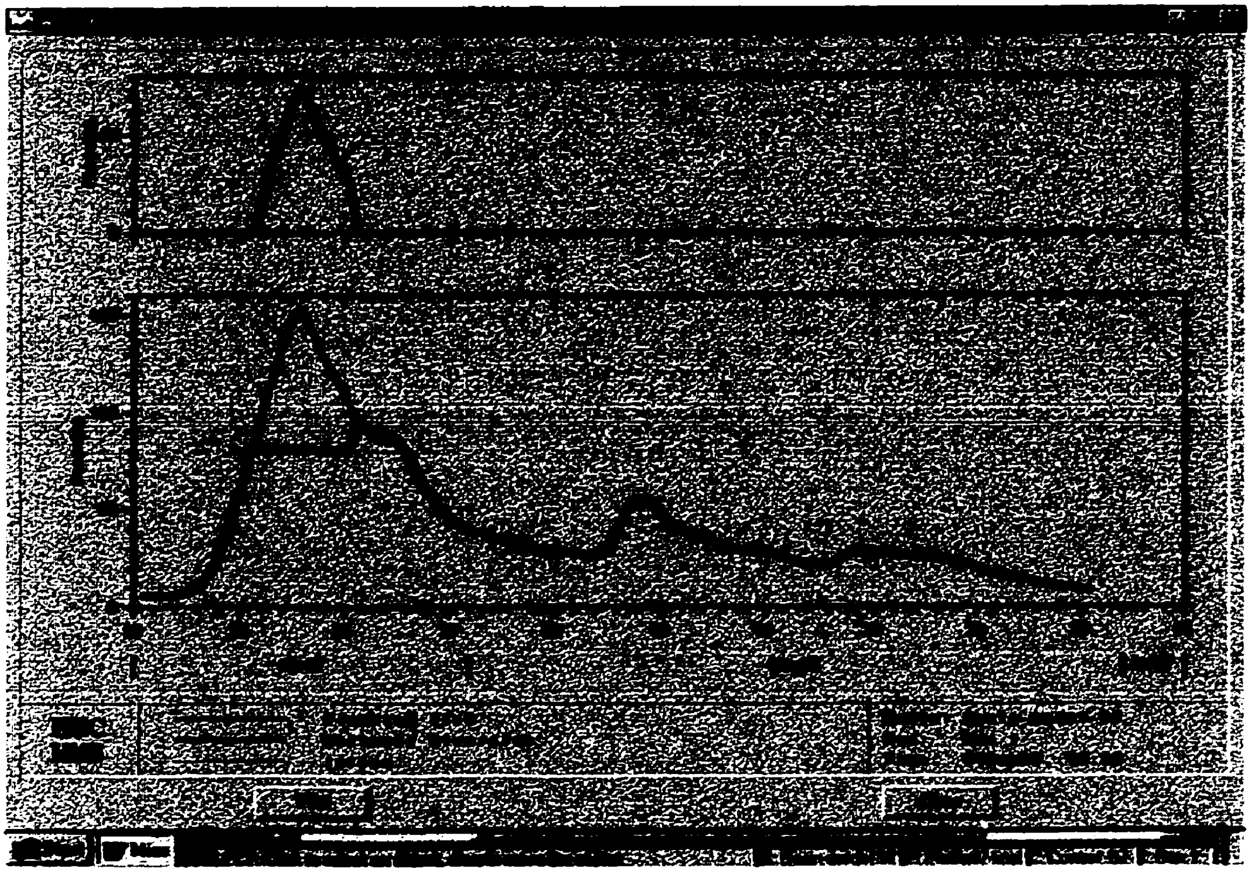

Figure 14c. 1997 Hydrograph for the Rat River Watershed with an additional 10% storage area. Total *artificial storage* impact is 18.4 x 10^6 m^3.

Comparing the results obtained from 1996 with those of 1997 (Table 4), several comments can be made. Given the higher flood frequency event of 1996, it appears that wetland areas have the potential to make to reduce overall flood water volume. Comparing these results with 1997, however, the total volume reduction is considerably less given this lower frequency flood event. The reduction for 1997 is approximately one half of that for 1996.

Table 4. A comparison of the three scenarios for 1996 and 1997.

Scenario	Percent Increase of Wetland Area	Total Wetland Area (km^2)	Total Flood Volume Reduction 1996 (%)	Total Flood Volume Reduction 1997 (%)
1	2	46.04	3.7	2.2
2	5	73.66	9.3	5.6
3	10	119.70	18.6	11.1

Note: Total flood volume reduction for each year is the ratio between the wetland storage for that scenario, and the total discharge volume for that year.

It is important to put the benefits of the flood volume reduction, as seen in Table 4, in perspective. Comparing the percent increase in wetland area with the total flood volume reduction for 1997, the results seem to be proportional. For example, a 2% increase in wetland area is equivalent to approximately a 2% decrease in total flood volume reduction. This relationship can also be seen in the 2 other scenarios for 1997. Because the diversion modeling these wetlands was located very close to where the Rat River meets the Red River, the area considered here, is prime agricultural land. Thus, although these percent increases in wetland areas could result in reduced flooding and increased wildlife habitat, it also would result in decreased agricultural production.

Another important factor to consider is the fact that these results are for the Rat River Watershed. Increasing wetlands by the percentages indicated in this report would likely not have any effect on the total flood volumes of the Red River during a low frequency flood. That is, given the highest percent increase in wetland area, and its corresponding total volume reduction, the decrease in damages experienced would be very modest if extrapolated to the entire Red River Basin. In another context, if wetlands were increased by 10% in all watersheds in the valley, a decrease in total flood volume of 11.1%, during a low frequency flood event, still is not significant. One must be careful when considering this as not all wetlands may yield such a high total flood volume reduction since temperature and climate are not uniform through the valley. Thus, there is a good chance that this 11.1% reduction would not be seen elsewhere.

It is crucial that the factors listed above, and the assumptions listed in the abstract of this thesis, be fully considered when reviewing the results in Table 4.

3.7 WETLAND FEASIBILITY

Based on the results generated for the Rat River Watershed a reduction in total flood volume can be accomplished with an increase in wetland area. To determine if wetland restoration is a cost effective method of reducing flood impacts a benefit-cost analysis should be performed. In this type of analysis, the benefits and costs are individually determined and compared. This allows decision-makers to make choices based on quantitative data.

There are several factors which should be considered when performing this type of analysis. The benefits and costs should be associated with the area of interest; in this case, the Rat River Watershed. Some of the costs associated with wetland restoration might include:

- the cost of taking prime agricultural land out of production
- the cost of actually restoring the wetlands – labour, supplies etc
- the cost of wetland maintenance and monitoring

Some the benefits associated with wetland restoration include:

- the benefit of reduced property damages caused by flooding

- increased wildlife habitat
- increased recreational areas

Because all of the data necessary to perform a comprehensive benefit-cost analysis were not available, only the total cost of restoring wetlands was considered. The values used in this report are based upon those values determined by Leitch et al. (1999) in their report entitled, "Draft Report: Effect of Wetlands on Flooding". A cost of $45 (U. S. dollars) per acre-foot of storage per year was used to determine total wetland costs for each of the three scenarios (Table 5). This value is the average total cost determined for simple restoration (1 foot bounce), per acre-foot of restoring wetlands within the Maple and Wild Rice Watersheds in the United States. This restoration cost is the *total* cost of restoring wetlands for water storage purposes only; that is, this is not the cost for restoring wetlands for ecological purposes.

Table 5. Total cost of wetland restoration per year for each of the three scenarios given a cost of $45 (U.S. $) for each acre-foot of storage per year, for 1997.

Scenario	Percent Increase of Wetland Area	Additional Wetland Area (km^2)	Total Flood Volume Reduction 1997 (%)	Acre-feet of Storage	Total Cost of Wetland Restoration per Year (US $)
1	2	18.42	2.2	2,987.19	134,424
2	5	46.04	5.6	7,467.96	336,058
3	10	92.08	11.1	14,935.93	672,117

In the first scenario, the addition of 18.42 km^2 of wetland area (ie. wetland area in addition to that which currently exists) resulted in a total restoration cost of $134,424 per year. The total flood volume reduction associated with this cost was 2.2%. For the second scenario, the addition of 46.04 km^2 resulted in a total restoration cost of $336,058 per year while an addition of 92.08 km^2 resulted in a cost of $672,117 per year. The total flood volume reductions associated with these scenarios are 5.6% and 11.1% respectively. It seems that these values are quite high given the modest total flood volume reductions determined through the modeling process.

CHAPTER 4: DISCUSSION AND CONCLUSIONS

4.0 THE ROLE OF WETLANDS IN FLOOD CONTROL

Based on the results generated in the Case Study of Chapter Three, a reduction in total flood volume can be accomplished with an increase in wetland area. The results clearly show, however, that given low frequency flooding events (high magnitude) the reduction in water volume really is minimal. This is apparent by simply comparing the results of 1996 with 1997 in table 4. This is due to the fact that the total flood volume was significantly greater for 1997. With a 2% increase of wetland area it was found that a 3.7% reduction in total flood volume occurred for 1996. For 1997, however, this reduction was 2.2%. A 5% increase in wetland area resulted in a 9.3% reduction for 1996, and only a 5.6% reduction for 1997. Similarly, a 10% increase in wetland area gave an 18.6% in 1996, and an 11.1% reduction in 1997. The trend is similar between the two years, however, the flood volume reduction is considerably more modest for 1997. That is, 1997 was 60% greater in flood volume than 1996, in the Rat River.

The reason that the results were so much more modest for 1997 than for 1996 is due to the fact that the sizes of the wetlands in the scenarios were kept consistent when modeling the two years. For example, scenario one for both years involved the use of 2% additional wetland area. This results in a greater impact for floods of a lower magnitude and a smaller impact for larger magnitude floods.

The modeling of wetlands using 'artificial storage' gave very interesting results. Not only did this technique reduce the total flood volume, it also reduced the peak. It is the reduction in the peak of the hydrograph that results in a reduction of damages to property. That is, if water is peaking at a lower level, then properties at slightly higher levels would fair better than if no 'artificial storage' was in place. This has the potential to be a very valuable wetland function. As such, this idea of 'artificial storage' is an option for flood control that deserves greater attention. As explained in Chapter Four, however, this 'artificial storage' is precisely that; it is artificial. It is not the manner in which natural wetlands behave. Despite this, this type of wetland storage could be considered in the form of constructed wetlands.

Constructed wetlands could be an option worth considering for localized community flooding. This would involve the construction of wetlands in very close proximity to the river channel. The idea would be that as soon as the discharge volume in the river exceeded the channel capacity, the water would overflow into the constructed wetlands. These wetlands would have to be in a location such that they would be the first site where the excess water would flow. This would involve the use of a control structure that would have to be monitored, and activated just prior to channel overflow. The restoration of localized wetlands might also be an option that communities along the tributary rivers might consider. It is important to remember, however, that high magnitude floods were occurring in the valley long before agricultural development really began; the flood of 1826 is the highest magnitude flood ever recorded.

4.1 UNDERSTANDING WETLAND FUNCTIONS HOLISTICALLY

A thorough understanding of the diverse functions of wetlands aids in establishing educated decisions regarding wetland preservation or transformation. The Wetland Evaluation Guide (Bond 1992) lists the following requirements of an effective assessment:

- knowledge of how wetland functions affect the regions surrounding them.

- understanding the social/cultural and production functions associated with bio-geo-chemical and hydrologic functions.
- understanding both the monetary and non-monetary value of the functions and the relationships between these functions.
- knowledge of all potential costs resulting from wetland conversion.

Understanding wetland functions holistically can aid in their preservation; that is, knowledge of all functions and their associated values may result in the preservation of a wetland due to the added values that may not have been considered had the wetland been only examined for one function. For example, a specific wetland may not provide any water quality benefits. That same wetland area, however, may provide habitat functions resulting in recreational value to society. If a manager was determining the fate of a wetland based on only its water quality benefits, a wetland such as this may be drained for other purposes. Understanding the recreational value of this wetland may, however, allow for its preservation.

The push by such environmental groups as the Sierra Club for an investigation into the role of wetlands in flood control may have been better founded had they pushed for a complete understanding of all functions of the wetlands characteristic of the Valley. Although investigating this specific hydrologic role was important, it may have been more beneficial had background work been done concerning all the ways in which a community could benefit from the preservation, restoration, or construction of wetlands.

4.2 CONCLUDING REMARKS

Wetlands are complex ecosystems that can be found all over the world. Due to increased pressures to clear land for agricultural purposes their numbers are slowly diminishing. With increased knowledge of the functions that these ecosystems can offer, society has recently begun to question the destruction of wetlands and to some degree has taken interest in their preservation.

Problems can arise, however, when all wetland functions are not clearly understood. Some wetlands are able to perform more functions than others, and some are able to perform them more efficiently. These abilities are site specific and are different for each individual wetland. Often, functions are unknown and a wetland is devalued due to a lack of available information. At other times, wetlands are assumed to perform functions that they can not. When determining whether to drain a wetland for other purposes, it is very important that all of its functions are fully understood. This has not always been the case. In particular, the role of wetlands in modifying low frequency flooding events has had minimal investigation, although many assumptions exist.

The Case Study to examine this function showed some interesting results. Although this study suggests that wetlands are of minimal value during spring floods of very high magnitude, they may be of significant value on a much smaller, local level and for floods of smaller magnitudes. Flooding within the individual watersheds of the Red River Basin is on a much smaller scale than it is for the Basin as a whole; it is the combination of all these watersheds that amounts to the massive total flood volumes in the Basin. Additionally, as discussed in Chapter Two, wetlands are able to perform many other functions that are of value to society. Communities could benefit and make more knowledgeable decisions if adequate information is made available to them.

4.3 RECOMMENDATIONS

The third objective of this research was to provide recommendations for both short-term surface water evaluations, and for wetland assessments. In order to make recommendations for the first topic it is helpful to again review some of the limitations of the Case Study. These limitations included a lack of really high resolution data for the construction of the DEM and a lack of hydrologic data for the watershed. As mentioned in the case study, the DEM is only as accurate as the data used to construct it. Higher resolution data would have resulted in a more accurate product. The lack of hydrologic data strongly limited the model, and the sub-routines within the model, that could be used for this research. The data also strongly limited the results of this study, as they are based upon only one low frequency flood year, 1997. Ideally, several years of data should be utilized when using such models. To create more accurate results concerning the role of wetlands in flood control the author recommends the following:

- the collection of very high resolution topographic data for all watersheds in the Red River Valley.
- a consistent collection of climate and hydrologic data for all watersheds in the Red River Valley, such that a distributed parameter model could be used.

Both of the above recommendations are very costly and would take a number of years to accomplish. This type of data, however, would be of use for other purposes as well as the enhancement of wetland modeling. For example, a detailed topographic database of the entire valley could allow for a comprehensive understanding of the flow pattern of water that exceeds the tributary river banks. This could be very helpful in determining if additional structures are necessary to avoid property damage, and where those structures should be located.

The economic analysis within the Case Study is limited due to data availability. It is important, however, that a complete economic analysis be completed in the future once data becomes available so that the % total flood volume reductions can be associated with the appropriate decreased damages. This will give a better understanding of the monetary benefits of wetland restoration.

To aid in the decision of whether the construction or restoration of wetlands should occur within the watersheds of the Basin, the following recommendation may be worth investigating:

- a thorough feasibility study concerning the benefits and costs of wetland restoration and construction and a comparison of these results with compensation costs given to flood victims.

This recommendation would have to take into account the value of all wetland functions and the opportunity costs associated with them. Research would first have to be done to determine the value of all agricultural land in the valley, and it would have to be compared with the value of that land if used for flood storage purposes. Different watersheds would yield different results since the value of agricultural land can vary significantly depending on location. This recommendation would thus require several feasibility studies in different watersheds.

The last objective of this study also included recommendations for wetland assessment. These include:

- the holistic analysis of a particular wetland's functions prior to any decisions regarding drainage, modification, or destruction. This involves a thorough investigation of all functions for the specific wetland area of interest.
- incentives for smaller communities within individual watersheds to investigate the functions and values of wetlands allowing for educated decisions to be made locally.

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APPENDIX A

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Procedures for Developing a Digital Elevation Model to aid in the Analysis of the Impacts of Wetlands on Flood Control in the Red River Valley of Manitoba

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Abstract

The Red River Valley of Manitoba has a long history of flooding. For years, research and hard work have gone into discovering methods to reduce the economic and social impacts resulting from high water levels each spring. One area where research is needed concerns how changes in the topography of the landscape affects not only the level of water in river channels, but also, the overland flow of water. Current hydrologic and hydraulic models are capable of modeling channel and overland flows, but they require significantly more detailed data to quantify the impacts that wetlands have on flood control. To accomplish this, a good quality Digital Elevation Model (DEM) is required. A DEM is simply a continuous spatial representation of the earth's surface. This paper focuses on some of the challenges encountered while trying to produce this type of model for a watershed in southern Manitoba.

1.0 INTRODUCTION

1.1 Background Information

The Red River Valley is located in what was once a glacial lake bottom. This former lake bottom forms a flat broad flood plain which produces high water levels in both the Red River, and on the surrounding land, each year. This river begins near Wahpeton, North Dakota and flows north 400 kilometres to Winnipeg, Manitoba. The spring of 1997 was no exception to high water levels. This flood resulted in tremendous losses, in terms of private and public property, for many individuals in both Canada and the United States, and for some areas, was considered to be the worst flood ever recorded (International Red River Basin Task Force, 1997). The severity of this flood has re-emphasized the importance of continued research into techniques to reduce the impacts of floods in the future.

One area where scientific research has been lacking concerns the role that wetlands play in reducing flood impacts. There is considerable speculation about whether the conversion of wetlands to agricultural lands has led to increased flows, and thus greater flooding in the valley (International Red River Basin Task Force, 1997). It is believed by the Sierra Club that the restoration of wetlands could lead to reduced peak river flows and healthier river systems (Sierra Club, 1998). There are several potential benefits suggested by this statement; the idea is that healthier river systems are able to accommodate larger volumes of water, than those river systems in poor condition, while at the same time reinstated wetlands are able to absorb larger volumes of water than agricultural lands (Sierra Club, 1998). It is, however, currently unknown if wetlands play a significant role in the reduction of flood impacts. The potential water storage capacity of wetlands is unknown and it is therefor difficult to quantify how the magnitude of flow could be altered, given different numbers and sizes of wetland areas.

The role that wetlands play in reducing flood impacts in the Red River Valley needs to be investigated. Current computer based hydraulic and hydrologic models do exist that can predict channel and overland flows, in addition to flood events. These models, however, do not adequately quantify the impact of wetlands on flood related events. Additionally, the topography of the landscape defines how gravity will influence the flow of water in a watershed and thus plays a significant role in the hydrologic system (Wolock and Price, 1994). In order to determine the impacts of wetlands on flood control a distributed-parameter hydrologic model in combination with detailed spatial data is required. This can be accomplished through the incorporation of a Geographic Information Systems (GIS) module into a hydrologic model.

The hydrologic model selected for this project is the Precipitation Run-off Modelling System (PRMS) designed by the United States Geological Survey (USGS). The combination of the GIS module with the PRMS will allow for the simulation of flooding events using precipitation, temperature and land use data for a particular watershed. It is

very important that sufficient time be allocated toward the task of procuring the spatial data into a suitable format. This is very easy to underestimate. The first step to allow topographical and hydrological parameters to be derived for the modelling of wetlands, was the production of a Digital Elevation Model (DEM). The remainder of this paper will focus specifically on the construction of the DEM for a particular watershed in the Red River Valley.

1.2 The Study Site

The Rat River watershed was selected as the study site for this project. The Rat River is located approximately 30 kilometres south east of Winnipeg and it flows into the Red River near a community called Ste. Agathe. The Rat River represents a typical river system within the Red River Basin. It drains an area of approximately 1550 km^2 and begins near Sandilands, flowing south for a short distance. It then flows west through what was once a large productive wetland. Much of this area is now used for agricultural purposes, however, there still exists the large Rat River Swamp, which is bisected by the river. Much of the peat layer has been removed in this swamp due to local fires, but some is still present to various depths. During frequent high water levels, which occur during the spring, the Rat River often overflows its banks resulting in the flow of water into Joubert Creek. This creek also flows west and lies just to the north of the Rat River. It eventually meets the Rat River at Ste. Pierre-Jolys.

1.3 Available Data

After an extensive investigation into the digital data available for the Rat River Watershed, it was found that one continuous set of data did not exist that would cover the entire area of interest, at a scale that was deemed acceptable. This is because the best data available in the province of Manitoba follows the Red River, which flows from south to north. The Rat River Watershed, however, flows east to west, and begins at an easting of approximately 722,000. Thus, it was decided that two very different data sets would have to be combined and utilized. The Topographic Mapping Division of Manitoba's Department of Natural Resources provided both data sets. From easting 722,000 to 670,000, break-line data in an ASCII file format, at a scale of 1:60,000, was used. From easting 680,000 to 634,000 digital topographic data in a DXF format, at a scale of 1:30,000, was used. There was a 10,000 metre overlap of data between eastings 670,000 and 680,000. Both data sets were in the same datum, NAD83.

Ideally, it would have been best to use one continuous data set, where the format and scale were the same. This would have made the construction of the DEM significantly easier, as there would have only been one data set to deal with. Additionally, the DEM itself would have been developed from a more consistent set of spatially distributed points, and thus resulted in a more consistent DEM.

1.4 System Requirements

ArcView GIS Version 3.1 was the geographic information system that was available for use with this project. A PC version of ARC\INFO was also utilized for part of the process. Up until the point of the final interpolation, a 300 MHz computer, with 64 Mg Ram was used. When the time came to run the interpolation, however, it was found that the above machine was not powerful enough. A UNIX version of ARC\INFO will be used for the final grid interpolation due to the large number of data points within the watershed. There are over 1, 024,000 points in total.

2.0 DEVELOPING THE DIGITAL ELEVATION MODEL

2.1 DEM Overview

A digital elevation model is a continuous spatial representation of the surface of the earth. These models can be produced from a large variety of information sources. Some of these sources include aerial photos, topographic maps and Global Positioning Systems. This data must be in a digital form in order to import it into a Geographic Information System (GIS) and it must be of a form that a GIS package can recognize. Once imported into a GIS, a spatial surface can be created. Because the data received for this project was not in a suitable format to be imported into ArcView, several steps were taken to accomplish this task; they are presented below.

2.2 Processing the 1:60,000 Data Set

The 1:60,000 data set contained the files that covered the eastern portion of the Rat River Watershed. As mentioned above, this data set was in an ASCII file format, with a ".dat" file extension, when it was received from the Department of Natural Resources. An ASCII file is simply a text file. In this particular data set there were 4 columns, none of which had a title associated with it. The first column for each row entry was called either "BREAKLINE" or "DTM". The second column contained the 'easting' for each point, while the third column contained the 'northing' for each point. The fourth, and final column, contained the elevation data. This particular format is not one that is suitable for importation into ArcView.

The very first step with this data set, however, was to eliminate any unnecessary information that would not be needed. The file initially contained 99, 10km X 10km tiles that covered the area of interest, plus much more. Using watershed boundary maps, which do not include any reference or co-ordinate system, in addition to topographic paper maps, UTM co-ordinates were determined for the watershed. At this point it was determined which tiles did not fall within the watershed, and they were discarded. This left 24 necessary tiles to work with.

Data can be added to ArcView in several different ways. The method selected for this project was to import each data table in 2 pieces. The first table for each tile was imported using a script, while the second table was imported as a database. The following paragraphs give a detailed account of the procedures involved.

Each of the 24 tiles were imported into a spreadsheet called Microsoft Excel. Once imported, the first column, called either "BREAKLINE" or "DTM", was deleted from each tile. This column was unnecessary and did not need to be brought into the GIS package. In its place, an identification number (ID), that would remain specific to each row entry, of each tile, was assigned to all entries. It was essential that this number be specific as it was later used as the common identifier between 2 tables, allowing them to be joined. Thus, each entry in each table now had an ID#, easting, northing, and an elevation.

Each table, representing 1 of 24 tiles, was then divided into 2 tables such that each tile now had associated with it: one table, with an ID# and an elevation, and another table that had an ID#, a northing and an easting data value. The table with the ID# and elevation was exported out of EXCEL, as an EXCEL file. It was then imported into a database called ACCESS and saved as a d-baseIV file. It was possible to simply export this table from EXCEL as a d-baseIV file, however, when the data set was examined in ArcView, some features were lost. For example, the decimal places were not preserved with this type of export. For this reason it was decided that Access would be used to perform this task. It is also important to note that Access will not import files with the extension ".dat", and for this reason, EXCEL was initially used. The second set of tables, which included the ID#, northing, and easting, were exported from EXCEL as comma-delimited files; this format was necessary as it allowed a script to be used in ArcView.

The files were then ready to be imported into ArcView. After importation a script called GPS2Shape was used to convert the ASCII comma-delimited files into shapefiles. A shapefile is simply a format that does not contain topology, but does store the attribute information and the geographical location of geographic features (ArcView 3.1). It is important to note that shapefiles are the only files that can be edited in this program (ArcView 3.1). With both tables for each tile imported into ArcView, the final task was to join them back together into one table. This was done using the identification number that was specific to each data entry. This completed the importation process for the 1:60,000 data set.

It may be possible to import the above data set in an easier fashion. There is a function in ArcView that seems to allow the direct importation of databases. This was tested with one tile and it seemed to work. It was not, however, tested with the large volume of data contained in all 24 tiles. Using this option would avoid having to divide each table into 2 tables. In addition, it would avoid use of the script. All tables could be imported into EXCEL and then imported into ACCESS and saved as d-baseIV files.

2.3 Processing the 1:30,000 Data Set

The 1:30,000 data set contained the files that covered the western portion of the Rat River Watershed. As mentioned above, this data set was in an DXF file format exported from a GIS program called CARIS, with a ".dxf" file extension, when it was received from the Department of Natural Resources. This file contained fields typical to a DXF file; Shape, Fnode#, Tnode#, Lpoly#...etc. The data set itself, represented features such as roads, rivers, bridges, lakes, buildings and many more. This data set is quite different from the 1:60,000 data set and it proved to be very challenging to work with.

ArcView is capable of importing DXF files. There was a major problem, however, in that the elevation field was read and displayed as containing values of zero, rather than the true values. When creating a DEM it is essential that the elevation data be supported. After contacting the Environmental Systems Research Institute (ESRI) for technical support, it was found that this problem was in fact a 'bug' within ArcView, that had not yet been corrected (Gregotski, pers. comm.). The next stage was to explore other possible file export extensions of CARIS that were compatible with ArcView.

An ARC\INFO interchange file extension called ".e00" was found that would allow for the exportation of the file from CARIS, into ArcView. The file was exported from CARIS as nine individual files. This was done because it proved to be impossible to export the entire data set as one file, due to its size. The ".e00" files proved to preserve the elevation field. The data files were then imported into ArcView. Problems arose, however, when it was attempted to import some of the larger files. For some reason, this could not be done. It was at this time that PC ARC\INFO became available. Even using this more powerful program, these files still could not be opened.

PC ARC\INFO is able, however, to convert many different file formats into one that it is capable of reading. DXF files are one of the format types that it is able to convert. The original DXF file was then used in PC ARC\INFO to get the data into a format that ArcView could read. While performing this conversion, many unnecessary themes within the file were removed from the data set. These eliminations included such things as buildings, trees, and text data. After the data was converted to PC ARC\INFO, it was 'cleaned' and 'built'. This created topology for the data set and allowed it to be brought into ArcView.

Within ArcView, a query was performed on the attribute table to select only those elevations greater than 0; there were some large negative values that were obviously incorrectly included in the original data set. Once this was done, a script called Theme.PolylineToXYZ (Nobrega, 1999) was used to convert the polylines to points. This was done so that the 1:30,000 data would have the same 'shape' characteristic as the 1:60,000 data set. This completed the importation process for the 1:30,000 data set.

2.4 Combining the Data Sets

The next stage involved bringing the two data sets together into one large file. Because the 1:60,000 data set was in 24 tiles this involved the merging of 25 files into 1 file. After completing this merge, the data was then ready for the final interpolation.

2.5 Selecting the Appropriate Grid Size and Interpolation Method

Research has been conducted concerning the appropriate grid size for digital elevation models. If processing time and space are a concern, as they were in this project, then it is often wise to test a small sample of the entire data set to determine if a smaller grid size best reflects the features of the landscape. It is important to note that if the grid spacing in some areas is fine enough to pick up significant details, then, in other places where variability is at a minimum, the grid will produce many unnecessary points that simply take up data storage space (Jones, 1997). The final digital elevation model ultimately depends on three factors: the accuracy of the original data, the spacing of the original data points, and the grid cell size determined by the interpolator (Zhang and Montgomery, 1994). That is, the DEM produced can not be any more accurate than the original survey data (Garbrecht and Martz, 1996; Montgomery, 1996).

To assist in determining the final grid cell size and method of interpolation for this project, one tile from the 1:60,000 data set was selected and different cell sizes and methods were tested. Decreasing the size of the cell exponentially increased the processing time, and the size of the final interpolated DEM, for that tile. For example, a tile with 8402 points required approximately 2 hours to interpolate and approximately 95.7 Megs of space when a 2-metre cell size was requested. Alternately, when a 5-metre cell size was requested, the processing time dropped substantially to approximately 20 minutes and the space required also dropped to 15.2 Megs. There was very little difference between the final interpolated grids. It was ultimately decided that a 10-metre cell size would be adequate to reflect the variability of the landscape (Fig. 1). It has been suggested that, in general, a grid size smaller than 10 metres really provides very little additional resolution with the final DEM (Zhang and Montgomery, 1994).

There are only two methods of interpolation that are offered in ArcView 3.1. These are Spline and Inverse Distance Weighting (IDW). After running several tests with the above sample tile, it was decided that Spline gave the most realistic results. Spline and IDW both required approximately the same amount of space while IDW generally required slightly less computation time. Overall, the results obtained using Spline were superior.

2.6 The Final Interpolation

The final interpolation on the entire watershed has yet to be run. ArcView does not respond to the request to interpolate the surface given the complete data set; this is probably due to the large number of points. At this point, UNIX ARC\INFO will most likely be used. Using this type of system will not only solve the size problem, but it will also decrease the computation time needed.

3.0 CONCLUSION

It has been a long process to construct a digital elevation model for the Rat River Watershed. The procedures outlined above would be very similar for many of the other watersheds in southern Manitoba. What makes this process so difficult is the fact that high resolution data for the southern portion of Manitoba is simply not available. The data is not even consistent in terms of there being a continuous data set for the watersheds that feed into the Red River. Additionally, the data is not in easily transferable formats. Spatial data is extremely important when determining flow runoffs. Ideally, it would be of great benefit if all of the watersheds in the Red River Valley could be surveyed. It is not just the Red River that leads to flooding in the valley, but all of the watersheds that feed into this river contribute substantially to spring run-off levels. If data were available, a digital elevation model of the entire valley could be constructed and flows determined based on all surrounding topography.

Despite all of the above listed problems, a reasonably accurate DEM can be produced from existing data. Notwithstanding the inherent limitations of this DEM it will provide much needed input for a hydrologic model. It is with the final hydrologic model that the impacts of wetlands on flood control will be determined.

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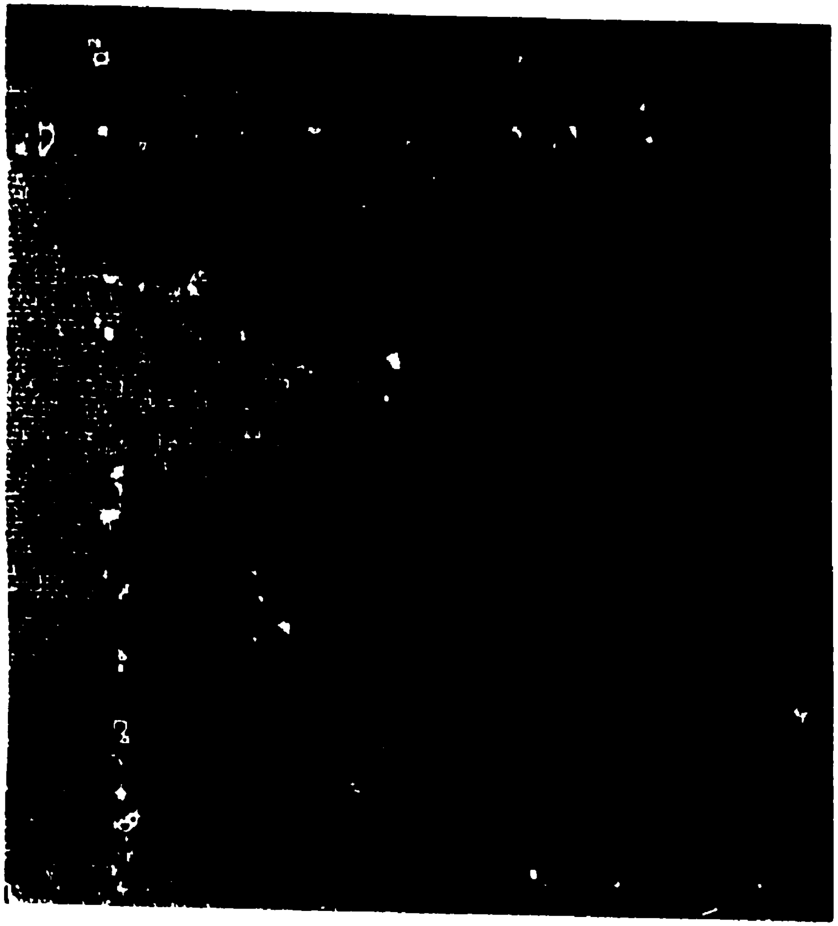

Figure 1. An interpolation with a 10m grid cell size, using a spline interpolation technique for a 10m X 10m tile in the 1:60,000 data set.

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DESIGN AND CONSTRUCTION OF THE LAKEWOOD STORM WATER BASIN IN THE CITY OF SASKATOON

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ABSTRACT

The Lakewood Storm Water Basin was identified as a potential project in 1986. The report identified an existing natural wetland adjacent to McKercher Drive and Heritage Crescent as a potential storm water storage basin. By storing the peak flows from the Wildwood Trunk Sewer in the basin, it would be possible to develop additional residential lands in the South East Sector of Saskatoon.

Several design options were investigated, ranging from a dry storm water detention basin to a constructed wetland. Ultimately, the wetland option was selected. The wetland option was selected because it enhanced the environment, park aesthetics and water quality, while still performing the prime function of providing storm water storage. Construction of the wetland began in 1996 and was completed in 1998. The wetland will go into full operation in 1999.

1.0 BACKGROUND

The South East Sector (S.E. Sector) is that portion of the City of Saskatoon located south of College Drive and east of Circle Drive (Figure 1). Storm water runoff is drained from the S.E. Sector via the Gray Avenue Trunk Sewer and its tributaries, the Wildwood Trunk Sewer and the Boychuk Drive Trunk Sewer. Two storm water basins were located in the south east sector prior to the construction of the Lakewood Storm Water Wetland, namely the Lakeview, Briarwood ponds (Figure 2).