# PRAIRIE PERSPECTIVES:
## GEOGRAPHICAL ESSAYS

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# Introduction

It is not surprising that this volume of papers, drawn from the 1997 annual conference of the Canadian Geographers' Prairie Division held at Portage La Prairie, is largely concerned with water. Earlier in the year, Manitoba had experienced its worst spring flooding of the century. In fact, as Rannie points out in the lead article, it was the worst flood in the Red River Valley since 1826.

The grandaddy of them all, the flooding of the Pleistocene Epoch, dramatically altered the physical geography of the Prairies and was largely responsible for current topography. In her paper, Grant analyzes the effects of subglacial meltwaters in Central Saskatchewan, arguing that the North Battleford fluting field and the broad plain adjacent to it were produced by flooding at regional scale.

Rannie's article provides a useful historical perspective of flood hazard in the Red River Valley as well as thoroughly chronicling the preconditions leading up to the flood and the procedures used in coping with the 1997 disaster. He also addresses some of the questions raised by the flood experience. Haque and Rahman offer a parallel paper that also relates to the 1997 flood. Their principal concern is to highlight the issues raised by the event and to propose ways of mitigating the effects of the flood threat and its aftermath on the affected population.

McDonald and McGinn are also concerned with spring meltwaters. Their paper deals with the influence and extent to which detention ponding delays runoff in small streams feeding into Clear Lake at Riding Mountain. Their work points to the advantages of creating retention ponds in the headwaters of larger drainage systems

The next two papers, by Kumar, Haque and Pawlak, and Kumar and Haque, respectively, address the obverse side of the coin. Their concern is to find ways of defining, forecasting and anticipating the effects of drought in the Canadian Prairies. Their research involves the development of models combining satellite data with agricultural and climatic records. The strategic advantages of such models in forecasting yields, and for the management and planning for marketing the crop, promises to be invaluable to the grain trade.

Just as the relative importance of cereal grain cultivation in Western Canada has declined, the economic importance of tourism and recreation has increased. Although tourism has not generally been regarded as especially important in Manitoba or Saskatchewan, it is of growing significance in both provincial economies. Much tourism and recreational development in both provinces depends in one way or another on water-based activities. The papers by Welsted and Everitt and Terry and McGinn both deal with the use of water as a recreational resource. Welsted and Everitt examine the requirements of water-based sports events at the 1997 Canada Games held in Brandon, Manitoba. They detail the course specifications and decision-making involved in locating the various outdoor, open water events included in the Games. One of these sites, the waterski facility on the Assiniboine River in Brandon, required significant modifications to the existing watercourse. Terry and McGinn recount the measures taken to minimize the impact of the changes and to monitor the downstream effects of the works.

The paper by Simpson and Hathout also addresses the potential impact of public works on the environment. They illustrate how GIS modelling can be used to determine the optimum routeway for an all weather road on the east side of Lake Winnipeg. The road, when built, will undoubtedly be used to open up new areas in the region to recreation and resource extraction. Wiseman and Berta likewise employ GIS modelling techniques in their investigation of indicator species analyis as a means of carrying out ecogeographic analyses of ecosystems. Their work has relevance for the management of such systems for a variety of purposes that would include recreation and conservation.

In contrast to the foregoing presentations which have a more physical orientation, the following two studies have a distinctly urban focus. Both the paper by Thraves and Barriault and that by Selwood and Kohm address the changing structure of tertiary activities in the inner city. Thraves and Barriault, employing Murphy and Vance's delimitation method, demonstrate that Regina's CBD has expanded over recent decades. However, they also show its functions have undergone extensive restructuring over the same period. In a similar vein, Selwood and Kohm examine elements of the sex trade, traditionally a centrally located function, that is now widely dispersed through the suburbs in response to changes in the industry and in consumer demand.

An integral component of the annual conference has always been a field trip to explore the local geography of the meeting venue. Rather than compiling an itinerary of the trip, Carlyle has elected to highlight its central theme, that is, the complex and varied nature of the so-called family farm in Manitoba's Portage la Prairie district. His paper discusses two widely different examples: a family-owned, large-scale corporation specializing in fresh vegetable production, and a Hutterite colony's multi-family, mixed-farming operation.

The editors would like to express their deep appreciation to Weldon Hiebert for his invaluable contribution to the production of this volume of *Prairie Perspectives*. Weldon designed its cover and either edited or drafted all of the figures and maps in the volume. He was also responsible for the page layout. In effect, Weldon oversaw the entire production process and the professional quality of the final product is due to his cartographic and design abilities.

It is hoped that this volume will serve as the model for a continuing series of volumes devoted to the diverse works of prairie geographers and those with an interest in the geography of the Canadian Prairies.

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Winnipeg 1998

# The 1997 Red River flood in Manitoba, Canada

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***Abstract:*** Record flooding of the Red River valley in the spring of 1997 caused extensive damage. In Manitoba, Canada, the emergency measures operation was one of the largest in Canadian peacetime history. Although the cost of the flood in Manitoba was very large ($500 million), flood control and damage reduction programmes successfully averted losses which would otherwise have been catastrophic. The causes and evolution of the flood, the emergency measures, the operation of the flood control system, and some issues raised by the event are described from a Manitoba perspective.

## Introduction

In the spring of 1997, the Red River valley of Manitoba, North Dakota, and Minnesota experienced record flooding. Beginning with the dyke failure and inundation of Grand Forks, ND, on April 19, coupled with the fires that simultaneously devastated a large area of the downtown, national and even international attention was focussed on the region as the flood crest moved down valley into southern Manitoba. Dubbed the "Flood of the Century" by the media, it was in fact the largest discharge in almost 2 centuries (since 1826). This paper will review the flood from a Manitoba perspective, with particular attention to the emergency measures and the functioning of Manitoba's flood control and damage reduction system. Some broad issues raised by the event will be noted.

## General Background to Flooding, Flood Control and Damage Reduction Measures in the Red River Valley

Beginning with the earliest historical accounts in the 1790's, the Red River valley has had a long record of flooding. At least 10 major floods occurred in the 19th Century, with those of 1826, 1852, and 1861 (in descending order) being the largest and, until 1997, larger than any since. Throughout most of the 19th Century, however, the population of the valley was small. Agricultural settlement and the development of urban centres (particularly Winnipeg) from the 1880's onward coincided with a long period of comparitively few floods and none of significant areal extent. Consequently, the majority of the population had little experience with floods and were unprepared for the disastrous 1950 event (the largest in the Manitoba reach of the river since 1861) which inundated 1650 $km^2$ and forced the evacuation of around100,000 people within the valley. Approximately $30 million (in 1950 dollars) were paid in damages and the true cost may have exceeded $100 million (United States Geological Survey 1950).

Following the 1950 flood, numerous federal and provincial agencies examined alternative ways to avert similar disasters in the future. The most immediate response was the construction of primary dykes (with sewer pumping stations) within the city which could contain flows up to a stage of 26.5 ft[1,2]; with emergency dyking on top of the primary system, this protection could be extended to the 1950 stage (30.4 ft above local datum). By 1997, this dyking system had reached a length of 110 km, much of which was incorporated into the street and boulevard system. In 1956, a Provincial Royal Commission was appointed to determine the relative economic benefits of the alternative schemes proposed by the studies and to recommend a course of action.

The Commission's report, issued in 1958, recommended a combination of structural measures to protect Winnipeg (Figure 1). The most important, and largest, of these was the Red River Floodway[3], a 47-km excavated earth channel designed to divert flow in excess of about 78,000 cfs around the eastern perimeter of Winnipeg. Flow into the channel is regulated by gates on the Red River at the southern city limit which elevate water levels upstream

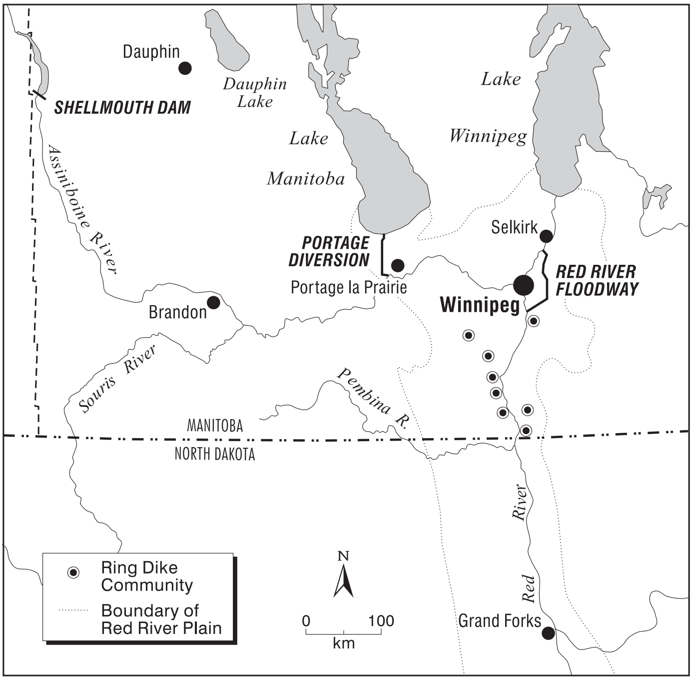


***Figure 1:*** *General location map.*

and cause excess flow to be diverted around the city, rejoining the Red 16 km north of Winnipeg where channel capacity is sufficient to convey the entire flow. Forty-three kilometers of dykes extend east and west of the river to prevent water from bypassing the control structure and entering the city. The *normal* operating rules for the Floodway limit the upstream elevation to that which would occur naturally (i.e. with no flood control measures) to avoid increasing the risk for upstream properties. This procedure would restrict stages within the city to a maximum of 25.5 ft or 1 ft below the level of the primary dykes. Under more severe conditions, however, when stage in Winnipeg could not be maintained at this level, these rules could be superceded to divert more water through the Floodway (as much as 100,000 cfs under the most extreme conditions). This would, however, require elevating the upstream water level beyond the "natural" uncontrolled level.

The second largest structure is the Assiniboine Diversion, an excavated 29 km-long earth channel 3 km west of Portage la Prairie (Figure 1) which is capable of diverting up to 25,000 cfs northward into Lake Manitoba, thereby preventing the water from entering the Red River in Winnipeg. Finally, the Shellmouth Dam on the upper Assiniboine provides additional control of Assiniboine water heading for the Red River.

With emergency dyking of low areas between the city's primary dykes and the river, the system was designed to protect Winnipeg from floods up to 169,000 cfs with a Return Period estimated by the Royal Commission at 165 years under normal operating conditions. The routing of water through this system during such a design flood is shown on Figure 2.

After major flooding in 1966, attention turned to the Red River valley south of Winnipeg. The eight largest communities (Figure 1) were surrounded by ring dykes which provided protection against flows up to the 1950 level. Under a federal/provincial Flood Damage Reduction Agreement (signed in 1976 and extended in 1981) the community ring dykes were raised to the 100-year level (and in some cases extended to enclose a larger area), flood forecasting capability was improved, and detailed maps of the flood hazard zones were prepared. A particularly important new element in these agreements provided for non-structural, institutional measures intended to discourage or regulate development in the flood hazard zone. Through these measures, senior governments agreed to withdraw mortgage guarantees and development incentives for new construction in the flood hazard zone which was not flood-proofed to the 100-year level.

Construction of the structural elements began in 1962; the Floodway was completed in 1968 and within 4 years all other components were in place. Their effectiveness was demonstrated almost immediately. From 1969 to 1979, the average flow of the Red River was the highest on record and the system was used to manage flows exceeding minimum flood stage in 9 of the 11 years. Two of these events, 1974 and 1979, were particularly large. In 1979, the estimated *uncontrolled* stage in Winnipeg was within a few centimeters of the 1950 level, flooding was extreme throughout the valley, and more than 7,000 people were evacuated; in Winnipeg

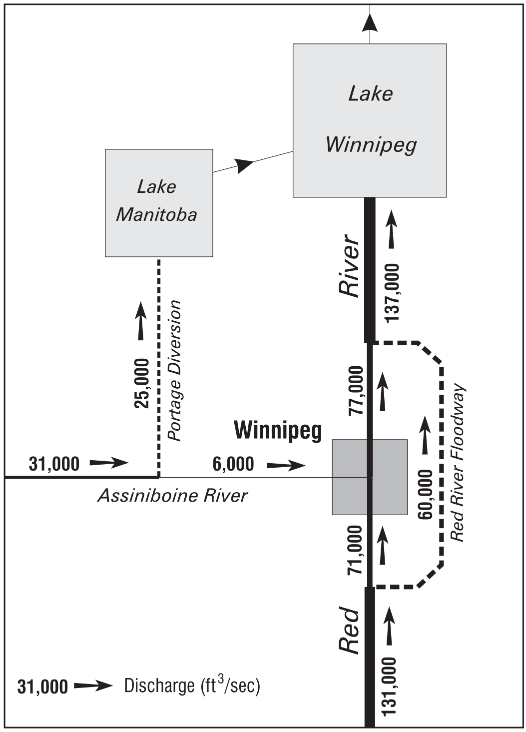


***Figure 2:** Routing of flow during a design flood (modified from Mudry et al. 1981).*

and within the community ring dykes, however, property damage was neglible and normal city activity in Winnipeg was scarcely affected. Mudry et al. (1981) estimated that by 1979, the gross value of damage reduction exceeded $1 billion (in 1979 dollars) and that the entire cost of the system had been more than recovered from *net* damage reduction. After this flood institutional measures were strengthened and individuals in the rural areas outside the ring dykes were assisted in elevating or dyking existing residential and some other types of buildings.

The system's value was again demonstrated during near-record flooding in 1996. South of Winnipeg, this event was the third largest *recorded* flood (only 1-1.5 ft lower than 1950/79) and in Winnipeg, the estimated *uncontrolled* flow equalled 1950/79 (because of a large contribution from the Assiniboine). Floodwater inundated a large area, isolating numerous communities and individual residences, but because of the control structures and damage reduction measures, the requirement for emergency measures was minor. Only about 100 homes required evacuation, and the total flood cost in Manitoba was only $12 million (Manitoba Government Information Services, 1996).

## Flood Forming Conditions in 1997

The weather during the winter of 1996-97 exhibited all of the classic preconditions for large floods in the Red River valley. After a wet fall and early onset to winter, winter snowfall was much above average. More importantly, the absence of significant thaw from November to March caused the accumulated water content of the snowpack to be much above normal throughout the Red River watershed.

At the beginning of the flood forecasting process in February, then, the combination of these factors was indicating major flooding, possibly to the 1979 level . Since this was well within the capacity of the flood protection system, flood preparations were locallized and no extraordinary emergency measures were being contemplated. Furthermore, a gradual melt beginning in early March suggested that the snowpack runoff might be released in a manageable fashion. By late March, forecast peak levels (assuming normal weather) were being revised downward and there was some prospect that widespread damage might be avoided.

This optimism was changed dramatically by a record snowfall on April 5-6 over most of the Red River basin. At Winnipeg, 58 cm were recorded and as much as 90 cm fell in the southern part of the basin. Although all major floods on the Red River have been the result of snowmelt, unusually heavy precipitation just before or during the snowmelt period is required to produce floods of 1950/79 or larger size. In 1997, the April blizzard provided this crucial event, transforming what would have been a large but manageable flood into one far exceeding any since gauge records began (in 1875 for stages in Winnipeg).

The importance of this snowfall can be gauged from the fact that in the1950 and 1979 floods, runoff from the watershed above

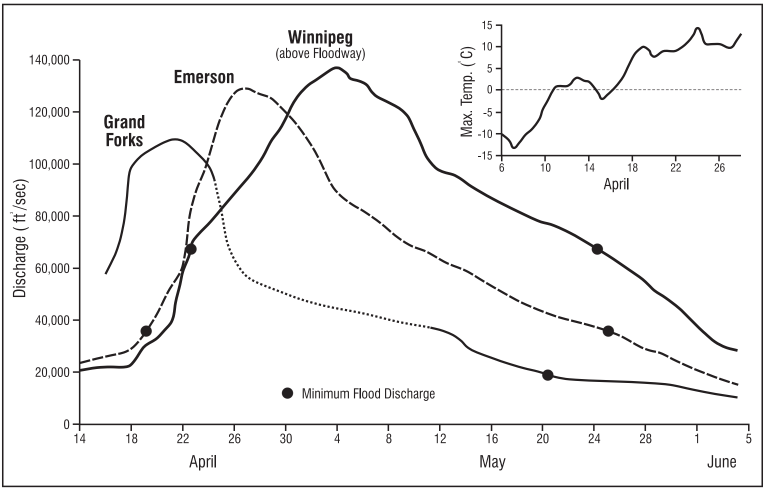


***Figure 3:*** *Hydrographs at Grand Forks, Emerson and Winnipeg (above Floodway) with minimum flood discharge. Inset: Daily maximum temperatures at Winnipeg, April 6-28.*

Winnipeg during the *entire* months of April and May was 50-70 mm. Thus, the 1997 storm added an amount of water to the basin approximately equal to the entire runoff during the two largest *recorded* floods. This was, of course, in addition to the heavy existing snowpack. Furthermore, although the southernmost portion of the basin received rain, the fact that most of this precipitation over the majority of the basin fell as snow had a critical effect on the timing of the runoff. Had the precipitation fallen entirely as rain, runoff would have been more rapid and as the main flood crest moved downvalley, much of the local runoff would have been dissipated and contributions by tributaries would have been smaller. This is, in fact, the normal pattern during major snowmelt floods— in Manitoba, tributaries have normally peaked before the main Red River crest arrives. In 1997, however, the blizzard was followed by 10 days of cold, mostly subfreezing, temperatures and very little melt, further delaying the runoff process. At Winnipeg, for example, only 10 maximum degree-days above 0°C accumulated between April 7 and April 17 (Figure 3 inset). In the southern part of the basin, however, more of the precipitation occurred as rain and very warm temperatures set in more quickly. Thus exceptional runoff was generated quickly in the southern basin but delayed further north. When strongly positive temperatures returned in Manitoba on April 18, snowmelt was being generated simultaneously over the entire Red River valley and the tributaries were close to their peaks as the main flood crest from the United States arrived. A crucial point which will be discussed below was the fact that the Assiniboine basin escaped this snowfall almost entirely.

## Emergency Measures

In March, some preparations had begun to protect the most vulnerable areas from possible flooding to the 1950/79 levels. After the blizzard, forecast stages were revised upward to 2-3 ft above the 1950/79 level and emergency measures were begun in earnest. The assistance of the Canadian Armed Forces was formally requested by the Province on April 10. Flood formation along the southernmost reach of the Red began in the following week, reaching its peak in Fargo on April 18 and in Grand Forks on April 21-22. The unprecedented discharge being recorded at Grand Forks caused further upward revisions of forecast peak stages throughout the Manitoba portion of the valley. These revisions and the catastrophic dyke failure in Grand Forks, elevated the flood preparations in Manitoba to those of a full-scale emergency and the images of flood and fire to the south galvanized the Manitoba populace.

In the valley south of Winnipeg, community ring dykes were raised to accommodate the forecast peaks with about 2 ft of freeboard and highway gaps through the dykes were closed. Outside the ring dykes, individual dykes were raised or constructed around several thousand residences and other buildings. Most farm animals and poultry were evacuated and equipment was moved to higher ground.

A State of Emergency was declared on April 20 and 21 for areas in the immediate path and on April 22, the Provincial government declared a general State of Emergency for the entire Red River valley. Although voluntary evacuation of some areas had begun earlier, a schedule of mandatory evacuations was recommended on April 23 and by April 30, 17,000 people had been evacuated from the valley, with a further 7,000 within Winnipeg (Manitoba Natural Resources 1997a). The total number of evacuees eventually reached 27,400 (*Globe and Mail* 1997). The magnitude of the task led to further requests for military personnel and equipment. Ultimately, 8,500 army, navy, air force, and coast guard personnel were deployed in the largest Canadian military operation since the Korean War. These personnel supplemented a civilian "army" of several thousand provincial employees, countless engineers, surveyors, equipment operators and others with technical skills seconded from the private sector, and tens of thousands of volunteers who built and patrolled dykes, maintained pumps, managed evacuation centres and supported others with cooking, transportation, etc.. In all its aspects, the month-long emergency management operation was the largest in Canadian peacetime history.

The most dramatic of the emergency measures was the construction of the "Brunkild" or "Z" dyke. As the flood crest approached Winnipeg, concern was expressed that the very high stages expected upstream of the Floodway might permit water from the Red and upper Morris Rivers to bypass the western portion of the Floodway wing dyke and enter the city via the La Salle River (which joins the Red just downstream of the Floodway control structure). To prevent this, an extraordinary engineering operation extended the wing dyke westward by 26 km (the Brunkild or "Z" Dyke) and augmented 15 km of the existing dyke (Figure 4). Construction of the dyke began on April 24 and continued on a 24-hour basis until its completion on April 28 (improvements were made over the next several days). In the main construction period, up to 400 pieces of earth-moving equipment were used to emplace approximately 750,000 $m^3$ of earth, 142,000 tonnes of limestone, 2,000 1-tonne "super sandbags", and 4,000 bales of straw. Forty kilometers of snow fence, 8 kilometers of oil boom and 2.4 kilometers of derelict vehicles were installed to absorb wave energy (Manitoba Natural Resources, 1997b). More than 450 people were involved in the effort, supported by airdropped flares to permit work at night.

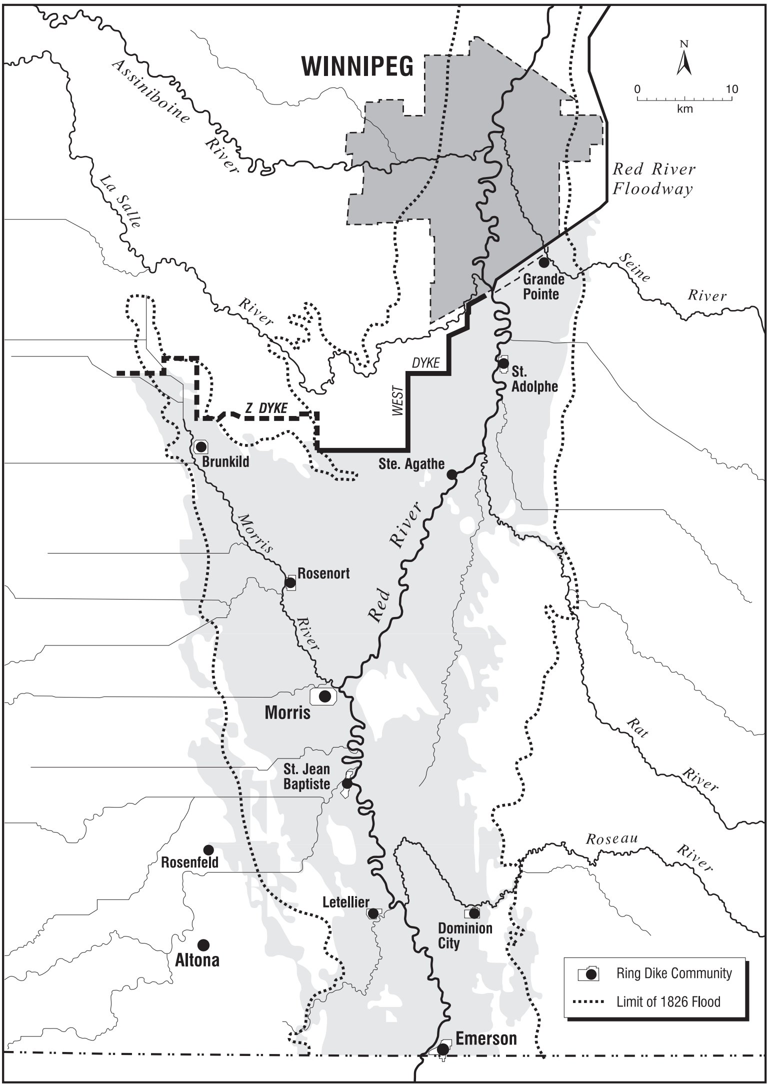


***Figure 4:*** *Flooded area in Manitoba, Z Dyke and limits of 1826 flood.*

In Winnipeg, the control system was expected to maintain peak stages at about 2 ft below the level of the primary dyke system. Consequently, the emergency dyking (involving 6.5 million sandbags and extensive earth dykes) was limited to about 570 (mostly residential) properties in areas between the primary dyke and the river. In addition, a 4 km-long earth dyke was constructed in the southern area of the city to redirect the flow of the La Salle River in the event that the Brunkild Dyke was breached. Residents of 3456 homes in several of these areas were evacuated, most as a precautionary measure, and others were put on evacuation notice should conditions worsen. Because of this dyking, only about 30 properties within the city were flooded, although a further 74 were damaged by basement flooding after about 30 mm of rain on May 7 exceeded the sewer pumping capacity (City of Winnipeg 1997).

North of Winnipeg, downstream from the Floodway outlet, the greater channel capacity was sufficient to carry the entire flow without flooding. Nevertheless, sandbag dykes were required to protect numerous homes on very low ground, particularly where locallized flooding occurred at the junctions of tributaries with the Red.

## Progress and Magnitude of Flood

The progress of the flood, from Grand Forks to Winnipeg is shown on Figure 3. The crest at Grand Forks occurred on April 21-22 and reached Emerson on the Manitoba-United States border on April 27. Even before the arrival of the main crest, however, widespread flooding was occurring along most of the Manitoba portion of the valley due to the melting of the heavy snowpack. Minimum flood stage was reached at Emerson and Morris on April 19 and in Winnipeg on April 22. The 1979 stage was reached in Emerson on April 23 and by April 25, 1979 levels had been equalled or exceeded along the entire river.

Most of the Red River tributaries in Manitoba were reaching their peaks in the April 20-25 period, close to the arrival of the main flow from the United States portion of the basin. The extensive nearly flat land bordering the river permitted floodwaters from both the Red and its tributaries to merge and spread over a broad area.

Eventually, the Manitoba portion of the flooded area created a 2000 $km^2$ water body with a maximum width of about 40 km, quickly named the “Red Sea” by the media (Figure 4).

Although the storage provided by this “lake” would normally flatten the hydrograph somewhat as the flood wave moved toward Winnipeg, much of the potential storage was already occupied by overland runoff and tributary overflow. This may partially account for the fact that peak stages exceeded 1979 levels by progressively larger amounts downstream- by 1.23 ft (0.38 m) at Emerson on April 27, 2.08 ft at Morris (April 30), 3.4 ft at Ste. Agathe (May 2), 4.19 ft at St. Adolphe (May 3), and 6.31 ft upstream of the Floodway at Winnipeg (May 4). These stages were generally 10-15 ft above minimum flood stage.

At Winnipeg, the Floodway began operation to control flow through the city on the evening of April 21, 13 days before the arrival of the main flood crest, to manage the high flows being generated by snowmelt over just the Manitoba portion of the valley. At the Floodway entrance, peak discharge of 138,000 cfs did not occur until May 4. Discharges on that day at various points in the vicinity of Winnipeg and on the Assiniboine (Figure 5) demonstrate the gravity of the situation and the magnitude of the disaster the flood control system averted. Without the control system, it is estimated that Winnipeg peak stage would have reached 34.3 ft (Warkentin, 1997), about 4 ft above the 1950 level and 8 ft above the primary dyking system. Such an uncontrolled flow would have flooded much of the city and forced the evacuation of a large percentage of the population of 650,000. With the flood control system operating, however, peak stage in the city was limited to 24.5 ft, 2 ft below the primary and secondary dykes.

As Figure 5 shows, most of this protection was due to the Floodway which at the flood peak carried 47% of the upstream flow (65,100 cfs) around the city. Once the crest was reached on May 4, the operation of the Floodway became a compromise among competing (and partially contradictory) objectives within Winnipeg and upstream of the Floodway. In both locations, the longer water levels against the dykes remained high, the greater was the potential for failure, leakage, or overtopping by waves and wind setup. In Winnipeg, where most secondary dykes were on the riverbank, the

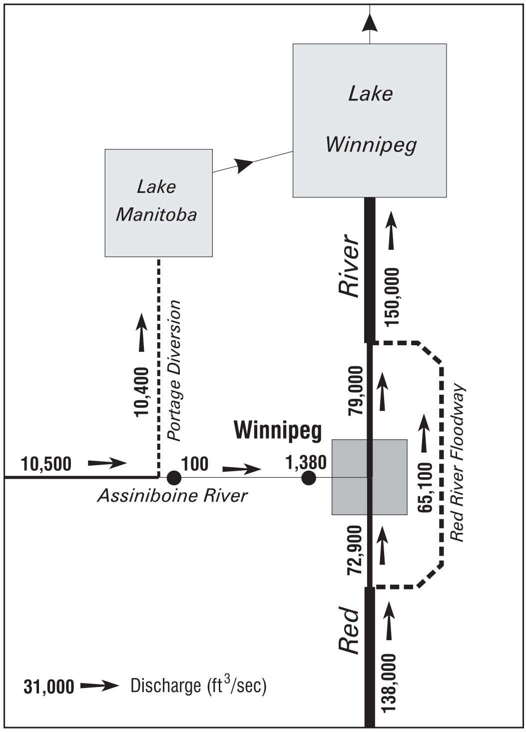


***Figure 5:*** *Routing of flow on May 4, 1997.*

threat of bank collapse from the weight of the dykes became an urgent concern. Thus, even after the crest had passed, water continued to be diverted at a high rate to reduce stages within the city as rapidly as possible and permit secondary dykes to be lowered or dismantled earlier. In addition, lowered city stages reduced the potential for damages from sewer backup if significant rainfall occurred. The permissable rate of stage reduction in the city was limited, however, by concern that too rapid a drop might itself have caused dyke or bank failure. Upstream of the Floodway, lower levels were desirable to reduce the pressure against dykes and eliminate the threat from wave action, wind setup, and leakage. When stages within the city fell below minimum flood level, flow through the Floodway was reduced more quickly, reaching zero on June 3.

Less well-appreciated by the media and public was the role played by the Assiniboine Diversion in reducing flows within Winnipeg. Although maximum runoff in the Assiniboine basin was only 0.17 $m^3$/sec/km compared with 1.18 $m^3$/sec/$km^2$ in the Red, flows were nevertheless above average and in the days leading up to the Red River crest at Winnipeg, approximately 11,700 cfs were being diverted out of the Red River system, virtually eliminating downstream flow toward Winnipeg (on May 2, flow downstream of the Diversion actually reached zero). Without this ability to reduce flow in Winnipeg, discharge within the city would have been about 15% greater and stages possibly 2.5 ft higher, exceeding the level of the primary dykes. To handle this additional water by routing more through the Floodway (which was already carrying about 9% more than its normal design capacity) would have further compromised the already critical state of the surviving dyked buildings within the backwater zone, and reduced the capacity to accommodate higher flows which might have developed with adverse weather.

The estimated *uncontrolled* peak stage and discharge in Winnipeg were 34.3 ft and 163,000 cfs respectively (Warkentin, 1997), approximately equal to the values estimated for the second largest known flood, in 1852. Thus, in 204 years of documented flood history in Manitoba, the 1997 flood was exceeded only by the 1826 event (which reached a stage about 2 ft higher in Winnipeg). The most recent frequency curves indicate that from Emerson to Winnipeg, the 1997 flood had a Return Period of 110-120 years.

The relative discharges of the Assiniboine and Red Rivers in 1852 are not known. Interestingly, however, diary entries by Reverend Abraham Cowley indicate that the Assiniboine exceeded bankfull stage from Portage la Prairie to modern-day Headingley:

> May 22, 1852: Reached Portage la Prairie; Here the people have been flooded out of their houses...
>
> May 24, 1852: Left Portage la Prairie & descended the river till nearly sun set... It has become difficult to land when one wishes the banks being generally overflowed.

> May 25, 1852: Reached White Horse Plain much of it is overflowed...

Prior to 20th Century dyking, natural bankfull discharge along this reach was 12-15,000 cfs (Mudry et al. 1983) and the quotations above indicate that discharges significantly in excess of this value were occurring close to the Red River peak date (c. May 19). If the uncontrolled 1997 peak stage in central Winnipeg was about the same as in 1852, it is possible that the 1997 flow on the Red upstream of the city may have been somewhat larger than in 1852.

As severe as the 1997 event was, but for two factors, it could have been significantly worse. The first was the favourable flow pattern of the Assiniboine River. As was noted above, most of the Assiniboine basin escaped the major blizzard that produced the exceptional runoff in the Red River basin. Upstream of the Assiniboine Diversion, discharge peaked at 29,500 cfs on April 20, two weeks earlier than the crest of the Red (at Winnipeg), and fell rapidly thereafter; by April 22, it was only 14,980 cfs, well within the capacity of the Diversion to re-route the entire flow as discharge of the Red approached critical levels. By the crest date of the Red (May 4), it had fallen to 10,500 cfs. In contrast, in 1996 maximum discharge was 32,700 cfs and the maximum ever recorded was 51,700 cfs in 1976. Clearly, the Assiniboine is capable of generating much more runoff than occurred in 1997 and had significant areas of the basin been affected by the blizzard, it is likely that peak discharge would have been larger and would have occurred somewhat later. Even the 1996 discharge exceeded the capacity of the Diversion and the excess downstream flow from a flow of that magnitude would have produced stages in Winnipeg near the level of the primary dykes. With the Floodway operating slightly above desired capacity, virtually any increase in the Assiniboine flow entering Winnipeg would have required either raising the city’s primary dyke system (which would have increased the magnitude of the emergency measures enormously, endangered more properties, and increased the number of evacuations) or diverting more water through the Floodway, causing flooding of even more properties in the backwater zone. With the negligible inflow of the Assiniboine, virtually the entire 1997 peak flow was from the Red River and the assumptions about the water gradient south of the confluence on which the normal operating rules for the Floodway were seriously compromised. Stages of 24.5 ft in central Winnipeg (which allowed for 2 ft. of freeboard) translated into relatively higher equivalent stages in south Winnipeg, coming within inches of overtopping the secondary dykes in St. Norbert (Manitoba Natural Resources 1997d).

The second mitigating factor was the favourable weather which prevailed after the blizzard. From April 7 to the flood crest at Winnipeg on May 4, precipitation at Winnipeg was only 70% (c.20 mm) of normal. A major rainstorm (30 mm) on May 6-8 came after the river had crested and had little effect on river stage, although it did cause sewer backup and damage to some Winnipeg homes. The greatest weather hazard came from strong (50-70 kph) south winds on several days when stages were near their crest. Waves and setup on the 2000-km$^2$ "lake" elevated downwind water levels and threatened the integrity of many dykes.

In the valley south of Winnipeg, ring dykes had been elevated to 3-4.5 ft above peak stages. With continuous monitoring and maintenance, the dykes held and little damage occurred within these communities. Individually dyked buildings in the predominantly rural area outside the ring dykes, however, fared less well. Almost a year after the crest (April 20, 1998) 5,247 private and 69 municipal damage and compensation claims had been filed (Siroka 1998). With slightly more than 50% of claims settled, $116 million had been paid out ($61.4 million to private owners and $54.6 million to municipalities). Published figures for expenditures on emergency measures, cleanup, and repair of roads and bridges exceed $120 million. When other costs such as uncompensated damage, lost income and business, donated goods and services, reestablishment of businesses, interest on lines of credit to municipalities, stabilizing damaged riverbanks in Winnipeg etc. are included, the ultimate costs of the flood may reach $500 million. Spurred by Canadian media attention, several national fund-raising campaigns raised c.$20 million to assist victims beyond official governmental compensation.

Damage severity increased downstream, being greatest in the Rural Municipality of Ritchot immediately south of Winnipeg where two communities suffered particularly heavy losses. Ste. Agathe (population 500) was not protected by a ring dyke, relying on a combination of road and railway embankments, some permanent dykes, and emergency dykes. This defence failed on April 29 when water washed out a section of temporary dyke and flooded much of the town. Grande Pointe is a residential community of 150 homes one km south of the Floodway and thus outside of its protection. On May 1-2, as flow upstream of the Floodway was nearing its peak, dykes around c.125 homes were overtopped.

A notable feature of Red River floods is their long duration. The large volume of storage within the valley which causes a gradual buildup to the peak also extends the recession limb over several weeks after the crest. In 1997, flow did not fall below minimum flood stage between Emerson and St. Adolphe until May 25-29, four weeks after the peak; at most locations, the river was above minimum flood stage for a total of 36-40 days. Thus the danger from dyke fatigue, leakage, waves, wind setup, and adverse weather required vigilance for some time after the crest passed.

Evacuees began returning to some regions on the margins of the flooded area on May 3-5 but the long recession delayed re-entry to most communities and homes near the river. Emerson was not re-occupied until May 12, 3 weeks after evacuation began and as late as May 15, 12,000 people remained evacuated (Manitoba Natural Resources 1997c). Most of these were permitted to return beginning on May 17. In Winnipeg, where the majority of evacuations were precautionary, most evacuees were resettled by May 15.

## Discussion

The 1997 flood raised (or resurrected) a number of broad issues, including such immediate concerns as the level and timing of damage assistance, the management of emergency measures, and the precision of forecast stage information on which dyke building in the valley was based.

Some of the strongest criticism concerned the operation of the Floodway. Flow into the Floodway is created elevating the upstream water level of the Red River and normal operating rules limit this upstream elevation to that which would have occurred with no control measures (i.e. in the absence of the Floodway, Assiniboine Diversion and Shellmouth Dam). In several previous floods, property owners in this affected area claimed that the control structure had created higher-than-natural water levels upstream. Predictably, the controversy was renewed in 1997 when for the first time it was necessary to divert more than 60,000 cfs to maintain stages within Winnipeg at design level. Beginning on May 1, upstream water levels were raised by about 0.5-1.0 ft[4] above the design or “natural” stage to increase Floodway discharge to 65,100 cfs. This decision was taken to provide 1 ft additional freeboard on the city dykes, to reduce the possibility of storm sewer backup, and to prevent overtopping of secondary dykes in the southern part of the city (Manitoba Water Resources 1997d).

After Grande Pointe suffered major damage, the May 3 headline in the *Winnipeg Free Press* proclaimed “Suburbs Sacrificed to Spare Winnipeg”. While the small artificial elevation of water level upstream may have been a minor contributing factor to the flooding of these properties, many of the assertions of residents of the upstream zone misrepresent the hydrological circumstances and the gravity of the situation. For example, the President of The 768 Association, representing the residents of Turnbull Drive immediately south of the Floodway control structure, offered the following critique of the operation of the control system:

> When one reviews the 1997 flood and in particular compares its progress to both the 1996 and 1979 floods... it is difficult not to conclude that the 1997 flood was made far worse than it should have been because of the operation of the control gates... Within 3 days of activating the control gates the flood waters south of the gates were approaching the historic 1950 levels... Most profound to me, was the degree by which the 1997 flood deviated from the pattern of the 1979 flood... Since >80% of the flood waters come from the ... (United States), and since during the time of the flood there was no significant precipitation, and since much of the local runoff had preceded the crest period,

> one would anticipate a similarity between the 1979 and 1997 floods. That similarity simply does not exist. (Hunter 1997)

The similarity Hunter felt should have occurred didn't because the hydrologic circumstances in 1997 were so different from those of 1979. As was noted above, the delay in significant melt for 10 days after the blizzard caused severe runoff to be generated simultaneously over the entire basin. In contrast, the severity of the 1979 flood was primarily the result of heavy rainfall in the United States portion of the basin during the snowmelt period. In 1997, levels equalling 1979 and/or 1950 were produced by "local or regional" runoff. The 1979 stage was surpassed at Emerson and Letellier on April 23, at St. Jean a day later, and by the morning of April 25 (about 3 days after the beginning of operation of the control gates), 1979 levels had been reached or exceeded along the entire Manitoba section of the river, 5-10 days before the arrival of the main body of water from the United States. By the morning of April 26, discharge at the Floodway entrance was slightly greater than the peak 1979 discharge and the crest was still 9 days away. Thus, Hunter's statement that "much local runoff preceded the crest period" ignores the fact that this "local" runoff was by itself capable of producing 1979 levels and initiating the operation of the floodway. Although the control gates were indeed raised very rapidly from April 22 to April 24, this was a response to the rapidly rising stage complicated somewhat by ice problems; actual stages during the period closely followed the computed natural stages until April 27 (Figure 6, Manitoba Water Resources 1997d). Thereafter, for the reasons noted above, stage was 0.5-1.0 ft above natural until May 7.

A more fundamental issue, however, is the fact that many of these buildings in the upstream "backwater" zone post-dated the beginning of Floodway construction and their presence compromises the most effective operation of the structure designed to protect the adjacent city of 650,000. This problem will continue to arise in future floods unless long-term policies for building in this area (including more strict and carefully enforced land-use regulation) are implemented. Within Winnipeg, numerous buildings

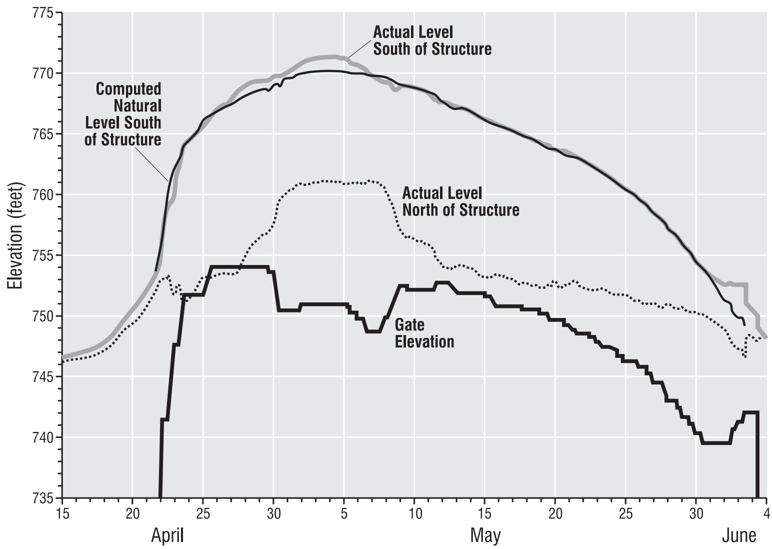


***Figure 6:*** *Actual and computed natural stages north and south of the Floodway and at James Avenue, and control structure gates elevations (after Manitoba Water Resources 1997d).*

which required dyking were located within the flood hazard zone where again, more strict land-use control within the flood hazard zone will be necessary to reduce the need for future emergency measures.

The 1997 flood also refocussed attention on the question of land drainage in the Red River Valley, an issue which was raised after the 1979 flood but which quickly died away during the subsequent drier period of the 1980's. Beginning early in the century, extensive artificial drainage of agricultural land in the valley has been effective in speeding the spring drainage of agricultural land and in draining wetlands for agriculture. It may also, however, have intensified runoff and increased effective drainage area by transforming non-contributing into contributing area. The increased incidence of flooding in the last 30 years has drawn attention to the drainage ditches as a possible contributing factor; while they are not the cause of major floods, their cumulative impact in exacerbating flood levels needs to be re-examined.

Not all consequences of the flood are negative. Every flood has left its own legacy of improvement in the region's ability to cope with its greatest natural hazard. The 1950 flood led to the construction of the basic control measures, focussing on Winnipeg. After the 1966 event, the ring dykes around valley communities were added to the infrastructure. The 1974 flood initiated discussion of flood-proofing and institutional measures without which the effectiveness of the structural measures would be gradually eroded. Finally, the 1979 flood led to an increase in the design standards for dykes within the valley, triggered the dyking and flood-proofing programme, and reinforced the need for institutional measures. The 1997 flood will produce a similar improvement in flood preparedness and further reduce the damages from future floods. Many new earth dykes will become permanent and the improvement of the community and individual dykes will provide greater protection. More strict land-use control and enforcement will further reduce the need for future emergency measures. The first steps in this direction were announced in July 1997. Under a joint Provincial and Federal programme similar to that implemented after 1979, community ring dykes will be improved, new ring dykes will be constructed (eg. around Ste. Agathe and Grande Pointe) and individuals will be assisted in permanently dyking, elevating, or relocating buildings to 2 ft (0.6 m) above the 1997 level at an estimated cost of $50 million (Manitoba Government Information Services 1997). The City of Winnipeg has also announced plans to increase the secondary dyke system, isolate health care facilities from the sewer system, improve pumping capacity, control urban drainage, and extend the regulation of land use.

Perhaps the most important legacy is the heightened general awareness of the hazard. The flood educated the public regarding the functioning of the control system and will undoubtedly ease the acceptance of the need for future expenditures, land-use regulation, and other damage-reduction measures. Understandably, the greatest media attention was devoted to the drama of the emergency response and the victims' losses. With some reflection, however, the biggest story of the 1997 flood was probably what didn't happen— the widespread flooding and wholesale evacuation of Winnipeg. The damages such an event would have entailed are difficult to envisage but would have been many billions of dollars. On a smaller scale, the undamaged ring-dyked communities and individual buildings throughout the valley were less newsworthy than the devastation suffered by Ste. Agathe, Grande Point and the many buildings whose dykes proved insufficient. Nevetheless, the fact that the flood control and damage prevention measures averted perhaps 95% of the damages that would otherwise have occurred (and virtually 100% of the damages they were designed to prevent) demonstrated the effectiveness of the programme of flood control and flood proofing which has been evolving in Manitoba over the last 50 years.

## Acknowledgements

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## End Notes

[1].Although SI units are normally preferable, local convention during the flood in media reports, published data and most discussions was to state stage and discharge in Imperial units. Since these units are so engrained in local usage, even within the professional hydrologic community, this convention has been followed in this paper. Thus stage is given in feet and discharge is given in cubic feet per second. All other data are given in SI units.

[2].Stages for the Red River in Winnipeg are stated in feet above the normal winter ice level at James Avenue, in central Winnipeg just downstream of the confluence with the Assiniboine. This reference elevation has been defined as 727.57 feet above sea level.

[3].The capitalized term "Floodway" used in this paper refers to the official name of the diversion channel around Winnipeg and should not be confused with the more general usage elsewhere to designate a specific portion of the floodplain.

[4].Existing rating curves (dating from the 1950's and 1960's) indicated that stage was about 1 ft above "natural" but the 1997 experience suggested that these curves yielded stages which were about 0.5 ft too low. Thus it was estimated that the "excess" elevation was only 0.5 ft above "natural" (Manitoba Natural Resources 1997d)

# Subglacial meltwater features in central Saskatchewan

**Nancy M. Grant, University of Manitoba**

***Abstract:*** The landscape in the Rural Municipalities of Viscount and Wolverine in central Saskatchewan contains an assemblage of glacial features that includes large-scale lobate gravel forms, discrete zones of hummocky terrain, a rudimentary anabranching channel system, and boulder-paved scour zones. These elements are associated with an ice marginal environment during the final deglaciation of the area, although it is unlikely that they are genetically related to the large-scale, integrated system of proglacial lake and spillway development that characterizes the Interior Plains. Using geomorphological and sedimentological evidence it is concluded that the assemblage of features was formed by a turbulent, non-channelized, subglacial flow event that issued from the glacier margin. In the subglacial environment, this highly erosional event produced morphologically distinct tracts of hummocky terrain and linear scours that are densely covered with boulders. The rapid deposition of multi-modal gravel in large lobate forms ensued as the flow moved from a subglacial to a proglacial environment.

## Introduction

The landscape of the Canadian Prairies is characterized by a complex network of proglacial lake basins and deeply incised valleys that developed as meltwater drained away from the southwest margin of the Laurentide Ice Sheet. The evolution of the network of spillways involved the impoundment of proglacial lakes along the ice margin and their subsequent catastrophic drainage due to influxes of large volumes of water and the opening of previously blocked, topographically lower outlets (Kehew and Lord 1986; Lord and Kehew 1987; Kehew and Teller 1994a). Landform assemblages, however, commonly occur in suites of several genetic types.

Different geomorphic forces operating at different times or a single geomorphic force operating under different conditions may contribute to the genesis of the various elements of a particular landscape. The possible contribution of subglacial fluvial processes to the evolution of the largely proglacial drainage system is one example of the latter circumstance. In light of the growing body of work identifying the significance of subglacial fluvial processes as causal mechanisms in the formation of numerous features of the Prairie landscape (Shaw and Kvill 1984; Shaw et al. 1989; Rains et al. 1993; Sjogren and Rains 1995; Grant 1997), it is reasonable to speculate that the subglacial and proglacial drainage systems may, in some respects, be genetically linked.

The landscape in the Rural Municipalities of Viscount and Wolverine in central Saskatchewan contains an assemblage of glacial features that includes large-scale lobate gravel forms, discrete zones of hummocky terrain, and a rudimentary anabranching channel system. These elements do not appear to be genetically associated with the larger scale integrated proglacial drainage system that developed as the ice front receded from the region. Alternatively, they formed during an earlier event as a highly turbulent, subglacial meltwater sheet flow that issued from the glacier margin.

## Regional Context

The Rural Municipalities of Viscount and Wolverine are located on the central Saskatchewan Plains approximately 120 km southeast of Saskatoon (Figure1). The study area is contained within the Assiniboine River Plain (Acton et al. 1960) that forms a central lowland bordered on the east by the Touchwood Hills Upland and on the west by the Allan Hills Upland. The gently undulating to rolling topography that ranges in elevation from 450 m to 600 m is characterized by a combination of almost featureless plains and hummocky terrain. Drift deposits in the area vary in thickness from 1 m to more than 300 m (Greer and Christiansen 1963). The most striking geomorphological aspect of the study area is its relationship to the large-scale system of proglacial lakes and spillways that formed during the final deglaciation of central Saskatchewan.

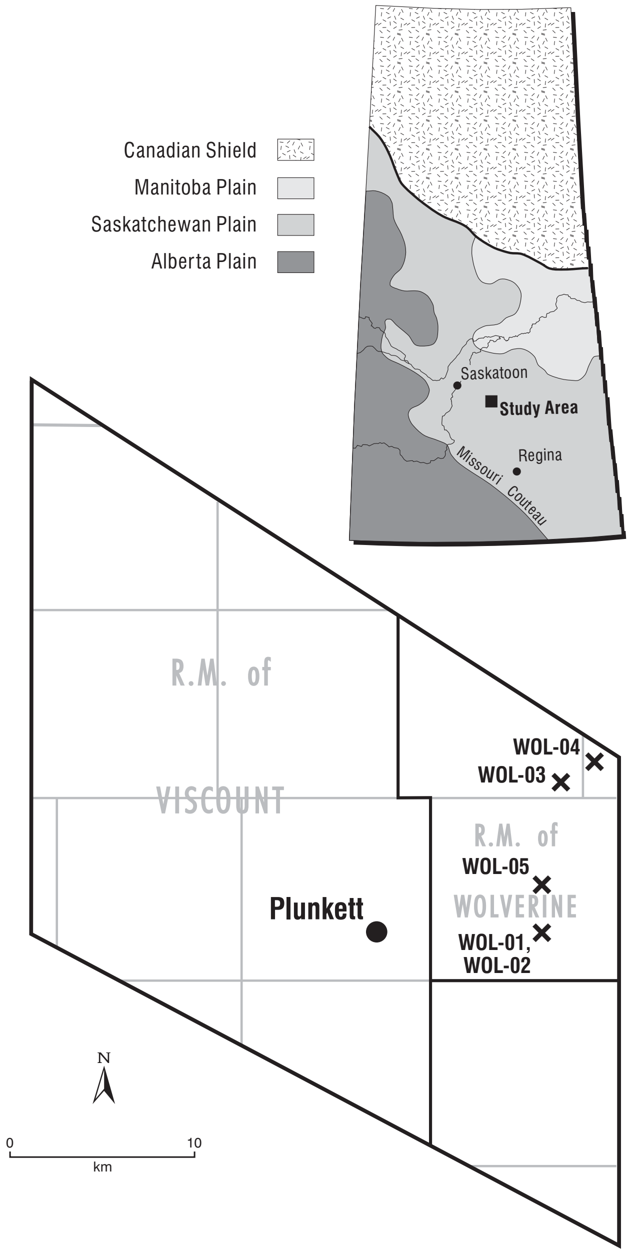



*Figure 1:* *Location of the Rural Municipalities of Wolverine and Viscount and the sites of exposures discussed in the text.*

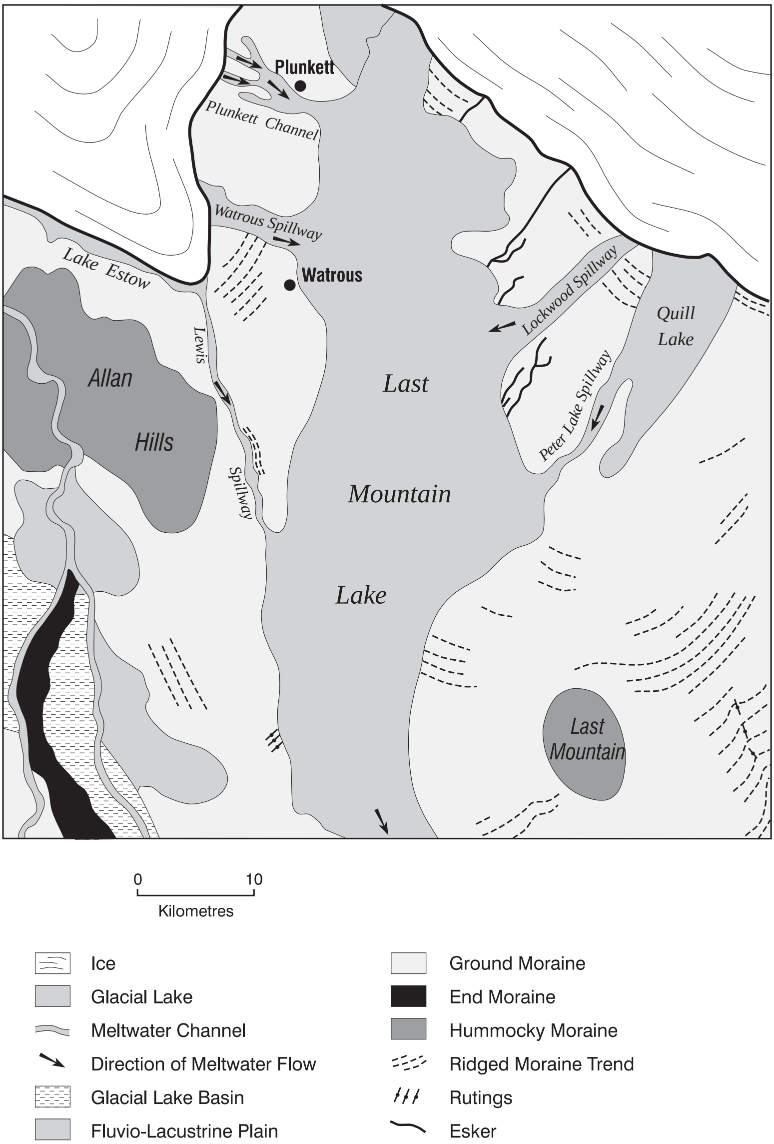



***Figure 2:*** *Deglaciation of central Saskatchewan and the development of the Plunkett Channel (adapted from Greer and Christiansen 1963).*

Kehew and Teller (1994a) provide a detailed synopsis of proglacial lake and spillway development in central Saskatchewan as it is currently understood (Figure 2). In their summation, the development of the large spillways occurred subsequent to the ponding of glacial Lake Saskatchewan, glacial Lake Elstow, and glacial Last Mountain Lake in isolated basins along the ice margin. With ice retreat these isolated basins were thought to have been joined as spillways were formed. Glacial Lake Elstow formed between the ice margin and the northern end of the Allan Hills. Kehew and Teller (1994b) determined that the lake was ponded on top of stagnant ice along its eastern margin and at its outlet. As melting of the ice front progressed, an outburst flood incised the Blackstrap spillway from glacial Lake Saskatchewan to glacial Lake Elstow across a divide of stagnant ice and over the western edge of the Allan Hills. During its early stages, glacial Lake Elstow was drained by the south trending Lewis spillway on the eastern edge of the Allan Hills, through the Last Mountain Lake valley and into the Qu'Appelle River. As the ice lobe filling the Last Mountain Lake valley retreated northward, the Lewis spillway was abandoned in favour of the southeast flowing Watrous spillway as an outlet for glacial Lake Elstow. In the interpretation of the deglaciation of the area by Greer and Christiansen (1963), there was a subsequent complex history of ice retreat and lake evolution that included the development of major re-entrants and at least one episode of ice readvance. Most of the meltwater flowing into the glacial Last Mountain Lake was believed to have originated in the interlobate area, though the Lewis spillway was also used (Greer and Christiansen 1963). With further retreat, the glacier was interpreted to have divided into two distinct lobes that had subglacial streams issuing from minor re-entrants. In the interpretation of Greer and Christiansen (1963), meltwater discharged from the northwestern lobe through the Watrous spillway, as well as the more northerly Plunkett channel. Kehew and Teller (1994b), however, reinterpreted the formation of the Watrous spillway. They concluded that the lobe of ice that occupied the Last Mountain Lake valley separated from the still active glacier in the Saskatchewan Rivers Plain. The Watrous spillway was then rapidly incised across a divide of stagnant

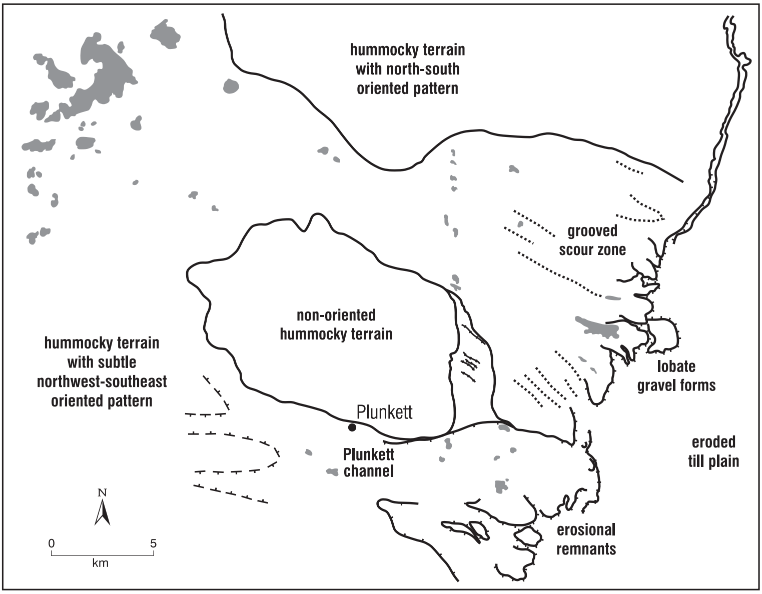



***Figure 3:*** *The study area contains a suite of landform elements including hummocky terrain, an extensively scoured zone, large-scale lobate gravel deposits and the Plunkett Channel.*

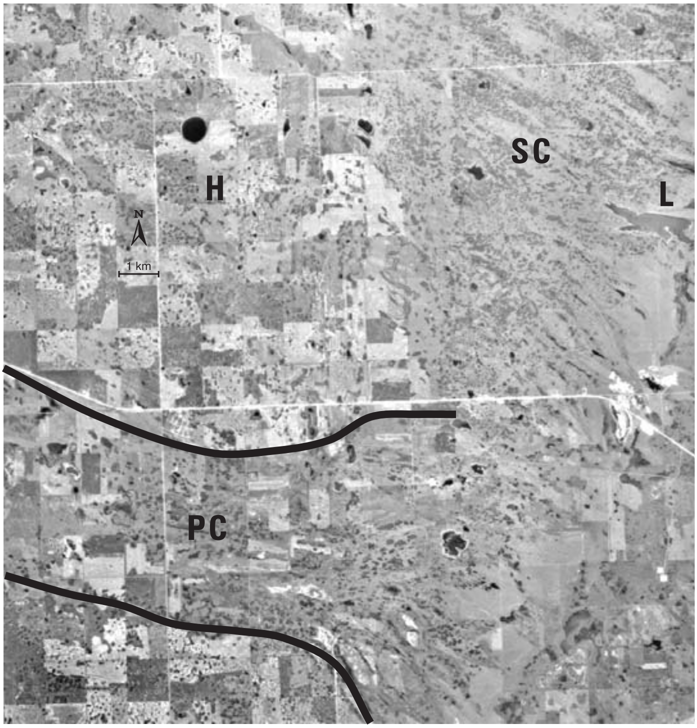
ice by a short-lived outburst that catastrophically drained glacial Lake Elstow into glacial Last Mountain Lake.

The purpose of this study was to investigate the origin of the suite of landform elements that are associated with the Plunkett Channel to determine whether or not its formation was coincident with the development and drainage of proglacial lakes during the final deglaciation of the area. In addition to the Plunkett Channel, there exist a series of large gravel lobes and distinctive tracts of hummocky terrain that are elements in an assemblage of geomorphic features that developed at the same time by the same formative event (Figure 3).

## Geomorphology of the Plunkett Channel and Associated Features

The Rural Municipalities of Viscount and Wolverine are located north of the Lewis and Watrous spillways on the eastern edge of glacial Lake Elstow (Figure 2). The predominant surficial deposits in this area include glaciolacustrine clay and silt, till, and till-lacustrine melanges (Edmunds 1962). The margin of glacial Lake Elstow is characterized by thin, discontinuous glaciolacustrine sediments that occur in conjunction with more widespread glacial deposits. These sediments grade into hummocky terrain composed of till and small pockets of glaciofluvial material. The hummocky terrain near the eastern margin of glacial Lake Elstow is highly variable in its geomorphological characteristics. In the northwest portion of the study area, the hummocky terrain has an average relief of approximately 15 m and is characterized by closely spaced hummocks that are separated by densely distributed, closed depressions. Small areas of less that a few square kilometres of flat-lying lacustrine deposits also occur. Many of the hummocks have circular and near-circular rim ridges enclosing central depressions at their apices. Generally, neither the hummocks nor the depressions exhibit any discernible orientation and no overall pattern within this zone is evident. It does, however, truncate an area of higher relief hummocky terrain to the north. In the older, higher relief terrain, lakes and small depressions have a large length-to-width ratio and are arranged in parallel lines that have a north-south orientation. The elevation is approximately 15 m higher than the hummocky area to the south and west and the relief ranges from 20 to 30 m.

The boundary between these tracts of hummocky terrain is marked by a narrow zone of very distinct northwest-southeast trending lineations. Linearly arranged lakes, depressions, and hummocks are contained within a 2.5 km wide, concave trough that is bounded on both sides by pronounced sharp-crested ridges. The trough diverges at its southeastern extent into a zone of low relief terrain that is characterized by a dense network of small northwest-southeast trending grooves. The grooves vary in depth and morphology from those with smooth, gently sloping sides to those with sharply defined margins, steep slopes, and pitted floors. The eastern margin of this scoured zone is sharply defined by a series of large, flat-topped, lobate forms composed of coarse gravel (Figure 4). The gravel lobes extend from north to south for a




Department of Energy, Mines and Resources A21849-6

***Figure 4:*** *Aerial photograph of gravel lobes and scour zone in the Rural Municipality of Wolverine showing the zone of scouring (SC) and depositional gravel lobes (L), hummocky terrain (H) and the Plunkett Channel (PC).*

distance of 10 km and range in width from 1 to 2 km. The leading edge of the lobes drops steeply 10 m to an extensive tract of eroded till plain. The boundaries between individual lobes are marked by elongate depressions that are very densely paved with boulders and generally contain water (Figure 5).

The eastern margin of the zone of gravel lobes is very sharply defined where it is superimposed on a north-south trending tract of almost featureless, eroded till plain. A soil survey map of the area shows that the soils associated with the eroded till plain are predominantly Solonetzic (Mitchell et al. 1947). The most prominent feature on the till plain is a series of sub-parallel, shallow, indistinct

***Figure 5:*** *A large zone of intense scouring is located immediately west of large lobate gravel deposits. The scours are characterized by elongate, water-filled depressions that are located in low area between adjacent lobes and a very dense surface boulder pavement.*

meltwater channels that trend northeast-southwest. Some of the channels are dry while others contain permanent and ephemeral streams and lakes that presently drain toward the southeast. The modern Wolverine Lake is the largest lake in the area and is contained within the westernmost channel where the flow of water southwestward is blocked by the superimposition of the lobate gravel deposits. Aerial photographs also reveal the presence of large-scale, slightly arcuate lineations that are concave toward the northeast. Portions of the arcuate lineations are obscured by the subsequent formation of the meltwater streams. These extremely subtle variations appear on the ground as small circular depressions that are less than 1 m in diameter and are paved with boulders.

The gravel lobes are bordered on the south by an east-west trending channel that Greer and Christiansen (1963) referred to as the Plunkett Channel (Figure 4). The channel has indistinct origins approximately 18 km to the west near the eastern limit of glacial Lake Elstow. The head of the channel, however, is separated from glacial Lake Elstow deposits by a topographic high of hummocky

***Figure 6:*** *The floor of the Plunkett Channel is characterized by elongate erosional remnants that have a dense covering of large, angular boulders.*

terrain that is approximately 10 to 12 m higher than the glacial lake bed and the channel. The mouth of the Plunkett Channel is composed of a series of small channels with highly variable depths that converge to form a more distinct channel that is approximately 4 km wide and 10 to 15 m deep. The floor of the Plunkett Channel is characterized by low relief hummocks and numerous water-filled depressions. Many of the hummocks have rim ridges and are linked in chain-like patterns in some areas. At its eastern limit, the Plunkett Channel abruptly widens and terminates at a position that is coincident with the position of the gravel lobes. The distributary channels are of varying depths though they share a common point of termination. The eastern limit of the channel quickly becomes indiscernible from the adjacent till plain. Near its eastern limit, the northern margin of the channel is indistinct as it grades into the southernmost gravel lobe while the southern margin curves slightly toward the southeast in a series of deeper, narrower channels that are defined by prominent erosional remnants. As with the gravel lobes, the sediments associated with the channel are superimposed on the eroded till plain to the east, obscuring the previously incised, small meltwater streams. The sediments in the Plunkett Channel are almost entirely till and are everywhere characterized by a dense surface cover of boulders (Figure 6). Only very small and isolated deposits of gravel are located at the margins and mouth of the channel.

The Plunkett Channel is separated from the trough in the hummocky terrain to the north by a small, though discrete area of hummocky terrain that exhibits little orientation in either its overall extent or in the pattern of hummocks and depressions. The flow that created the lobes and that which created the Plunkett Channel merged to define the eastern limit of the non-oriented hummocky terrain.

## Sedimentology

To determine the origin of the glacial landforms in the Rural Municipalities of Viscount and Wolverine it was necessary to determine the relationship between the external form of the features and their internal structure. Sedimentological information was gathered by logging available exposures located in active gravel pits and by collecting samples where appropriate. Comprehensive maps and grain size data produced by the Saskatchewan Department of Highways and Transportation were also used to provide information from sites that are not presently accessible.

**Site WOL-01:**

Site WOL-01 (SW15-34-24-W2) is located in an active portion of a large gravel pit near the southern margin of the lobate gravel deposits. The exposure consists of 3 m of multimodal gravel overlying till. The clasts are mainly granule and pebble size with smaller amounts of cobbles. There is a very low proportion of sand and smaller grain sizes and no sediments larger than cobbles. The deposit is poorly sorted and composed of angular to subangular clasts of predominantly carbonate and crystalline lithologies (Figure 7). With the exception of a slightly coarser upper unit that varies in thickness to a maximum of 0.5 m, the deposit shows very little variation in grain size from the surface to the base. Subtly defined,

*Figure 7: The sediments in the gravel lobes are multimodal gravels that range in depth from 2 to 4 m and are generally very uniform throughout the entire area. Paleoflow was from west to east (right to left in the photograph).*

large-scale cross-bedding indicates a palaeoflow direction from west to east.

**Site WOL-02:**

Site WOL-02 (S15-34-24-W2) is a large Saskatchewan Department of Highways and Transportation gravel pit that covers an area of nearly 3.5 $km^2$, though most of it is presently inactive. The gravel pit is located 0.5 km west of exposure WOL-01. Grain size data derived from test holes throughout the pit indicate that the deposit is composed of very uniform gravel that shows little variation either areally or with depth and that the observations made from exposure WOL-01 are generally representative of the area. Most of the deposit is composed of multimodal gravel that is dominated by granule to cobble sized clasts with very little sand and finer material or material larger than cobbles. Sand, where it does occur in significant amounts, is restricted to scattered pockets along the margins of the lobate forms. The only areas that contain boulder sized clasts are those that are composed of till to the surface with no overlying stratified sediments. These areas of till are located near the proximal end of the lobes and are associated with northwest-southeast trending grooves that extend into the area of the lobes. Variations in the thickness of the gravel correspond to the morphology of the lobate forms. The thickest units of gravel are at least 4 m and occur near the eastern margin of the lobes. The gravel occurs as a thin surface covering between the lobes and near their proximal ends in the west.

**Site WOL-03:**

Site WOL-03 (NE35-34-24-W2) is a rehabilitated Saskatchewan Department of Highways and Transportation gravel pit located near the northern margin of the gravel lobes. While no exposures are available, test hole data indicate that the sediments are very similar to those further south. Up to 4 m of very uniform, multimodal gravel rests on till. The thickness of the gravel varies from 0.4 m to 4 m with a general thickening of the deposit from west to east. Pockets of finer deposits that are composed primarily of sand are restricted to the eastern distal portion of the lobe. Test holes located within a groove that separates the gravel pit from the lobe to the south are composed of till with no overlying stratified material.

**Site WOL-04:**

Site WOL-04 (SE1-35-24-W2) is located 0.5 km north of site WOL-03 in a small gravel pit at the northern edge of the gravel lobes. Again, poorly sorted, multimodal gravel dominated by granule to cobble sized clasts rests on till. The lobe in this area has a west-east extent of less than 0.5 km. At the margins of the lobe the surface materials are composed of till. The morphology of the lobe is characterized by boulder covered west-east trending ridges and swales.

**Site WOL-05:**

Site WOL-05 (NE23-34-24-W2) is located on the flat surface of a large lobe approximately midway between the northern and southern limits of the lobes. The lobate forms in this area are large and very clearly defined. The lobes have steep eastern margins that drop steeply 10 to 20 m to the eroded till plain to the east. The gravel deposits are similar to other areas. They are poorly sorted, multimodal sediments dominated by granule to cobble sized clasts that overlie till. The western edge of the deposit is defined by large, deep scours that are paved with boulders. To the north and south, the lobe is separated from adjacent lobes by narrow grooves that are composed of till.

## Discussion

The lobate gravel deposits and the associated rudimentary anabranching channel system in the Rural Municipalities of Viscount and Wolverine are interpreted to be late-glacial features. While they are likely associated with deglaciation and an ice marginal environment, it is unlikely that they are associated with the large-scale, integrated system of proglacial lake and spillway development that characterizes the Interior Plains (Kehew and Teller 1994b). The gravel deposits do not have the characteristics of typical glaciofluvial facies that might be expected in such an environment. Commonly occurring subaqueous fans that develop as meltwater streams flowed into ice-marginal lakes are generally characterized by well-developed bottomset, foreset, and topset deposits (Reineck and Singh 1986). These sedimentary units are notably absent in the deposits in the study area. Nor do the lobate gravel deposits exhibit the proximal to the distal transition from coarse-grained glaciofluvial sediments to fine-grained glaciolacustrine sediments that are typical of deltas. Glaciofluvial subaqueous fan deposits also characteristically exhibit lakeward progradation and a pattern of migration that produces overlapping sediment lobes. The resultant feature is typically a narrow fan-shaped ridge (Reineck and Singh 1986) which again is in sharp contrast to the broad lateral extent of the gravel lobes and their minimal overlap.

Similarly, the lobate gravel deposits do not have the characteristics of subaerial deposition in an outwash plain or sandur deposit. These types of deposits begin where glacial meltwater streams form braided outwash plains and fans (Reineck and Singh 1986). As a stream fans out from a point source most of its coarse load is deposited in a low-slope flood fan. Where multiple meltwater streams form, individual fans may coalesce to produce a broad, gently sloping plain that is incised by the streams. The outwash plains, therefore, are composed of stratified glacial sediments transported and deposited in bars and channels by fluvial action. As with subaqueous fans, there is a marked, though not necessarily uniform, decrease in grain size and an increase in pebble roundness in a downflow direction away from glacial deposits. The outwash deposits are typically characterized by poor to moderate sorting, rapid alternation of beds that vary in degree of sorting, abundant scour and fill structures, and multimodal grain size distributions. With glacier retreat, outwash plains are deposited successively over glacial deposits (Reineck and Singh 1986).

Ice contact features composed of glaciofluvial stratified sediment, such as kames, also commonly occur in the Interior Plains. Kames are mound-like features that occur in isolation or in groups that are deposited near the ice margin under the influence of flowing water. The steep-faced mounds of stratified material are left on the landscape as the ice recedes. Typically the sedimentary structure of the kame deposits conform to the outer shape of the mound in a concentric peel pattern with abundant penecontemporaneous deformation structures (Reineck and Singh 1986).

In contrast to these commonly occurring types of features, the lobate gravel deposits in the Wolverine and Viscount area are notable for their marked uniformity in grain size diameter and distribution with little lateral or longitudinal variation. In addition, the gravels lobes do not have the distinctive elements of subaqueous or subaerial fans or ice-contact features in either internal structure or external morphology. The sediments in the lobes are weakly stratified, multimodal gravels that are primarily granule to cobble size with a small fraction of finer than sand-sized particles. The multimodal grain size distribution and lack of obvious bedding represents an environment of continuous deposition of bedload and suspended load with a continuum of sizes (Shaw and Gorrell 1991). The deposit represents a high energy facies with a powerful, unidirectional flow that rapidly deposited the gravel lobes during a single, short-lived event. There is no obvious evidence of a point source for the meltwater or of divergent and overlapping flows that would be expected in the case of a subaqueous fan or an outwash plains.

The lobes in this case were simultaneously formed, in contrast to the multiple lobes of fans that form in response to changing flow conditions. There is no geomorphic evidence that the deposition of the gravel was related to a strongly channelized flow.

In addition, there are no deformation structures in the sediments indicating that the subsequent glacial action evident in most ice contact features did not occur. The very sharply defined lobate forms at the eastern margin of the deposit indicate a very abrupt cessation of the formative flow. Deposition may have occurred in a subaqueous or subaerial environment. The preservation of the steep-fronted lobate form and the lack of evidence of reworking by fluvial or lacustrine processes subsequent to the deposition of the lobes suggests that deposition in a subaerial environment was more likely.

Further evidence for a high energy, turbulent, non-channelized flow of water as the formative mechanism of the gravel lobes lies in the boulder-paved depressions immediately upflow of the lobes. The orientation of the longitudinal depressions between the individual lobes indicates a flow direction approximately from west to east in accordance with the palaeoflow that deposited the gravel. Fluvial erosion is the only process that could have had the sorting capability to form the boulder lag. Furthermore, the size of the boulders indicates that the flow must have been very vigorous. The depressions are scour zones that are, at least in part, the source area for the material in the gravel lobes. The density of the surface boulder pavement indicates that large amounts of diamicton were eroded and removed from the area during the formative flow. Predominantly granule to cobble sized material with minimal amounts of finer sediments were immediately deposited forming the lobate features. The meltwater flow that scoured the terrain and deposited the gravel was not channelized, but instead was a sheet flow that was at least as wide as the 10 km north-south extent of the scoured area.

The area of gravel deposition is very sharply defined indicating an abrupt change in flow conditions that caused a sudden decrease in the competence of the flow to carry its sediment load. Such conditions could arise from the sudden release of constrained water and subsequent flow expansion. There is no geomorphological evidence to suggest that meltwater was released by the breaching of morainal deposits. Furthermore, the separation of the area of scouring from proglacial lake deposits to the west by a topographic high of hummocky terrain eliminates the catastrophic drainage from a proglacial lake as the source of the flow. Alternatively, the required conditions of flow could have been produced by the release of a subglacial, englacial, or supraglacial reservoir of meltwater from the ice sheet. Such a flow moving toward the ice margin, under conditions of high pressure and high velocity, would be expected to be highly erosive. Upon reaching the ice margin, the meltwater would continue unrestrained in a jökulhlaup-type flow. Sharpe and Cowan (1990) described comparable conditions in their interpretation of stratified end moraines in northwestern Ontario where widespread outbursts of subglacial meltwater are hypothesized to have flowed into glacial Lake Agassiz, depositing broad and coalescing subaqueous lacustrine fans.

The source of the meltwater flow that deposited the gravel lobes in the Wolverine and Viscount area is difficult to determine due to the lack of geomorphological evidence. Such evidence would not necessarily exist if the source of the water was subglacial or englacial. The erosive activity of the water, however, would be expected to be in evidence in areas adjacent to the zone of intense scouring and subsequent deposition. The variation in the character of different zones of hummocky terrain upflow of the gravel lobes may also be due to the subglacial meltwater flow. The tract of hummocky terrain immediately west of the gravel lobes is characterized by a dense, poorly integrated network of small-scale, rudimentary channels and a larger groove and ridge morphology at its northern margin. The overall orientation of the channels and the groove is generally from west to east. Most significantly this area truncates a zone of higher elevation and higher relief hummocky terrain to the north that has prominent north-south trending lineations. The truncation of the northern zone of hummocky terrain suggests that the landscape was produced by erosional processes. The development of the rudimentary channels and the relationship between the hummocky terrain and the zone of scouring and gravel deposition suggests that fluvial processes were also responsible for the formation of the hummocky terrain. There are no sedimentological data available from the hummocky terrain in this portion of the study area to confirm that the hummocks are in fact erosional features. Investigations in other regions (Rains et al. 1993; Munro et al. 1996; Grant 1997) however, do suggest that subglacial fluvial erosion was a possible formative agent of hummocky terrain.

The surface on which the gravel lobes were deposited provides further indications of the repeated occurrence of turbulent sheetflows of subglacial meltwater. The gravel lobes are superimposed on a north-south trending tract of eroded till plain. The plain is very flat and almost featureless with the exception of very low relief, slightly arcuate transverse ridges and shallow, circular scours. The scours are preferentially located within swales between subparallel ridges. The ridges are interpreted to be remnants resulting from the erosion of the intervening swales. The dense network of small, shallow, generally circular scours are paved with boulders indicating a very high energy, turbulent formative flow. The absence of surface sorted sediments indicates that the eroded material was completely removed from the area.

The only significant subsequent modification of the till plain was the incision of a series of small-scale, shallow, subparallel meltwater channels that trend northeast to southwest. The meltwater channels cross cut the transverse lineations and therefore formed at some time after the ridges. The meltwater channels contain modern lakes and ephemeral streams that generally do not drain out of the area. The development of the meltwater channels may be associated with deglaciation and a progressively westward retreating ice lobe as interpreted by Edmunds (1962) and Greer and Christiansen (1963). A subglacial flow of meltwater, however, cannot be discounted as a possible origin for the channels. Regardless of the process that incised the meltwater channels, their development occurred prior to the event that scoured the terrain to the west and deposited the gravel lobes. The gravel lobes are superimposed on portions of the meltwater channels, disrupting the southwestward flow of water. Reincision of the channels did not occur subsequent to the deposition of the gravel lobes.

The formation of the Plunkett Channel represents the progressive channelization during the waning flow stage of the initial subglacial sheet flow event. Shoemaker (1992a, 1992b) hypothesized the transition of subglacial sheet flows to tunnel channels due to the inherent instability of sheet flows induced by lateral pressure gradients. Sjogren and Rains (1995) describe a network of integrated channels in east-central Alberta that were interpreted to have formed in a subglacial environment under hydrostatic pressure by a single, highly erosive, meltwater flow. The channels are characterized by varying degrees of anabranching and highly variable sizes, shapes, and orientations. Longitudinal grooves, abundant boulder deposits, composite and residual streamlined hills indicate formation by the flow of highly turbulent water. The position of the channels on top of a modern drainage divide, evidence of reverse gradients, and localized glaciotectonic features induced by pressure from overlying ice were interpreted to indicate a subglacial origin for the channels.

The Plunkett Channel is a short, relatively broad meltwater channel which was formed by the same event that deposited the gravel lobes. The indistinct head of the channel is separated from lacustrine deposits to the west by a topographic high that does not appear to be breached at any point along its length. The flow that eroded the Plunkett Channel, therefore, was likely initiated in a subglacial or englacial environment. In contrast to the head of the channel, the distal portion is deeper and has better defined margins. The floor of the channel in all areas, however, is characterized by densely spaced hummocks and depressions and smaller, poorly defined subchannels that were formed by more intense erosion. The Plunkett Channel widens abruptly at its mouth and diverges into a series of more distinct subchannels that are separated by large, streamlined erosional remnants and a narrow zone of gravel deposition. The gravel deposits are superimposed on the northeast to southwest trending meltwater channel that was previously incised into the adjacent till plain. The gravel deposits at the mouth of the channel quickly terminate where they are superimposed on the eroded till plain. These characteristics of the mouth of the Plunkett Channel coincide with comparable aspects of the scoured zone and gravel lobes to the north.

## Summary and Conclusion

The gravel lobes in the Rural Municipalities of Wolverine and Viscount represent a depositional event that is related to the larger scale erosion of the immediate upflow landscape by a turbulent sheet flow and the erosion of the laterally adjacent Plunkett Channel by a highly turbulent channelized flow. The sediments in the lobes indicate a depositional environment of high velocity and rapid sedimentation. The source for the gravel was the glacial sediments immediately upflow. The most intense erosion occurred at the western margin of the lobes that resulted in large elongate scours that are paved with boulders. Less intense erosion produced the hummocky terrain at least as far as the higher ground that separates it from the hummocky terrain and lacustrine deposits approximately 25 km to the west. The width of the sheet flow that eroded the landscape was at least as wide as the zone of gravel deposition. The gravel lobes appear to mark the northern extent of the sheet flow as indicated by its relationship to the immediately adjacent tract of older hummocky terrain to the north. The southern limit, however, is more difficult to discern. It may correspond to the Plunkett Channel, or the Plunkett Channel may have been incised into a portion of the landscape that was influenced by the sheet flow. South of the Plunkett Channel the effects of the sheet flow may grade imperceptibly into the surrounding hummocky terrain. The Plunkett Channel represents channelized flow that would be expected to occur during the waning flow of the sheet flood.

The geomorphological relationships between the various elements of this landscape provide evidence for the likely sequence of events that shaped the landscape. The fluvial erosion of the till plain upon which the gravel lobes and mouth of the Plunkett Channel are superimposed occurred when ice covered the region. Subsequent to the creation of the eroded till plain, very little further geomorphic activity shaped the landscape until the deposition of the gravel lobes. The northeast to southwest trending meltwater channels are very shallow and narrow and were likely formed as meltwater drained along a retreating ice margin or at some time under the ice prior to the deposition of the lobes. The lobate form of the gravel deposits indicates a very abrupt change in the flow conditions that eroded the hummocky terrain and the scours. They represent conditions of sudden flow expansion and a consequent reduction in the capacity for the flow to transport its sediment load. Such conditions might be expected to develop as water driven under hydrostatic pressure in a subglacial environment issued from the ice front into a subaerial or subaqueous environment. Given this interpretation, the position of the ice front would, therefore, correspond to the position of the zone of intense scouring and the proximal end of the gravel lobes. Similarly, the flow through the Plunkett Channel was highly erosive through the portion that was incised in a subglacial environment. Erosional remnants, differential scouring and a dense boulder lag throughout the channel with minimal deposition were caused by a highly turbulent flow. As the channelized flow reached the ice margin, abrupt flow expansion caused a reduction in velocity and the deposition of the coarsest fraction of the sediment load. The finer material was transported away from the area by the meltwater flow event.

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# Coping responses to the 1997 Red River Valley flood: research issues and agenda

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***Abstract:*** Prevention and mitigation of floods and their associated losses require extensive research, investment decisions, maintenance and modifications of flood-control infrastructures, and preparedness at the regional, local, and individual levels. The experience of flood-hazards management in the North America has shown mixed results: the flood frequency declined during the last four decades but the economic losses continued to rise. Several analysts link the 1993 floods of the Midwest to the major structural intervention in the region. The flood diversions also often cause harmful effects upon the floodplain inhabitants by influencing flood levels in areas which are not normally flood-prone. The increasing vulnerability of the floodplain inhabitants raises new questions and issues. Based on the experience of both urban and rural communities of the Red River valley, this research attempts to determine the most significant research agenda for the late 1990s; it explores and reviews the current research issues and problems in flood-hazards studies. Focus-group based interviews and discussions in some selected communities were conducted to obtain necessary data. The study concludes that although flood-loss mitigation measures were in general successful, institutional efforts to minimize the human cost, especially in terms of psychological distress and coping with uncertainty, were not adequate. Public participation in the emergency decision-making process was absent or minimal. Finally, future research needs and directions for studying floods in the Red River basin of USA and Canada are explored.

## Introduction

The Red River plain in Manitoba has a high natural potential for flooding (Way *et al.* 1997) as it is located on a former glacial lake bottom and is surrounded by the Southwest Uplands and

Precambrian Shield (Corkery 1996). The rising water in the Red River valley during April 1997 alarmed emergency experts and managers in Manitoba, and they declared an all-out "war" against it. The so-called "flood of the century" approached Manitoba like a threatening tidal wave in April and then ebbed in May. This image of encroaching floodwater was matched by a similar flood and ebb of concerns in the minds of Manitobans regarding the safety of life and property. The estimated flooded area was over 1,836 square kilometers (Figure 1). Water levels in the valley were the highest they had been in nearly 150 years, while the economic loss due to the flood of 1997 was measured in hundreds of millions. The effect of the devastation left by the flood of 1997 remains evident throughout the Red River valley. Any lessons learnt from this disaster are of great importance in preparing for, and coping with, future floods.

In terms of human response, the war against the rising water was fought on all fronts. Altogether, more than 19,000 people were evacuated from rural Manitoba and 8,900 from the City of Winnipeg. Most evacuations were made prior to the peak discharge in individual localities and were based on flood forecasts. The general public response to the 1997 flood was effective. As shown in Figure 1, a good portion of the City of Winnipeg that was under water during the flood of 1950 was not flooded in 1997. Many probabilistic factors associated with nature were key elements in this success. However, despite the general success in protecting Winnipeg -- the main city of the province -- there were shortcomings in the response strategies. Some communities were devastated by the vigor of the flood, particularly those which were not protected by a permanent ring dike. It has also been argued, chiefly by residents of some of rural communities, that they were flooded because water was diverted to save the City of Winnipeg. This implies that the flooding of some communities may have been caused by human action. Resentment and disputes arose in local communities concerning the strategic and tactical approach to emergency flood response offered by the regulators.

In effect, the 1997 flood provided a new impetus for rethinking and redesigning many facets of human responses to floods and other similar types of emergencies and disasters. Research aimed

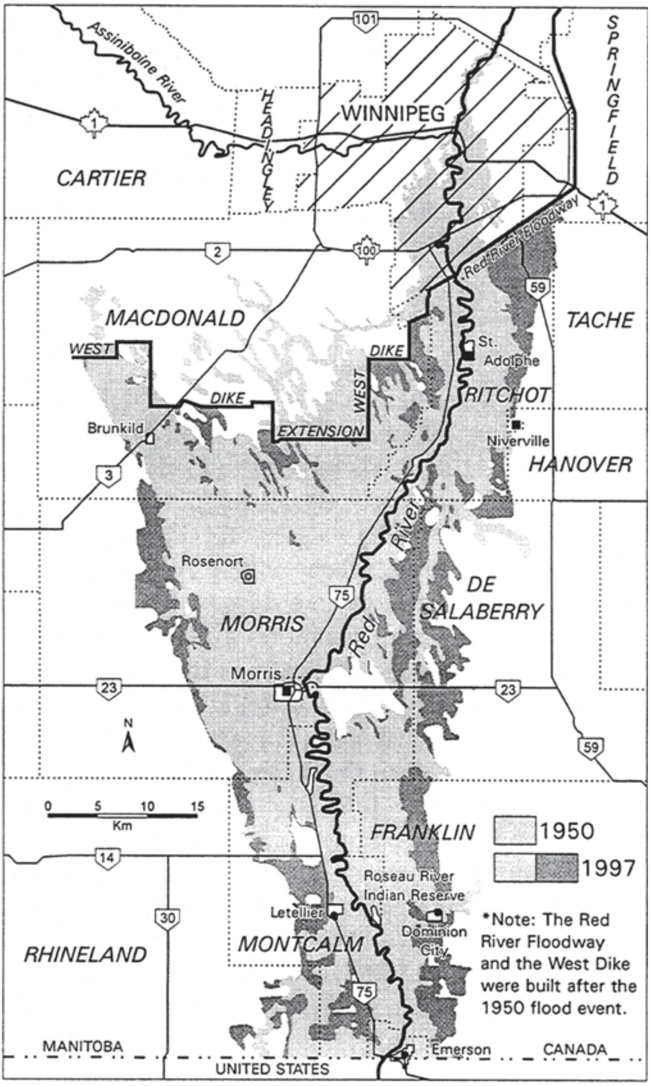


***Figure 1:*** *Areas flooded by the Red River in 1950 and 1997 (Source: Modified from* Areas Flooded by the Red River in 1950, 1979, 1996, and 1997 Map *[Winnipeg: Manitoba Natural Resources, Water Resources Division, 1997])*

at determining the methods and issues for effective prevention and mitigation of future disasters is a pressing need. The general aim of this paper is to determine the key research issues, with a focus on social dimensions. The specific objectives of this paper are threefold: (i) to identify the planning and implementation problems encountered during, and issues arising from, the 1997 Red River flood experience; (ii) to determine social scientific research agenda; and (iii) to explore directions for future research on flood and disaster mitigation and management.

## Preparedness and Planning: Problems and Issues

**Flood Prediction and Warning:**

Manitoba's Water Resources Branch, Department of Natural Resources, uses an index type of model to predict the Red River runoff volume and peak discharge. The model used for runoff outlooks is founded on statistical relationships for the American portion of the watershed, considering the entire area within the United States as one basin for computation. Autumn soil moisture is used to calculate an antecedent precipitation index (API) based on weighted monthly precipitation from May to October. Other variables employed are the cumulative winter precipitation that includes effective spring precipitation, and a degree-day type melt index. A winter temperature index is used to estimate sublimation losses and soil temperatures (Warkentin 1997).

Flood routings from Emerson to Winnipeg are executed employing the Muskingum method. Although this procedure performed very well for the 1997 flood in Manitoba, in general it did not enable accurate predictions of flood levels on the floodplain well away from the river. Forecasting overland flows on the floodplain was extremely difficult due to the lack of historical data and the unknown effects of the road and railway network. A dynamic routing model needs to be developed to address this problem (Simanovic 1997; Warkentin 1997). Other alternative models should also be developed and tested.

**Data Management:**

As a result of the recent proliferation of data procurement techniques and dissemination technologies, there were ample data available on various aspects of flood risks and of associated issues before prior to the occurrence of the 1997 flood (Towle 1997). However, because they were not available in a systematic manner and related to meet specific needs, logistical resources and management decisions could not achieve their full potential. How should this task be coordinated? Due to the incompatibility of goals and mandates of various government and nongovernment agencies, the task will not be easy. In order to achieve a higher level of efficiency in data and information management responsible institutional measures will be required. This aspect deserves serious research attention.

**Flood Prevention: Planning and Management:**

Existing flood planning strategies in Manitoba involve both structural-control works and organizational methods. The present flood control works consist of the Red River Floodway, the Portage Diversion, the Shellmouth Dam on the Assiniboine River, the primary diking system within the City of Winnipeg, and community diking around settlements in the valley (Rannie 1996). During the 1997 event, the floodway diverted flows around the City of Winnipeg from 21 April to 3 June 1997. The peak discharge at the floodway was at 1840 cubic meters per second on 4 May 1997, and within Winnipeg the peak of 2265 cubic meters per second occurred on 1 May 1997.

The west dike of the floodway inlet control structure, which impedes floodwater from bypassing the floodway and entering Winnipeg from the west, required rapid extension and elevation. Along with the reinforcement of 15 kilometers of the existing west dike, 25 kilometers of new dike were constructed in just five days. Overall, due to the relative success in flood forecasting and the effectiveness of the flood control works, property and other economic damage was minimized relative to the damage potential. Still some communities were devastated by the flood; an example is the town of St. Agathe which was not protected by a permanent ring dike. As indicated earlier, it has also been argued by some that diversion of floodwater to save the City of Winnipeg caused the flooding of rural communities. That is, flooding of some communities was the result of human action. A recent study, prepared by the Manitoba Water Commission, confirms that the operation of the Red River floodway contributed to excessive flooding in Grande Pointe (Kuxhaus 1998). The ethical responsibility to compensate the victims is a crucial policy issue; in response the Commission's report, the provincial government announced a one-time removal of the $100,000 compensation cap for flood victims and increased flood-proofing assistance for homeowners from $30,000 to $60,000.

The above stated conflicts resulted in some discontent among the local first responders. This situation was observed by the investigators during a field visit to the communities of the Red River valley. A key person responsible for local municipal emergency response stated:

> . . . just when you are done with putting up a dike around your property you are forced to leave. Someone was needed to maintain the dikes, run the pumps. All your effort, time, money, assistance from neighbors and volunteer works were rendered meaningless by the force evacuation order [by Emergency Management Organization].

It appears that the dispute stemmed from the issue of authority over decision-making (Figure 2). As shown in Figure 2, the institutional roles and interagency relationships are depicted in the administrative structure of emergency preparedness in the Province of Manitoba. This raises the question: who in the current authority structure has the legal right to decide? Certainly, local municipalities are responsible for the first response in emergencies (Figure 3). Apparently all the rural municipal mayors/reeves and councils were involved in the management of the emergency that was created by the 1997 flood in the Red River valley. Several key questions are relevant here. Were the chief executives of the rural municipalities (mayors/reeves and the councils) effectively prepared and did they play their proper roles in the recent emergency? Did they use the essential components of emergency response (i.e.,

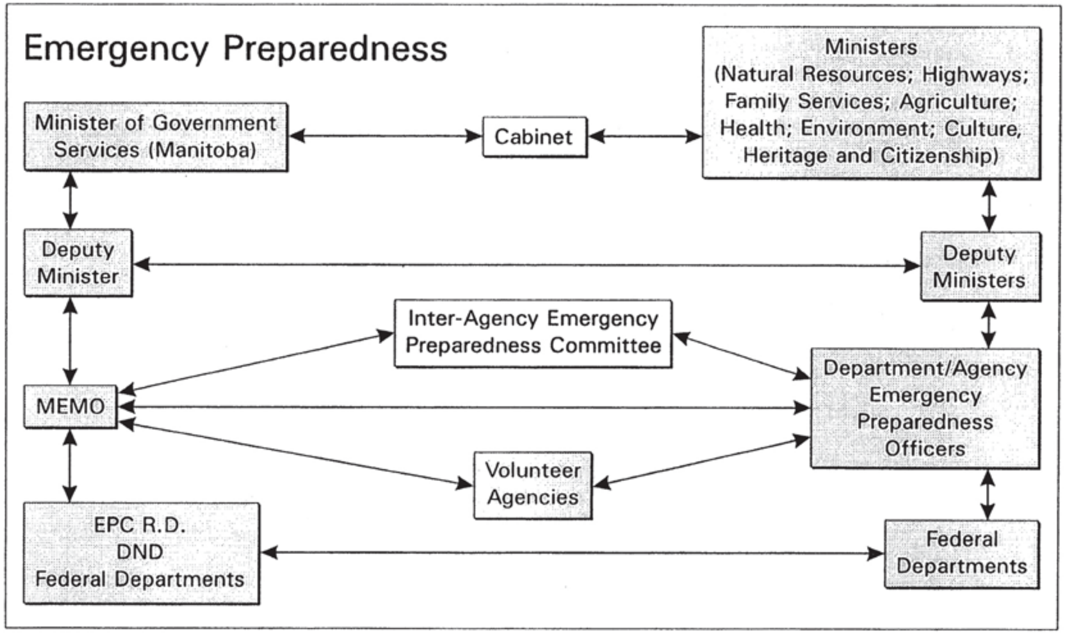


***Figure 2:*** *Administrative structure of emergency preparedness in Manitoba (Source: Modified from H. Clayton,* "Coordination and Decision Making" *in* Red River '97: The Flood of the Century - Causes, Impacts, Managment *[Winnipeg: Canadian Water Resources Association, 1997])*

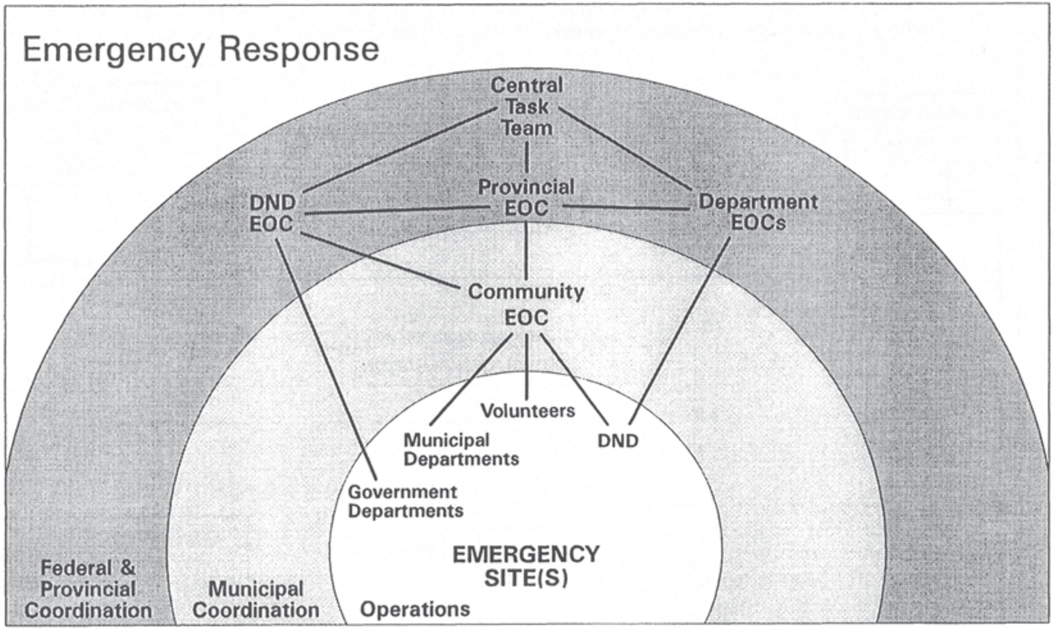


***Figure 3:*** *Emergency response system during the 1997 Red River Flood (Source: Modified from H. Clayton,* "Coordination and Decision Making" *in* Red River '97: The Flood of the Century - Causes, Impacts, Managment *[Winnipeg: Canadian Water Resources Association, 1997])*

emergency plan, communication system, a call-out system, authority structure) effectively? Was there an adequate exchange of ideas, plans and decisions through different levels of public agencies?

The Manitoba Emergency Management Organization (MEMO), the provincial disaster management agency, provides necessary support to the local communities when local capacity is overwhelmed by an emergency. The emergency response concept, according to the MEMO, states that:

> responsibility to respond is at all levels starting with those closest to the emergency. As the magnitude of the event surpasses the capability of a particular individual(s), organization or level of government to respond, responsibility moves to the next logical level. Involvement of the next level of response does not remove the responsibility or authority of those levels closer to the emergency (cited in Epp, Haque and Peers, 1998).

In general, emergency management during the 1997 flood followed a "command-control" or a "top-down" approach (Figure 2). The Provincial Government Flood Management Task Force, headed up by the Water Resources Branch with representatives from the City of Winnipeg, Manitoba Hydro, the University of Manitoba, the Canadian Armed Forces Engineering Division and Acres-Wardrop engineering consultants, was set up in April. One of the responsibilities of the task force was to identify potential emergency situations or developments to communicate these to the Emergency Measures Organization (EMO), the City of Winnipeg, and the municipalities, and to initiate the required evacuation and repopulating measures.

The command-control approach has several limitations. One is the incipient urban bias in policy design and implementation. Emergency measures undertaken during the April-May flood of 1997 generated some bitter criticism of the province's response in some of the communities in the Red River valley (e.g., Grande Pointe, Ste. Agathe, Macdonald Municipality, and St. Jean Baptiste). This is indicative of different perceptions of the flood as an emergency and local expectations of appropriate response measures. Another limitation in the command-control approach was its failure to minimize gaps in public perception and knowledge of risk assessment. If emergency policies aim to succeed, effective public involvement is required for the pre-disaster, disaster, during and post-disaster planning. The issue of public participation will be addressed in a later section.

**Emergency Authority Implementation:**

Contrary to a common perception, people living in flood-prone areas are not helpless victims. They can defend themselves by using common sense and past experience to form a general perception of the hazard. Despite this documented assertion (Kuban 1994), emergency managers tend to treat the people in flood areas as helpless victims who need rescuing. The common person's understanding of risk of flood-hazard (i.e., perceived risk) differs significantly from the risk calculations made by experts (i.e., objective risks).

Planning and implementation decisions, based on mathematical and statistical models and on physical parameters, important as they are, appear to ignore completely the main players in emergency response and management -- the people. These actual resource-users often become another set of statistics -- as victims. Community members in the Red River valley alleged that the emergency managers appeared at their door as an authoritative rescuer "with a Big-Brotherly attitude." This attitude disregards the needs of the people as they understand them. The resentment about Manitoba Emergency Management Organization's mandatory evacuation order reflects such differences in needs assessment (Heinrichs 1997).

## Human Dimensions: Risk Perception and Local Views

**Risk Perception and Planning:**

Risk perception and subsequent preparedness for emergencies correlate with culture and "worldview." The pioneering work of Douglas and Wildavsky (1982) showed that sociocultural processes largely govern the selection of risks; thus cultural selection of risk is not linked directly to objective risk measurements or the physical reality of the risk. For this reason, cultural attitudes towards the environment must be identified in order to develop multi-jurisdictional emergency preparedness plans.

In deciding on the mandatory evacuation order, the MEMO reasoned that while people's lives were in danger their priority was still to save their property. The authors gathered that the authorities even threatened coercive measures if residents did not evacuate voluntarily (Heinrichs 1997). This forced evacuation was blamed for property damages during the flood. "When experts from the MEMO decide for us what to do, they must bear the responsibility for the consequences; along with authority comes responsibility," asserts Herm Martens, the Reeve of Rural Municipality of Morris. Martens also points to the manner in which the mandatory evacuation order was passed to the municipalities. He suggests that since the letter which carried the order was not signed by anyone from MEMO, no one wanted to take responsibility.

Apparently, there was also an element of misunderstanding resulting from misinformation or lack of timely communication. Whatever the reason, a psychosocial barrier was created between the people of the valley and emergency managers. This is not desired by either party. This barrier could have been avoided by giving the residents a sense of partnership in managing the emergency. Because there is a divergence in perceptions of risk and emergencies between the general public and the experts (including scientists, regulators, and managers), "risk communication" plays a significant role in effective response to emergencies. Generally, "risk communication" has been a one-way process that develops and delivers a message from the expert or agency to the public. In recent years, the recommended approach has changed to a process of interactive exchange of information (Kasperson and Stallen 1991). This process is necessary because recipients are uncertain about the accuracy of the risk-related message due to a past history of deceit or lack of credibility, and a self-serving or selective use of information by those in authority. An assessment of the effectiveness of risk communication is thus essential in order to determine the state of emergency preparedness of a community. Also, a research project should address the variability in perception of, and response to the flood hazard, as well as the attitude (acceptance and/or opposition) towards government emergency policies among the local first responders. Factors that might differentiate local first responders on the basis of shared values, beliefs, knowledge and life experiences should also be considered.

**Local Experience and Adaptation:**

Under the present legal and constitutional rules of Canada, the responsibility for initial action in emergencies lies with the individual (Emergency Preparedness Canada 1993) though involvement of the various levels of government are common in most large scale emergencies and disasters (Figure 3). Thus, the risk perception of individuals, their interest and access to information, and their logistical and psychological preparedness to respond have a profound effect upon the quality of emergency preparedness. These areas need further investigation.

Community or local-level adaptation to risks is by and large associated with prior experience with a similar event. Societal experience often leads to better preparedness in anticipating natural disasters. Examination of past experiences, past coping strategies, the type of emergency responses and the role of involved agencies, problems encountered, and post-event modification of emergency plans at the community level would help to understand the level of coping ability and to determine the areas where improvement could be made. An essential part in emergency planning is to establish the status and awareness of emergency preparedness within various rural communities. Empirical evidence suggests that prior beliefs, past experiences, emergency management, planning and training all influence the subsequent evaluation of, and preparation for, environmental hazards. Research on disaster management, therefore, needs to address important issues related to preparedness and response capabilities at the local first responder level in the disaster sites.

Theoretically, local-level units such as rural municipalities are supposed to develop their own emergency preparedness plan according to the perceived needs and objective environmental and social conditions in the area. As infrequent, low-probability events are commonly underestimated by individuals and often by collectives, there appears to be a general failure to undertake the required initiative and to allocate resources for disaster mitigation measures and emergency preparedness. Many factors may be used to explain the failure of disaster and emergency preparedness; these may include cognitive dissonance; poor efforts and results in public education; personality conflict in the local administration; and the lack of finance, capital equipment, and human resources. The significance of these factors needs to be spelled out for policy formulation.

**Conflicting Goals and Interests:**

Furthermore, the goals and interests of regulators, managers, and resource-users, are not always homogeneous. This situation can lead to conflicting actions. A common conflict is between the public/social goal of saving lives and public assets versus the individual goal of saving personal property and assets. Also, when public decisions are taking into consideration societal benefits and the costs of actions (such as discharge diversion, evacuation, compensation to certain groups of disaster victims), they may increase the susceptibility of certain communities and individuals to disasters. The grievances of the affected communities may translate into political and social disorder affecting productivity and economic growth. For example, a dispute developed between the local first respondents and the Provincial Emergency Managers (PEM), and between other agencies involved in the coordinated interagency forum for emergency response (Werier 1997; Moncrieff 1997). This reflects different perceptions of a flood as an emergency and different expectations of appropriate response measures at different levels of the government. On the whole, these disputes were resolved without any visible incidents.

A process of informed consent through public involvement when undertaking non-structural measures to prevent and mitigate floods may be the way to deal with disputes. But how to achieve this goal? How to put the process into operation is another major question. Future research should aim at addressing these issues.

## Public Involvement

While the "public hearing" encourages people's participation in planning, the process is not very effective. People are asked to express their opinion of a project after a decision has already been made. The attitude is "agree or not, we are going on with the plan." This in turn implies that the expert "knows best." There is no way to express doubt about the expertise of hydrologists, geologists, engineers and other scientists. As well, there is the possibility that such an attitude will close the door to sharing other people's knowledge and experience. In theory, public-decision making processes encourage "people's participation" in all crucial social matters. If people are to bear some responsibility in the matter of damage control, they should be allowed to share the decision-making process and the planning for their own well-being. In many instances, they are the first to respond to and manage emergencies.

## Concluding Remarks

Disagreements about various aspects of emergency measures between the experts, the people, and various responding agencies appears not uncommon in Canada. A "command-control" type of disaster management (see Figures 2 and 3) generates differences and conflicts among the stakeholders. The net result of these disagreements are not conducive to the successful management of emergencies. Dominant social scientific studies of perception of, and response to, hazard risk identify crucial differences in the judgments of risk by experts and the general public. Empirical studies have shown that human adjustment and response to environmental hazards (both natural and technological) are influenced by the characteristics of the hazard itself, and by people's perception, experience, and socioeconomic status (Slovic *et al.* 1980; Hewitt 1983).

It is imperative to understand the level of awareness of, and attitude towards, disasters and disaster management in Manitoba. It is essential to establish the status and awareness of emergency preparedness within various rural communities in the Red River valley in the aftermath of the so-called "flood of the century." In order to understand the nature of and variability in the perception of the flood hazard, and the attitude (acceptance and/or opposition) towards government emergency measures and policies within the population, factors that might differentiate individuals (shared values, beliefs, knowledge and life experiences) must be considered. Researchers should also ask what role each local community should play and how to use the knowledge of the general public to augment that of the "experts."

## Acknowledgements

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# The impact of depression/detention storage on the spring freshet, Clear Lake Watershed, Riding Mountain, Manitoba

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**R.A. McGinn, Brandon University**

***Abstract:*** Snowmelt studies in the Clear Lake watershed suggest that detention storage in small lakes, beaver ponds and wetlands can account for a significant attenuation in the spring lake levels. This project examines the impact of detention storage volumes retained within the Aspen Creek and Octopus Creek sub-basins of the Clear Lake Watershed. Detention storage in the Aspen Creek watershed is associated with numerous beaver pondings and beaver influenced small lakes and associated wetlands. In the Octopus Creek sub-basin small lakes represent the greatest volume of stored water and beaver pondings are of relatively little significance.

Mean annual water equivalent depth of snow measured in the Aspen Creak watershed is 12.0 cm and represents approximately 880 $dm^3$ of potential runoff. High water marks recorded in beaver pondings indicate that an additional 80 cm depth of runoff could be stored in the Aspen Creek beaver ponds throughout the summer. This value represents approximately 64 $dm^3$ of runoff. Consequently detention storage in beaver ponds represents approximately 7% of the potential spring runoff.

A more conservative 10 cm rise in water levels documented for small lakes and wetlands in Octopus Creek watershed represents approximately 675 $dm^3$ storage value. Mean annual water equivalent depth of snow measured in the Octopus Creek watershed is 9.0 cm and represents approximately 3089 $dm^3$ of potential runoff. In the Octopus Creak watershed detention storage accounts for 22% of the potential snowmelt runoff.

## Introduction

The Clear Lake Watershed is centrally located on the Riding Mountain Uplands in southwestern Manitoba (Figure 1). The

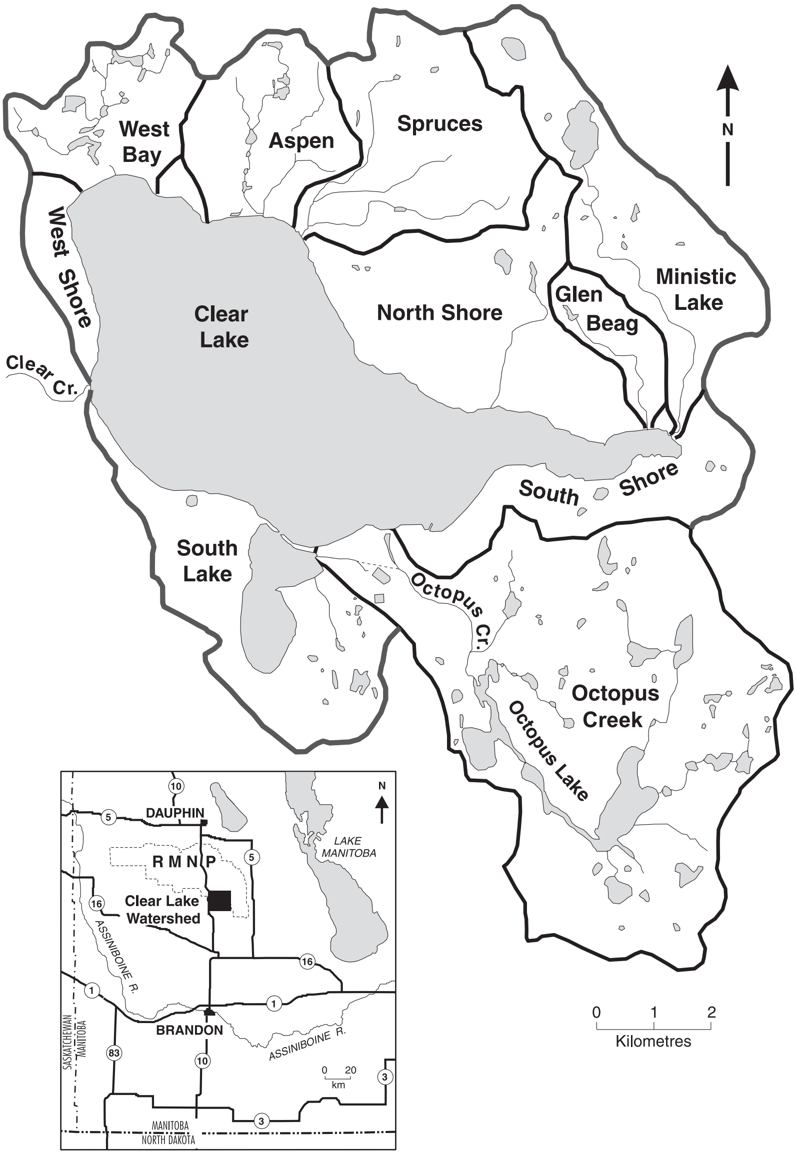


***Figure 1:*** *Clear Lake watershed.*

watershed drains an area of 142.18 $km^2$ of which over 56 percent is located within Riding Mountain National Park. Approximately 46.0 $km^2$ of the Clear Lake watershed is classified as standing water and wetlands. This value represents 39% of the contributing drainage area for Clear Lake.

Snowmelt studies (McGuire 1997, McGinn and Rousseau 1997) in the Clear Lake watershed suggest that both detention storage and depression storage in beaver ponds, small lakes and wetlands can account for a significant attenuation in the spring lake levels.

Depression storage is defined as the volume of water (precipitation or snowmelt) required to fill all natural depressions in a watershed to their overflow levels. Depression storage does not contribute to runoff but ultimately infiltrates or evaporates (Lo 1992). Detention storage, a term often confused with depression storage, is the water on the ground above the overflow level of depression storage (Lo 1992) and includes surface and channel detention but does not include depression storage.

## Objective

This paper focuses on the Aspen Creek and Octopus Creek sub-basins of the Clear Lake Watershed and examines:

1. depression storage volumes,
2. the significance of beaver pondings to the depression storage, and
3. the impact of depression storage on the snowmelt freshet.

## The Study Basins

Aspen Creek watershed is located within the boundaries of Riding Mountain National Park (Figure 1). This sub-basin of the Clear Lake watershed has a drainage area of 7.325 $km^2$ (Table 1). Approximately 86% of the total area is covered in conifer, mixed and aspen forest while open meadows represent 3.16% of the cover. Surface water accounts for 8.74% (0.640 $km^2$) of the total area and wetlands, an additional 2.22% (0.163 $km^{2)}$. There are no developed lands or cultivated fields in the Aspen Creek watershed.

***Table 1:*** *Cover types in the Clear Lake watershed: the Aspen Creek and Octopus Creek sub-basins.*

| Surface Cover | SUB-BASINS Aspen Creek | Octopus Creek |
|---|---|---|
| Conifer (km$^2$) | 2.934 | 1.650 |
| % Sub-basin | 40.06 | 4.57 |
| Mixed (km$^2$) | 3.248 | 3.637 |
| % Sub-basin | 44.34 | 10.08 |
| Deciduous (km$^2$) | 0.108 | 10.510 |
| % Sub-basin | 1.48 | 29.14 |
| Open (km$^2$) | 2.31 | 1.362 |
| % Sub-basin | 3.16 | 3.77 |
| Agriculture (km$^2$) | 0.000 | 10.463 |
| % Sub-basin | 0.00 | 29.00 |
| Wetlands (km$^2$) | 0.163 | 4.485 |
| % Sub-basin | 2.22 | 12.43 |
| Water (km$^2$) | 0.640 | 2.268 |
| % Sub-basin | 8.74 | 6.29 |
| Developed (km$^2$) | 0.000 | 1.699 |
| % Sub-basin | 0.00 | 4.71 |
| TOTAL (km$^2$) | 7.325 | 36.073 |
| % Sub-basin | 100.00 | 100.00 |

Depression storage in the Aspen Creek watershed is associated with 24 beaver pondings constructed along the natural water courses and 13 beaver influenced small lakes and associated wetlands (Figure 2). An index of beaver activity within a watershed was developed by calculating the number of beaver ponds per unit area of watershed. In the Aspen Creek watershed the beaver pond density index was calculated to be 5.05 ponds $km^{-1}$.

Approximately 90% of the Octopus Creek watershed is located outside the park boundaries (Figure 1). This sub-basin of the Clear Lake watershed has a drainage area of 36.073 $km^2$ (Table 1). In contrast to the Aspen Creek sub-basin, only 43.79% of the Octopus Creek drainage area is forest covered, predominantly aspen woodlots. One-third of the total area of the Octopus Creek watershed is developed land and cultivated fields. Surface water covers 6.29% (2.268 $km^{2)}$ of the total drainage area and wetlands account for an additional 12.43% (4.485 $km^2$).

Octopus Lake, other small lakes and large wetland areas are major depression storage features in the Octopus Creek watershed (Figure 3). There are 14 beaver pondings in this watershed. These are of relatively little significance to the total volume of depression storage. Two dams positioned at the outlet of Octopus Lake, however, may be of importance, in that they act as a lake level control structure. The beaver pond density index for the Octopus Creek watershed is 0.388 ponds $km^{-1}$.

In summary, the two sub-basins of the Clear Lake watershed are characterized by different types of depression storage. The Aspen Creek watershed is a natural watershed in which depression storage is significantly influenced by beaver activity. The Octopus Creek watershed represents a developed drainage basin in which depression storage occurs in Octopus Lake, other small lakes and wetlands.

## Procedures and Methodologies

The Manitoba Forest Inventory Cover Maps (1983) derived from 1979 aerial photographs, identify forty-four cover types in the Clear Lake watershed. These recognized cover types have been

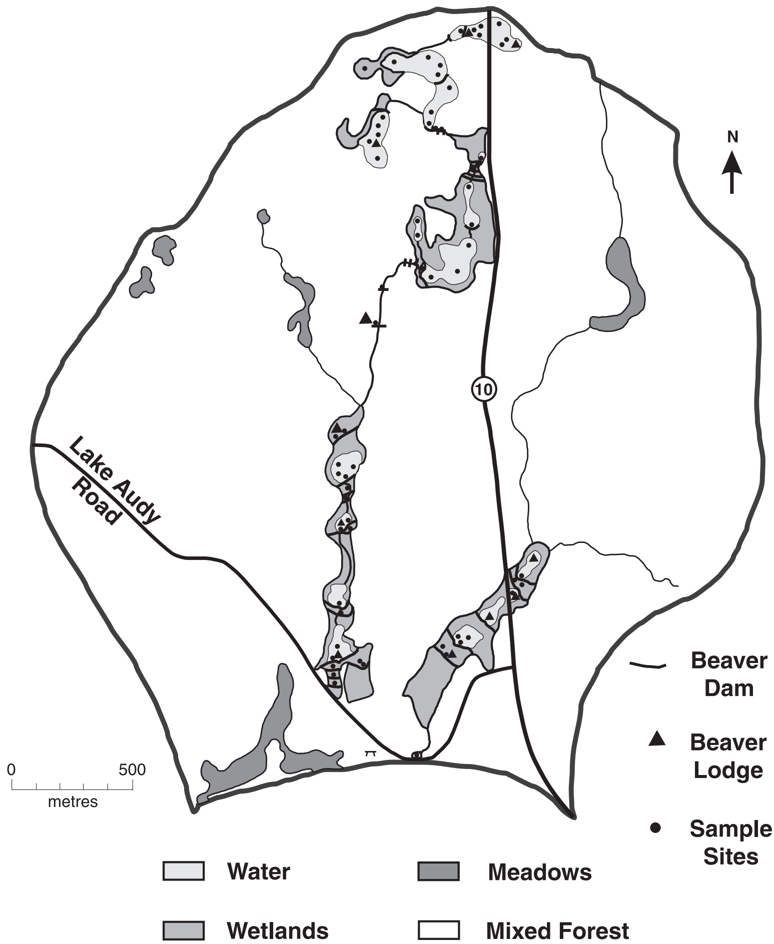


***Figure 2:*** *Depression storage in the Aspen Creek watershed.*

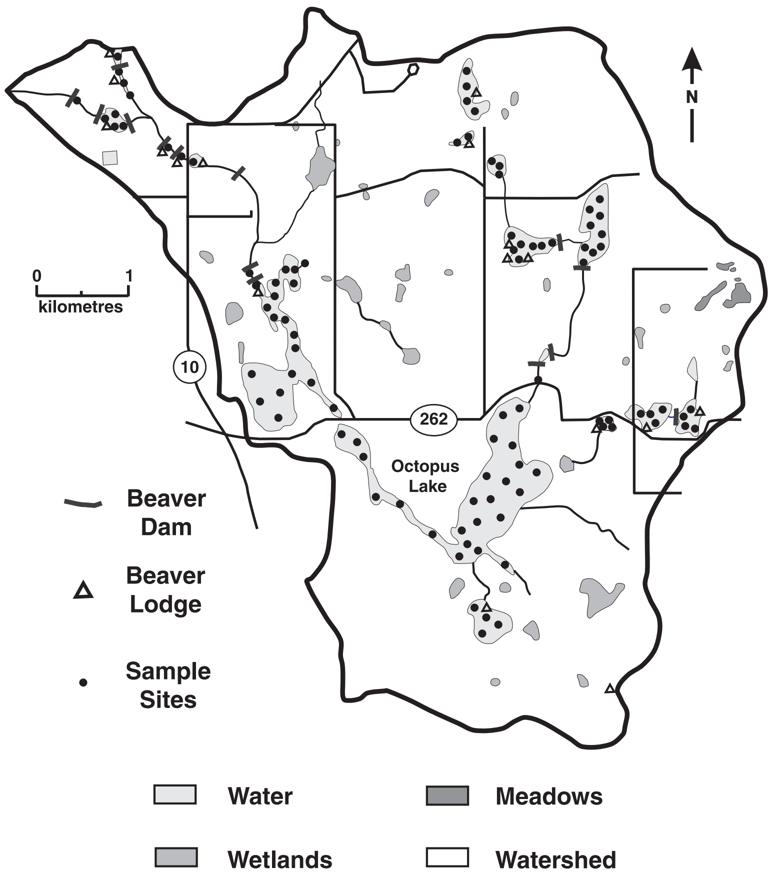


***Figure 3:*** *Depression storage in the Octopus Creek watershed.*

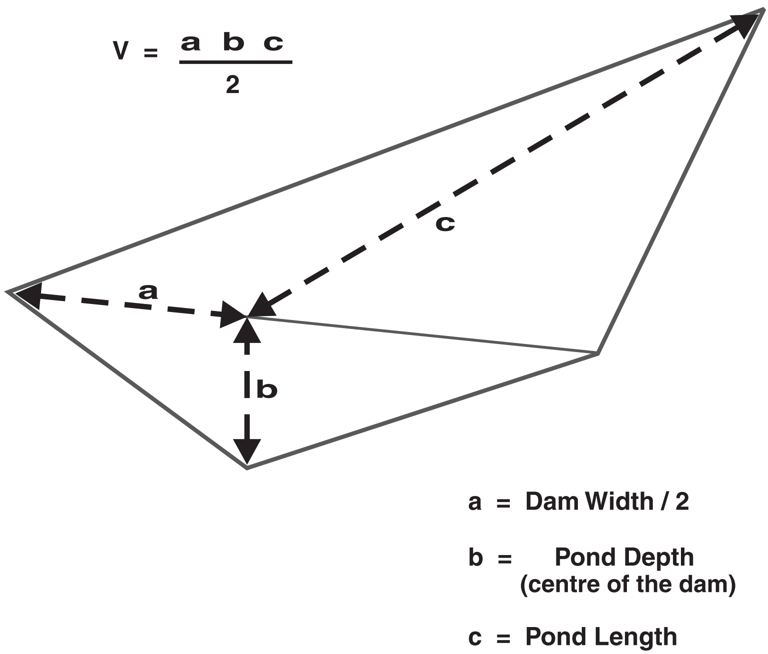


***Figure 4:*** *Volumetric beaver pond model.*

grouped into eight natural vegetation associations (Table 1) and are described as follows:

1. Coniferous Forest (Conifer): white spruce, black spruce, balsam fir, and western larch.
2. Mixed Forest Parkland (Mixed): aspen, balsam popular, birch, and conifers. Some small open areas.
3. Deciduous Forest (Deciduous): aspen, birch, balsam popular, and shelter belts
4. Open: natural meadow.
5. Agriculture: cleared land, cropland, hayland, pastures, fence lines, ridge prairie and abandon land.
6. Wetlands: marsh, muskeg, moist prairie, wet meadow and drainage ditches. Species include willow, dwarf birch, and shrubs.
7. Water: lakes, streams, beaver ponds and dugouts.

8. Developed: townsite, beaches, cottage sub-divisions and summer camps.

Units 7 (standing water) and 6 (wetlands) are of the most concern in this paper. Surface areal measurements were derived from geographic information systems analysis (SPANS) of orthophotos.

Depth measurements were obtained during winter while the small lakes, beaver ponds, and wetlands were accessible over the ice cover. In small lakes depth measurements were spatially distributed so as to provide reasonable bathometric coverage. Volumetric storage values were calculated on the basis of areal measurements and the lake bathometry.

In beaver ponds depth measurements were sounded at several spatially separate sites and provided an estimate of mean pond depth. Maximum depths were recorded adjacent to the planometric centre of the dam structure. A model was developed to estimate the storage waters retained in the beaver ponds. The model is based on the accepted calculations for the volume of a four sided pyramid

($V = a \cdot b \cdot c$). Applying the model to beaver pond morphology (Figure 4),

$$V = a \cdot b \cdot c/3, \text{ where:}$$

a represents one half of the dam width,
b is water depth adjacent to the centre of the dam, and
c is the planometric length of the pond.

Aerial photographs were used to measure dam width and pond length.

High water markings on drowned trees were recorded. These markings provided evidence of historic water levels and were later used to estimate depression storage depths.

## Results and Discussion

**Aspen Creek Watershed:**

Mean annual water equivalent depth of snow measured in the Aspen Creek watershed is approximately 12.0 cm and represents 880 $dm^3$ of potential runoff (McGuire 1997, McGinn and Rousseau 1997). During the winter months 511 $dm^3$ of water are normally held in depression storage. Beaver ponds contribute an additional 211 $dm^3$ (30%) to this value.

High water marks recorded in the beaver pondings indicate an addition 70-120 cm depth of runoff could be stored in the Aspen Creek beaver ponds and associated wetlands throughout the summer. This value represents approximately 168-289 $dm^3$ of runoff. Other measurements suggest that the more conservative 20 cm rise in the small lakes could store an additional 112 $dm^3$ of runoff. Consequently, in the Aspen Creek watershed, depression storage in small lakes, beaver pond and beaver influenced wetlands represents approximately 32-46% of the potential spring runoff. Aho (1997) suggests that up to 50% of potential runoff infiltrates. When maximized infiltration losses are considered, the detention storage in the Aspen Creek watershed could represents 64-92% of the total spring runoff.

**Octopus Creek Watershed:**

Mean annual water equivalent depth of snow measured in the Octopus Creek watershed is approximately 9.0 cm and represents 3247 $dm^3$ of potential runoff (McGuire 1997; McGinn and Rousseau 1997). Depression storage held in the Octopus Creek sub-basin during the winter months is calculated to be 3010 $dm^3$. A 20 cm rise in water levels, documented for Octopus Lake and applied to other small lakes and wetlands in the watershed, represents approximately 1433 $dm^3$ of surface runoff. In the Octopus Creek watershed depression storage accounts for 44% of the total potential snowmelt runoff. Mean maximum spring infiltration losses (50% of total runoff; Aho 1997) increase the significance of depression storage held in small lakes and wetlands. In the Octopus Creek watershed it has been calculated that on average 12% of the total potential snowmelt runoff enters Clear Lake during the melt season. Freshet runoff measurements taken on Octopus Creek near the outlet into Clear Lake over the last three years support this observation. Significant runoff was recorded during spring 1995, when the Octopus Creek watershed received 29% (2.6 cm) more snow than normal. There was no measurable runoff from the Octopus Creek sub-basin for years of average snowpack accumulation (1995-96 and 1996-97).

## Conclusion

Depression storage can account for a significant attenuation of spring lake levels in Clear Lake. Depression storage in the Aspen Creek sub-basin is significantly influenced by beaver activity. In this watershed the beaver pond density index is 5.05 ponds $km^{-1}$ and beaver impoundments represent at least 30% of the total depression storage in the watershed.

In the Octopus Creek sub-basin the beaver pond density index is 0.388 ponds $km^{-1}$ representing only 14 beaver impoundments in over 36 $km^2$. Spring runoff depression storage is held in Octopus Lake, other small lakes and wetlands. Two beaver dams are significant in that they act as a water level control structure at the outlet of Octopus Lake.

When potential infiltration losses (50% of potential runoff) are considered, approximately 64-96% of snowmelt runoff from the Aspen Creek sub-basin is held as depression storage. In the Octopus Creek sub-basin, 88% of snowmelt runoff is retained in Octopus Lake, other small lakes and wetlands.

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# Determining agricultural drought using pattern recognition

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**M. Pawlak, University of Manitoba**

***Abstract:*** Determining agricultural drought is a challenging task because of its complex and creeping nature. The deviation of crop yield from its long-term mean is applied to define agricultural drought. In the Canadian Prairies, nevertheless, no specific figure of such deviation has yet been established for this purpose. In this paper, we consider a case study of Swift Current, Saskatchewan. On the basis of varying percent deviation from the mean wheat yield, and using yield and climatic data (namely monthly temperature and precipitation for the period from 1975-1994), various possible scenarios of drought are examined. Data are divided into two distinct categories : i) drought and ii) no-drought. The error correction procedure of the pattern recognition is then applied in order to find a case wherein the drought could be linearly discriminated from the no-drought category. It is expected that this study will assist in defining and predicting drought in the Prairies.

## Introduction

Agricultural drought refers to the significant reduction in crop yields due to soil moisture deficits. Due to an intricate relationship between crop yield and soil moisture deficit (Stewart 1983), analysis of agricultural drought becomes complex. The complexity is further increased by the difficulty in defining drought precisely (Yevjevich 1978). However, one of the common ways of defining drought is based on the deviation from the mean yield of a major crop in the region (Kumar 1993). A threshold value (percentage reduction from the mean yield) is selected and drought is considered to have occurred if crop yield is below the threshold.

In this paper, we choose different thresholds to define agricultural drought in Swift Current crop district, Saskatchewan, using yield of spring wheat, and climatic data. Subsequently, error-correction procedure of pattern recognition is applied to examine whether drought can be linearly classified. Success in classifying drought is expected to assist in drought prediction.

**Pattern Recognition:**

Pattern recognition (or machine perception) is a computerized process of classifying objects. Application of pattern recognition can be found in image processing, medical engineering, criminology (i.e., identification of finger prints), speech recognition, and signature identification (Duda and Hart 1973). In geography, pattern recognition can be applied in classifying patterns of some geographic phenomena, for example, drought. Process of pattern recognition begins with formation of pattern vectors which, in the present case, refer to drought vectors.

**Vectorizing Drought:**

Once drought is defined in terms of yield reduction, corresponding yield-affecting variables are chosen as elements of drought (or yield) vector. For example, if these elements are precipitation and average temperature, yield vectors can be shown as points in two-dimensional display (Figure 1).

As shown in the Figure 1, some of the yield vectors can be termed as drought vectors depending on the threshold value of the yield chosen to define drought. In the figure, there exist two categories: drought, and no-drought. Once the numbers of categories have been selected and corresponding vectors defined, error-correction procedure of pattern recognition can then be applied to test if a linear dividing line can be determined to separate the categories. In case of a positive result, the dividing line can be used to classify an unknown vector as belonging to one of the two categories.

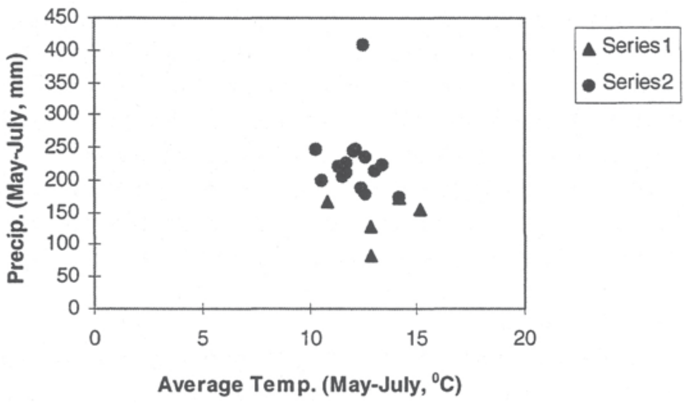


*Figure 1:* *Display of yield vectors, an example; Series 1: no drought, Series 2: drought.*

**Error Correction Procedure:**

The error-correction procedure is applied in three steps (Duda and Hart 1973) : i) All the vectors belonging to both the categories are augmented by adding additional element of 1; elements are the variables in different dimensions representing a vector, ii) All the elements in every vector of second class (say, drought vectors) are multiplied by -1 (Table 1) , and iii) Finally, a solution vector W is determined such that product of W with any yield vector exceeds zero i.e.,

$$\mathbf{Y_i W > 0 \qquad \text{for all } i} \tag{1}$$

where **i** is used to identify a vector and ranges from 1 to the total number of vectors in both categories.

The process of determining **W** commences with **W** as a unit vector i.e., all the elements of **W** are 1. It is followed by generating the product of **W** with individual yield vector one after the other. The moment the product does not satisfy the condition in case of any yield vector, the **W** is corrected as following:

$$\mathbf{W_{k+1} = W_k + c/k * Y_i}, \tag{2}$$

***Table 1:*** *Vectorizing yield elements; elements with negative sign represents drought.*

| Year | Spring wheat yield (t/ha) | Percentage deviation from the mean yield | Drought identified by 'd' * | Elements in a yield vector | | |
|---|---|---|---|---|---|---|
| | | | | cv-t ** | cv-p *** | Augmenting element |
| 1975 | 1.67 | -2.77 | | 0.286 | 0.059 | 1 |
| 1976 | 2.21 | 28.67 | | 0.170 | 0.198 | 1 |
| 1977 | 2.04 | 18.77 | | 0.139 | 0.177 | 1 |
| 1978 | 1.71 | -0.44 | | 0.174 | 0.092 | 1 |
| 1979 | 1.53 | -10.92 | d | -0.302 | -0.096 | -1 |
| 1980 | 1.54 | -10.34 | d | -0.117 | -0.161 | -1 |
| 1981 | 1.8 | 4.80 | | 0.260 | 0.160 | 1 |
| 1982 | 2.21 | 28.67 | | 0.268 | 0.137 | 1 |
| 1983 | 1.88 | 9.46 | | 0.308 | 0.200 | 1 |
| 1984 | 1.28 | -25.48 | d | -0.276 | -0.154 | -1 |
| 1985 | 0.91 | -47.02 | d | -0.188 | -0.080 | -1 |
| 1986 | 2.08 | 21.10 | | 0.166 | 0.127 | 1 |
| 1987 | 1.86 | 8.29 | | 0.142 | 0.124 | 1 |
| 1988 | 0.5 | -70.89 | d | -0.139 | -0.098 | -1 |
| 1989 | 1.67 | -2.77 | | 0.229 | 0.091 | 1 |
| 1990 | 2.08 | 21.10 | | 0.223 | 0.152 | 1 |
| 1991 | 2.23 | 29.83 | | 0.243 | 0.132 | 1 |

* when 10% deviation considered drought
** Coefficient of variation in temperature
*** Coefficient of variation in precipitation

where **c** is greater than 0 (chosen as 1 in the present case) and **k** starts with zero for unit vector **W** and is increased by one every time a correction is required. **Yi** is the yield vector causing correction in **W**. This process of correcting **W** continues until the required condition (Eq. 2) is met.

## Methodology

In drought classification, selection of an appropriate definition of drought and subsequently the feature extraction to select elements to vectorize drought are essential components. Agricultural drought is qualitatively related to crop yield**,** but for a numerical analysis of drought, a quantitative definition is required. One way of defining drought quantitatively is through the use of an index crop i.e., a major crop in the region (Kumar 1993) . In the Canadian Prairies, yield of spring wheat, a major export crop, is therefore considered as a base to define drought.

After defining drought, variables are explored to characterize drought in form of drought vectors. Since drought is defined on the basis of yield, all the yield-affecting variables can be examined if they are to be considered as elements of drought vectors.

The crop yield depends on various factors (Parry et al. 1988). In the Prairies, however, weather is the main factor limiting yield and causing droughts (Walker 1989). The weather related variables that are consistently available across the Prairies are temperature and precipitation and they have been directly or indirectly used in yield estimation (Raddatz et al. 1994). Based on these considerations, temperature and precipitation data have been considered as basic parameters to form yield vectors. Additional variables are also derived from the basic parameters.

**Data Collection and Analysis:**

Considerations applied in defining and vectorizing drought led to the data collection. Spring wheat yield, monthly temperature, and precipitation were collected for the period 1975-1994 for the study area, Swift Current, Saskatchewan. Though we obtained the required data from the Canadian Wheat Board, their original sources were the Statistics of Canada, for yield data, and the Environment Canada, for weather data.

Various thresholds of percent deviation from the normal yield with an interval of 5% were considered with initial threshold of 10%. However, only thresholds of 10, 25, 45 and 70 were found to be relevant, other thresholds did not make a difference in the number of drought vectors defined on the basis of thresholds.

A total of 12 variables was considered to vectorize drought. Some of the basic variables are shown in the Table 2. The complete list of variables included i) Win-Tavg (average temperature from November to March), ii)Win-P (total precipitation from November to March), iii) May-T (average temperature in May), iv) May-P (total precipitation in May), Sum-Tavg ( Average temperature from May to August), Sum-P (total precipitation from May to August), Sum1-Tavg (average temperature from May to July), Sum1-P (total

***Table 2:*** *Some basic variables used to characterize yield or drought vectors.*

| Year | yield (t/ha) | %dev mean yld | avg-t (nov-apr) | win-p (nov-apr) | may-t | may-p | jun-t | jun-p | jul-t | jul-p | aug-t | aug-p |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1975 | 1.67 | -2.77 | -7.4 | 119.9 | 10.1 | 57.9 | 14.7 | 60.7 | 20.6 | 43.0 | 14.8 | 36.6 |
| 1976 | 2.21 | 28.67 | -5.4 | 108.9 | 13.4 | 16.0 | 15.0 | 130.0 | 18.8 | 51.0 | 19.1 | 48.2 |
| 1977 | 2.04 | 18.77 | -4.0 | 58.6 | 13.3 | 115.7 | 16.9 | 30.8 | 18.0 | 76.2 | 14.4 | 22.4 |
| 1978 | 1.71 | -0.44 | -8.9 | 140.5 | 12.15 | 53.85 | 17.1 | 49.65 | 18.5 | 34.45 | 17.5 | 21.7 |
| 1979 | 1.53 | -10.92 | -10.4 | 110.2 | 9.0 | 36.5 | 16.4 | 64.5 | 19.7 | 39.0 | 18.6 | 27.1 |
| 1980 | 1.54 | -10.34 | -5.1 | 68.1 | 14.1 | 12.4 | 16.2 | 94.4 | 18.4 | 66.3 | 15.0 | 42.9 |
| 1981 | 1.80 | 4.80 | -3.0 | 85.7 | 12.1 | 26.3 | 12.95 | 103.8 | 18.6 | 79.8 | 20.6 | 29.3 |
| 1982 | 2.21 | 28.67 | -8.4 | 109.4 | 9.0 | 121.2 | 15.6 | 32.1 | 17.7 | 102.8 | 17.0 | 51.2 |
| 1983 | 1.88 | 9.46 | -4.6 | 117.4 | 9.6 | 45.8 | 16.1 | 27.1 | 19.1 | 121.7 | 21.3 | 28.9 |
| 1984 | 1.28 | -25.48 | -5.2 | 78.0 | 10.6 | 35.3 | 16.1 | 74.5 | 20.1 | 32.2 | 20.7 | 17.0 |
| 1985 | 0.91 | -47.02 | -7.1 | 103.4 | 13.8 | 34.1 | 13.7 | 16.1 | 20.1 | 20.7 | 16.9 | 26.6 |
| 1986 | 2.08 | 21.10 | -5.6 | 84.4 | 12.2 | 97.3 | 17.2 | 54.7 | 17.3 | 68.9 | 18.1 | 22.8 |
| 1987 | 1.86 | 8.29 | -2.1 | 69.3 | 14.1 | 22.6 | 18.6 | 31.9 | 18.3 | 72.6 | 14.8 | 57.1 |
| 1988 | 0.50 | -70.89 | -3.4 | 52.6 | 15.6 | 28.5 | 21.6 | 63.8 | 20.1 | 30.1 | 17.9 | 44.9 |
| 1989 | 1.67 | -2.77 | -7.1 | 107.4 | 11.5 | 77.3 | 16.4 | 90.2 | 20.5 | 32.4 | 18.1 | 74.6 |
| 1990 | 2.08 | 21.10 | -3.9 | 109.3 | 10.8 | 52.2 | 16.5 | 62.8 | 17.8 | 102.3 | 18.7 | 15.9 |
| 1991 | 2.23 | 29.83 | -5.2 | 132.7 | 11.4 | 71.7 | 16.0 | 152.3 | 18.7 | 89.5 | 20.8 | 41.4 |
| 1992 | 1.96 | | -2.3 | 73.0 | 11.2 | 41.8 | 15.4 | 34.6 | 16.4 | 72.2 | 16.1 | 49.0 |
| 1993 | 2.21 | | -5.4 | 108.7 | 12.5 | 15.2 | 14.3 | 80.6 | 15.6 | 86.9 | 16.3 | 112.7 |
| 1994 | 1.83 | | -6.9 | 116.7 | 12.2 | 65.8 | 15.7 | 76.2 | 18.9 | 29.3 | 18.1 | 37.4 |

precipitation from May to July), CV-T (coefficient of variation in temperature from May o August), CV-P (coefficient of variation in precipitation from May to August), CV1-T (coefficient of variation in temperature from May to July), CV1-P (coefficient of variation in precipitation from May to August).

Selecting two out of the total of 12, six pairs of variables were considered to vectorize yield. The pairs included i) Win-T, and Win-P, ii) May-T and May-P, iii) Sum-T and Sum-P, iv) Sum1-T and Sum1-P, v) CV-T and CV-P, and vi) CV1-T and CV1-P. From the four definitions of drought (thresholds 10, 25,45,70 %) and , for each drought definition , six definitions of yield vectors, a total of 24 cases were developed. The error-correction procedure was applied to investigate if the drought could be linearly classified. To accomplish this, a computer program was written to find out if, for any threshold or any definition of yield vector, it was possible to separate drought from the non-drought category.

## Conclusion

In the classification procedure of the computer program, an iteration limit of 2000 was set. It was found that in no case did the solution vector W exist. Nevertheless, in the present study , only a limited number of cases were considered. Additional combinations need to be tested for a conclusive determination of drought characteristics. Further research in this direction is in progress. The use of non-linear techniques in classifying and predicting drought is being explored.

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# Forecasting wheat yield in the Canadian Prairies using climatic and satellite data

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***Abstract:*** Wheat yield forecasting is a significant component of planning and management of wheat exports from the Canadian Prairies. Commonly, regression models employing agroclimatic data pertaining to post-planting period are used as forecasting tools. However, the planning process of wheat export requires yield estimates even in advance of crop planting. Such advanced estimates are possible by using time series analysis. In this paper, we use both regression and time series approaches to develop models to forecast spring wheat yield using climate and satellite data pertaining to Swift Current, Saskatchewan.

In the case of regression, two categories of models were developed. In the first category, the climate data i.e., accumulated precipitation from April to July, and average temperature during the same period were used as independent variables. The second category included NOVAA/ AVHRR satellite data based Normalized Difference Vegetation Index (NDVI) in addition to the climate data used in the first category. While the climate data were available for 1975-1994 period, the satellite data were available only for 1987-1994 period. Hence, the time series models and the first category of regression models were developed using the 1975-1991 data and tested for the 1992-1994 period, while the second category of regression models were developed using 1987-1992 data and tested for the years 1993 and 1994. Based on the mean absolute percent error, the comparative performances of the models are presented and discussed

## Introduction

Wheat is a major crop in the Prairies and its export contributes significantly to the Canadian economy. About 20 to 30 million tonnes of wheat is exported every year from the Prairies. The variation in exports is attributed largely to drought-prone climate, which, if not accurately predicted, can result in millions of dollars of loss. The export targets and prices that are set much in advance of crop harvests may not turn out to be accurate after a drought occurrence.

Since weather is the single most important factor affecting wheat yields in the Prairies, temperature and precipitation data over the crop growing period are used to forecast wheat yield. Most commonly, regression models are used for the purpose, and the weather data after the crop has been planted are employed. But the yield estimates are required even prior to crop-planting, for advanced export planning by a marketing agency such as the Canadian Wheat Board (CWB). Yield estimation prior to crop planting is possible by using time series analysis wherein a forecast of yield in the following year is made on the basis of yield data in the past. In this paper, we have developed models using regression as well as time series analysis and have provided comparative results that may be helpful in making optimum decision regarding wheat export from the Canadian Prairies.

## Data Used

Spring wheat yield, climate, and satellite data pertaining to Swift Current, Saskatchewan, were used in the study. The yield and satellite data were originally obtained from Statistics Canada, and the climate data (temperature and precipitation) from Environment Canada. The satellite data refer to AVHRR (Advance Very High Radiometric Resolution) sensor of NOAA (National Oceanic Atmospheric Administration) satellite. The NOAA / AVHRR data is available in five wavelength channels, but only the first two channels (red : 0.58 - 0.68 m, and infrared : 0.725 - 1.10 m) have been commonly utilized to develop various indices for monitoring vegetation conditions (Goward et al., 1991). NDVI as defined below, has been found to be a globally useful index in crop yield estimation (Barnett and Thompson, 1982; Brown et al, 1982; Rudorff and Batista, 1990; Bullock, 1992).

$$\mathbf{NDVI=(R-IR)/(R+IR)} \qquad [1]$$

***Table 1:*** *The dataset used in the study.*

| Year | Yield (bu/ac)* | Total Precipitation (April-July), mm | Average Temperature (April-July), $^0$C | NDVImax (week23-week30) | NDVIavg (week23-week30 |
|---|---|---|---|---|---|
| 1975 | 24.9 | 198.3 | 10.58 | | |
| 1976 | 32.8 | 215 | 13.05 | | |
| 1977 | 30.4 | 222.9 | 13.40 | | |
| 1978 | 25.5 | 178.9 | 12.63 | | |
| 1979 | 22.7 | 166.7 | 10.85 | | |
| 1980 | 22.9 | 171.6 | 14.20 | | |
| 1981 | 26.8 | 243 | 12.08 | | |
| 1982 | 32.9 | 248.2 | 10.30 | | |
| 1983 | 28 | 212.4 | 11.70 | | |
| 1984 | 19 | 127.4 | 12.90 | | |
| 1985 | 13.5 | 84.3 | 12.85 | | |
| 1986 | 31 | 247.6 | 12.18 | | |
| 1987 | 27.6 | 173 | 14.23 | 106.8 | 36.1 |
| 1988 | 7.4 | 155.4 | 15.13 | 125 | 117.2 |
| 1989 | 24.9 | 236.3 | 12.58 | 160.5 | 104.4 |
| 1990 | 30.9 | 227.1 | 11.75 | 169.6 | 140.6 |
| 1991 | 33.2 | 409.3 | 12.53 | 179.5 | 132.8 |
| 1992 | 29.1 | 204.4 | 11.55 | 189.6 | 131.3 |
| 1993 | 32.9 | 219.8 | 11.35 | 155.6 | 114.6 |
| 1994 | 27.2 | 186.8 | 12.45 | 171.3 | 123.1 |

* bu/ac (bushel per acre) which is equivalent to 0.06725 t/ha .

where **R** and **IR** are the reflectance in the red and the infra-red bands of the AVHRR sensor of the NOAA satellite.

The weekly NDVI values (Julian week 23 to week 30 i.e., June and July) for the 1987-1994 were used in the analysis. This period was chosen as there is high level of canopy coverage during this period and yield is considered to be related to NDVI during this period. The complete data set used in the study is given in Table 1.

## Wheat Yield Estimation

The yield can be estimated by radiative and temperature regimes, soil water available for plant growth, plant nutrients , interference of pests and disease, and farm management activities (Parry et al., 1988). Various models have been developed based on basic as well as derived parameters related to soil moisture, weather , and crop characteristics. For example, some of the parameters that have been used in wheat yield estimation are albedo i.e., ratio of reflected light to incident light on the crop during the growing season (Idso et al. ,1979), moisture anomaly index i.e., difference between monthly observed precipitation and climatically appropriate precipitation, ratio of evapotranspiration to potential evapotranspiration (Sakamoto, 1978), crop water use i.e. total evapotranspiration (Slabbers and Dunin , 1981), canopy temperature indices i.e., Stress Degree Day, Temperature Stress Day and, and Crop Water Stress Index (Diaz et al., 1983). All these studies were carried out on experimental basis requiring data that are otherwise difficult to measure and therefore not available for consistent period over a large area such as the Prairies. In western Canada, Raddatz et al. (1994) estimated average yield of Spring wheat using regression analysis. End-of-season ratios of water- use to water demand and the modelled days-to-maturity were used as variables. Up to 69 percent of the variation in the observed yields of spring wheat could be explained by the regression models.

## Methodology

Two different approaches of forecasting: statistical regression, and time series analysis have been attempted in this paper as explained in the following.

## Regression Analysis

**Yield versus climatic variables:**

Considering spring wheat yield as dependent variable, and average temperature (April to July) , T, and total precipitation (April to July), P, as independent variables, a regression analysis was conducted using 1975-1994 data. Three different regression models using 1975-1991, 1975-1992, and 1975-1993 data were developed to forecast yields in the year 1992, 1993, and 1994 respectively.

As can be seen from Table 1, the yields were very low in the year 1985, and 1988, due to drought. To examine the effect of

***Table 2:*** *Regression analysis using climatic data.*

| Year | Reported yield (bu/ac) | Estimated Yield (bu/ac) | | | |
|---|---|---|---|---|---|
| | | Using continuous data range | | Using discrete data range (excluding 1985,1988 data) | |
| | | $R^2$ | Yest. | $R^2$ | Yest. |
| 1992 | 29.1 | 0.57 | 26.92 | 0.49 | 26.95 |
| 1993 | 32.9 | 0.57 | 28.42 | 0.48 | 27.9 |
| 1994 | 27.2 | 0.57 | 24.74 | 0.45 | 26.47 |
| | MAPE (%) | | 10.05 | | 8.42 |

drought on forecasting, the 1985 and 1988 data were excluded from the dataset and regression analysis was repeated. Table 2 shows the results thus obtained. The mean absolute percent error (MAPE) as defined blow was used as a measure of accuracy of the models.

$$\text{MAPE} = \frac{\sum_{i=1}^{n} |Yest.i - Y| / Y * 100}{n} \qquad [2]$$

where ***Yest.*** is estimated yield, **Y** is reported yield and ***n*** is number of observations.

**Yield versus climatic and satellite data:**

The NDVI data were available only for 1987-1994 period. A common data set (1987-1994) was therefore used for regression analysis. The yield was predicted for the year 1993 and 1994, using 1987-1992, and 1987-1993 data respectively. Regression analysis was repeated for the dataset without 1988 data (the drought year). Regression results thus obtained are given in Table 3.

**Time Series Model:**

The yield, Yt, was modelled as a function of time. In general such models can be written as (Abraham and Ladolter , 1983):

***Table 3:*** *Yield prediction using regression models using climatic and satellite data.*

| Variables used | Predicted yield (bu/ac) | | | | | | | | MAPE(%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1993 (reported yield : 32.9 bu/ac) | | | | 1994 (reported yield : 27.2 bu/ac) | | | | | |
| | using 1987-92 | | excluding 1988 data | | using 1987-93 | | excluding 1988 data | | using full data | excluding 1988 data |
| | $R^2$ | Yest. | $R^2$ | Yest. | $R^2$ | Yest. | $R^2$ | Yest. | | |
| T,P | 0.68 | 31.81 | 0.49 | 29.18 | 0.71 | 26.37 | 0.44 | 28.55 | 3.18 | 8.14 |
| T,P, NDVIavg | 0.94 | 32.82 | 0.54 | 24.17 | 0.94 | 24.33 | 0.54 | 26.24 | 5.40 | 15.03 |
| T,P, NDVImax | 0.94 | 41.78 | 0.58 | 32.25 | 0.88 | 22.13 | 0.67 | 25.99 | 22.82 | 3.21 |

$$\mathbf{Yt=f(t:\boldsymbol{\beta}) + \boldsymbol{\varepsilon}_t} \quad [3]$$

where $\mathbf{f(t:\boldsymbol{\beta})}$ is a function of time **t** and an unknown coefficient $\boldsymbol{\beta}$**:** $\boldsymbol{\varepsilon}_t$ refers to uncorrelated errors.

The 1975-1994 yield data was used to construct the following time series. To test performance of each model, the yields in 1992, 1993, and 1994 were forecast using 1975-1991, 1975-1992, 1975-1993 data respectively.

**Trend analysis:**

Two types of trend models were attempted: linear, and quadratic. The linear model can be defined as

$$\mathbf{Yt= \boldsymbol{\beta}_0 + \boldsymbol{\beta}_1 t + \boldsymbol{\varepsilon}_t} \quad [4]$$

where $\boldsymbol{\beta}_1$ represents the average change from one period to the next, and quadratic trend model accounting for curvature in the trend is defined as

$$\mathbf{Yt= \boldsymbol{\beta}_0 + \boldsymbol{\beta}_1 t + \boldsymbol{\beta}_2 t^2 + e_t} \quad [5]$$

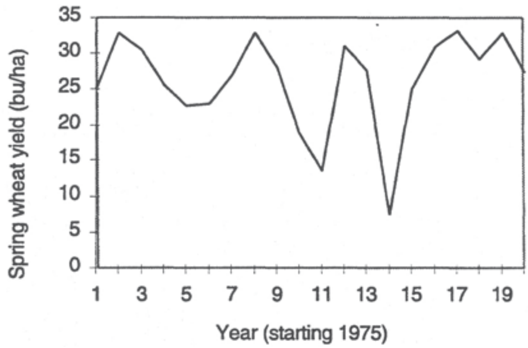


***Figure 1:*** *Yield variation in Swift Current (1975-1994).*

Since 1985, 1988 data appear to have distorted the trend (Figure 1), the trend models were also fitted on yield series wherein the 1985, and 1988 observations were replaced with the mean yield. Table 4 gives the results thus obtained.

**Moving average method:**

This method uses moving averages to smooth out noise in a time series . Moving length was chosen as 2 in the present case as there is frequent fluctuation in yield series.

**Exponential smoothing:**

This method uses an exponentially weighted average of all past values of series to calculate smoothed value at each period. The nitial value was calculated by backcasting.

**ARMA model**

Here, the observation at time t, Yt, is modelled as a linear combination of previous observations,

$$\mathbf{Yt} = \sum_{j\geq 1} \pi_j \mathbf{Yt\text{-}j} + \varepsilon_t \qquad [6]$$

Such a representation is called an autoregressive model , since the series at time **t** is regressed on itself at lagged time periods.

***Table 4:*** *Yield prediction using trend analysis.*

| Year | Reported yield (bu/ac) | Predicted yield (bu/ac) | | | |
|---|---|---|---|---|---|
| | | linear trend | | quadratic trend | |
| | | no-change in data | drought yields replaced with mean yield | no-change in data | drought yields replaced with mean yield |
| 1992 | 29.1 | 24.08 | 28.38 | 29.45 | 32.12 |
| 1993 | 32.9 | 25.03 | 28.71 | 30.9 | 31.98 |
| 1994 | 27.2 | 26.61 | 29.8 | 33.63 | 33.57 |
| | MAPE (%) | 14.45 | 8.26 | 10.31 | 12.20 |

Such an autoregressive representation can lead to models with many parameters that may be difficult to interpret. However, autoregressive models can be approximated by autoregressive moving average (ARMA) models of the form :

$$Yt= \phi_1 Y_{t-1} +...+ \phi_p Y_{t-p} + \varepsilon_t - \phi_1 \varepsilon_{t-1} -...- \phi_q \varepsilon_{t-q} \quad [7]$$

In these models the observation, Yt , is written as a linear combination of past observations and past errors, p and q are the orders of the autoregression and of the moving averages. An appropriate model can be built from the past data following an approach developed by Box and Jenkins (1970). On observing the respective graphs, values of both p and q were found to be 2, and as a result ARMA (2, 2) was used to forecast yield. The results of moving average, exponential smoothing and ARMA model are given in Table 5.

## Results and Discussion

Regression results are shown in Table 2 and Table 3. When regression models were tested to forecast yield, the mean absolute percent error (MAPE) was minimal (3.18%) for the models using

***Table 5:*** *Yield prediction using moving average, exponential smoothing and ARMA models.*

| Year | Reported yield (bu/ac) | Predicted yield (bu/ac) | | | | |
|---|---|---|---|---|---|---|
| | | Moving average | Exponential smoothing | | ARMA | |
| | | | no change in data | drought yields replaced with mean yield | no change in data | drought yields replaced with mean yield |
| 1992 | 29.1 | 32.05 | 25.9 | 30.3 | 30.01 | 25.02 |
| 1993 | 32.9 | 31.15 | 26.15 | 28 | 19.4 | 24.7 |
| 1994 | 27.2 | 31 | 26.7 | 28.2 | 26.7 | 31.5 |
| | MAPE (%) | 9.81 | 11.12 | 7.56 | 15.33 | 18.25 |

only temperature and precipitation data. These models were developed using contracted datasets (1987-1992 and 1987-1993). Contrary to a pre-analysis assumption, the NDVI did not improve model accuracy. It can be attributed to distortion in NDVI values because of clouds or other unknown factors. In the presence of clouds, which are frequent weather feature of the Prairies, the NOAA/AVHRR image does not show ground features but clouds, and therefore does not reflect crop conditions. Besides, presence of fallow fields may also affect the NDVI values. A typical NDVI profile distorted under cloudy conditions is shown in Figure 2.

Under normal conditions, NDVI profile looks like a normal curve. If the NDVI values are adjusted for clouds, the data may help improve the model's accuracy. Further, the average NDVI was found to be a better indicator of yield compared to the maximum NDVI. But again, more reliable findings can be achieved only with appropriately-adjusted NDVI data.

In order to examine the effect of droughts, the analysis was repeated on the dataset excluding drought data (1985, 1988). In the larger dataset, the prediction errors reduced from 10.05 to 8.4 %

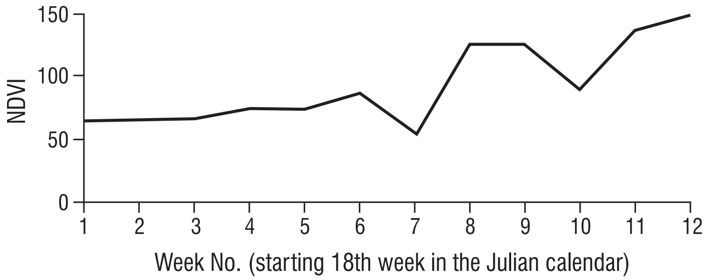


***Figure 2:*** *Drop in NDVI values due to clouds.*

(Table 2). However, a similar trend was not observed in the case of the shorter dataset (Table 3). In regression models using, T and P, using T, P, and NDVIavg, the error increased . But, when the NDVImax was used in place of NDVIavg, exclusion of the 1988 data improved the model accuracy drastically (percent error reduced from 22.82 to 3.21). It can be seen from the Table 1 that the NDVI value for the minimum yield (7.4 bu/ac) in 1988 was very high (125), and even higher than in 1987 when the yield was rather normal (27.6 bu/ac). This tends to reveal that the NDVImax is not a good indicator of yield under drought conditions.

The rationale behind use of time series analysis for predicting the yield can be verified from the fact that yield affecting variables such as temperature, and precipitation have well- known time dependent cyclic variations. In the Prairies, precipitation is the main factor affecting yield and is part of a time dependent global hydrological cycle. Therefore, the yield can be indirectly considered as a time dependent parameter assuming that all other yield affecting factors are stable. As can be seen from Table 4 and 5, time series models were developed using data with no change in their values and using data in which the observations in 1985 and 1988 were replaced with the mean values. Fitting a trend line in the yield series, the quadratic trend showed better results (error 10.31 %) than the linear trend (14.45%). When the yields in drought years were replaced with the mean yields, linear trend provided an improved performance (error reduced to 8.26%) while the quadratic trend showed a decline in accuracy (error 12.20 %).

From Table 5, it is evident that the ARMA model gave the poorest result. The best results (error only 7.56 %) were achieved in case of exponential smoothing for the case where the drought yields were replaced with the mean yields. However, when no change in the data was made, the moving averages method gave a better result (error 9.81%). Hence, in the case of drought, the moving average technique may be a better option, while in the case of normal yield or moderate drought conditions, an exponential smoothing provides a more reliable forecasting technique.

## Conclusion

1. A regression model based on average temperature (April o July) T, and total precipitation (April to July) was found to be the best among all the models developed in the study.
2. The average weekly NDVI for the period from June to July was a better indicator of wheat yield than the maximum NDVI over the same period.
3. In time series analysis, exponential smoothing of the yield series provided best estimates under normal conditions. However, the moving average method showed better performance under drought conditions.

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# Water games: the location of water-based sports events at the 1997 Canada Games

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***Abstract:*** The 1997 Canada Games were held in Brandon, Manitoba from 9 to 23 August. The choice of the City of Brandon as a site for the games was a coup for this urban area, but also created problems for the local organizers with respect to the location of some of the events. Included in the games are 18 sports, some land-based and others water-based. In this paper we shall concentrate on the water-based events, in particular those which take place outdoors. Outdoor water-based sports include canoeing and rowing, sailing, and water-skiing. Although the games were associated in people's minds with Brandon, suitable facilities did not exist within the city limits for all the sports. This was particularly true of the outdoor water events. It was possible to modify the Assiniboine River in Brandon to accommodate the requirements for water-skiing, but events in the other sports had to be located outside the city, in rural Westman: the canoeing/ rowing at Minnedosa Lake and the sailing at Pelican Lake. In this paper we shall discuss the specific physical requirements for water-based sports, the locational options that were available, and the sites that were finally chosen.

## Introduction

In recent years there has been an increase in the amount of leisure time available to people in general and to those in the western world in particular. Associated with this growth has been an increase in demand for recreational pursuits to fill these discretionary hours, and recognition of recreation not only as a major land use and industry, but also as a valid area for academic study (Ryan 1991: x). Although geographers are usually not interested in all activities designed to fill this newly created void, they are especially interested in outdoor recreation.[1]

"Canada is blessed with rich and varied opportunities for people to participate in outdoor recreation" (Wall 1989: vii). Although the image of Manitoba held by many Canadians is of a uniform and even boring landscape, the province has a variety of physical and human environments, many of which are conducive to, and attractive for, outdoor recreation (Everitt 1997). Whereas Winnipeg tends to concentrate on urban and cultural attractions, rural Manitoba (outside "The Perimeter") is noted for outdoor activities, and as a result, recreation has become a major contributor to the economy of Manitoba (Gill 1996: 289).[2]

Although, on average, most recreation time and money in Manitoba is spent by Manitobans, this is not the case for "mega-events," which by their nature are designed to attract people from far-off parts, thus boosting the economy of a region and at the same time helping to make for a successful event (Butler 1997). A mega-event is difficult to define in some instances. A "happening" of major significance to Holland, Manitoba, for instance, might not be of great importance to Winnipeg. However, the event to be discussed in this paper, the Canada (Summer) Games would qualify as "mega" on a Canadian scale, by whatever definition.

There was considerable excitement in the City of Brandon when the community was awarded the 1997 Canada Games, as the Games bring with them the promise of an influx of paying customers, national exposure in the media, and the prospect of the development of physical facilities that would not otherwise be economically feasible.

However, when a community is awarded "the Games" it undertakes to provide the necessary facilities for 18 different sports, of which 12 are land-based and 6 (canoeing, diving, rowing, sailing, swimming and water-skiing) are water-based. As noted above, part of the rationale for the awarding of the Games to small communities is to encourage them to build facilities that they would not normally be able to afford. With limited exceptions, Brandon was able to provide the physical requirements for the various sports. We shall concentrate on the water-based sports because they presented the greater challenge for the organizers. In addition such

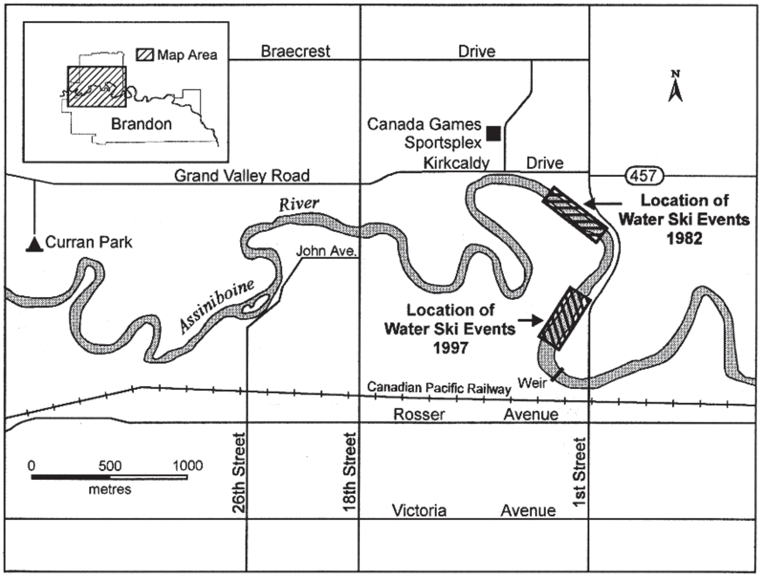


***Figure 1:*** *The Assiniboine River at Brandon.*

sports are not commonly associated with a small city - prairie environment and arguably provide a more valuable case study for recreational geographers.

The swimming and some diving were held at the pre-existing Sportsplex which dates from the Canada Winter Games held in Brandon in 1979 (Figure 1). However, this facility was not completely acceptable as it has only 6 lanes whereas ideally 8 lanes should be available. Also, a second warm up pool is required within reasonable distance of the competition pool and there is not one of a sufficiently high standard in Brandon. Moreover, the Sportsplex pool has limited facilities for spectators; so the only people allowed to watch the swimming events were the competitors, coaches, parents of competitors, and members of the media.

The Sportsplex pool was unacceptable for diving except for one metre springboard diving. At an early planning stage, the city had projected the building of an outdoor diving facility near an existing pool at Curran Park at the western edge of the city (Figure 1). The building of the diving boards would have been combined with the construction of a series of water slides to ensure subsequent use. However, the projected development proved to be too expensive, and consequently the three metre and tower diving had to be held at the Pan Am Pool in Winnipeg.

Fortunately these were the only instances in which Brandon was delinquent in providing facilities. However, the other water-based events (water-skiing, canoeing and rowing, and sailing) provided some problems for a city which has only one significant water body, the Assiniboine River, within its boundaries. Thus, it was necessary to look outside the city for suitable locations for the canoeing and rowing (taken as one sport) and sailing events.

In all cases when choosing a location the organizers asked themselves two questions: 1) is there a club or other group near the venue that will help to plan and run the events? and 2) if money is put into developing a venue, is it likely that it will be used in later years?

## Water-Skiing

As the Assiniboine River is the only water body in Brandon it was inevitable that it would be considered as a venue for the water events. It had some advantages as a location for water-skiing:

1) There is a water-ski club in Brandon that could help organize the competition.
2) This being the case it was likely that facilities developed for the Games would be used in subsequent years.
3) Water-skiing competitions have been held on the Assiniboine before (the Western Canadian Water Ski Championships in 1982), although in a slightly different location from that eventually selected (Welsted 1989).
4) It is within the city and therefore provides easy access for spectators.
5) The existence of a weir at Third Street meant that a regular water level could be maintained during the games (Figure 1).
6) Parts of the river are sheltered; therefore rough water was not likely to be a problem.

There were, of course, some obvious disadvantages:

1) The Assiniboine is a meandering river with few straight stretches.

2) The river is narrow and shallow.
3) Water quality is not good.
4) The river has a current which is a factor when considering whether records have been achieved.

Despite these disadvantages the events were held on the river. The problems were either overcome or ignored. A relatively straight stretch of the river was chosen just above the weir at Third Street (Figure 1). At this location the river was widened and deepened, so that it was broad enough and deep enough for the competitors, and at the same the banks were given a more gentle slope. This provided safety for the skiers as well as access for spectators, and as the excavation was in a park area of the city, there was relatively little impact on prior land use. As far as we know there were no complaints about the water quality and we are told that the current in the river dropped to an acceptable speed just before the competition began.[3]

The Manitoba Department of the Environment required an assessment of this site under the <u>Environment Act</u>.[4] One outcome of the assessment was a requirement to monitor sediment passing along the river before, during, and after construction (Terry and McGinn 1998). Another assessment was required under the <u>Manitoba Heritage Resources Act</u>. Fortunately the resulting study found no archaeological sites at this location.[5]

## Canoeing and Rowing

These sports have different requirements from water-skiing:

1) The course has to be longer -- 1000 metres in the case of canoeing, and 2000 metres in the case of rowing.
2) The water body has to be wide enough to accommodate 6 lanes.
3) There should be little or no flow in the water.These ruled out the Assiniboine as a possible venue and attention inevitably focussed on Minnedosa Lake (Figure 2), an artificial lake created by the damming of the Little Saskatchewan River (Punak and Welsted 1989).

The location had several advantages:

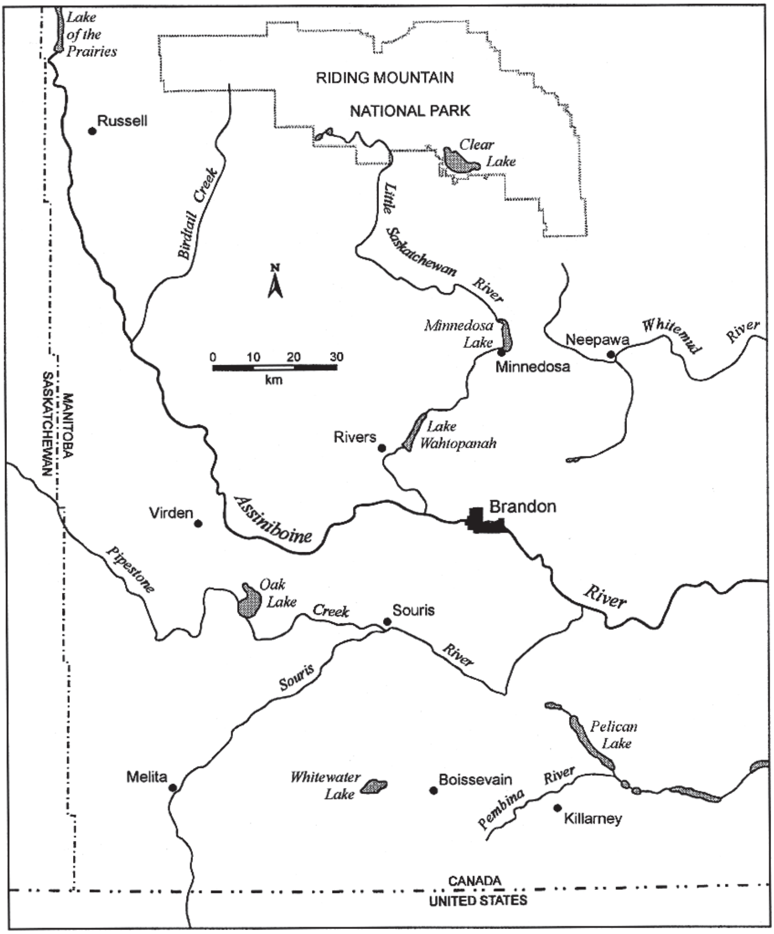


***Figure 2:*** *Water bodies of southwest Manitoba.*

1) An interested community in Minnedosa who would help with the organization of the events and would ensure subsequent use of the facilities.[6]

2) Although not in Brandon, it is within easy commuting distance of the Games centre, and Minnedosa itself provides a good pool of spectators.

3) The lake is long, yet wide enough to carry the necessary lanes.

4) It is sheltered to the east and the west.

5) The sides of the Little Saskatchewan Valley provide good spectator view points.

As with any location there were some disadvantages, the main being:

1) There was concern about sedimentation at the north end of the lake.[7]
2) Water level in the lake can fluctuate depending on inflow from the Little Saskatchewan River and the height of the dam at the outlet in Minnedosa. However, the problems were not insurmountable. No dredging of the lake was required, although the starting point of the 2000 metre rowing events at the north end of the lake was close to shallow water. Some weed harvesting was done and some beaches were elongated for ease of boat launching and to improve spectator viewing. The Town of Minnedosa controls the dam level and was able to maintain a constant water level during the games. As no construction was involved the Canada Games Society was not required to conduct either an environmental assessment or an assessment of heritage resources in order to have this venue approved.

The venue was a success. Buoys, cables and other equipment purchased for the games have been stored, and it is believed that at least some of the events for the Pan American Games, based in Winnipeg in 1999, will take place on Minnedosa Lake.

## Sailing

Sailing on the Assiniboine is not possible, so an alternative had to be found. Clear Lake in Riding Mountain National Park was one possibility,[8] but the first choice was always Pelican Lake, located 73 km south of Brandon (Figure 2). Pelican Lake has had a chequered history as a recreational resort, depending largely on the water level in the lake (Welsted 1992). The Pembina River Diversion Scheme which aimed to increase and stabilise the level of the lake was completed in 1993 and in the relatively wet years since then the lake level has risen.

As with the other venues, there were advantages and disadvantages to the location:

The advantages were:

1) There is a yacht club in the area whose members have been sailing on the lake for many years. They were able to provide the necessary organizational background and ensure that any facilities built would be used in the future.
2) The lake is long and relatively narrow, but easily wide enough to set out a competitive course.
3) Good steady winds blow along the lake on a regular basis.

Disadvantages were:

1) The lake is a considerable distance from Brandon (nearly an hour's drive).
2) There is no nearby population base from which to draw which to draw spectators.
3) A new breakwater was needed to protect an area for docking and launching.
4) The quality of water was poor. The Pembina River diversion scheme has increased the level of the lake but it has not improved water quality.

Despite these drawbacks Pelican Lake proved to be an excellent location. The distance from Brandon and the lack of a large population base in close proximity were not factors as sailing is not a big spectator sport under the best of conditions. A breakwater was built at the north end of the lake. The poor water quality was not a factor as sailors do not expect to spend much time in the water. The Canada Games Society was not required to conduct an assessment of impact on heritage resources, but under the <u>Navigable Waters Pollution Act</u>, the Society was required to include culverts in the breakwater to prevent stagnant water on its landward side, and to install a navigation hazard light at the end of the breakwater.

The event was blessed with a week of warm, sunny, windy weather (on one day it was too windy) enabling the events to proceed smoothly. Improvements to the yacht club house and the building of the breakwater with docking facilities have ensured that future competitions will take place at this location.

## Conclusion

Locating and providing the necessary physical facilities for the outdoor water events at the Canada Games was a considerable challenge for the organizers based in a small prairie city. However, at relatively minor cost suitable venues were selected and adapted to provide excellent facilities both for competitors and spectators. In keeping with one of the aims of the Games, the facilities will be preserved and it is likely that all three -- the Assiniboine River, Minnedosa Lake, and Pelican Lake -- will continue be used for sports recreation and that future competitions will take place on them. Unlike some other mega events, the Canada Games held in the Brandon area appear to have achieved most of their stated objectives.

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## End Notes

[1].In this paper we shall attempt to avoid many of the terminological pitfalls that characterize a new research area - such as the study of recreation. Thus although tourism and outdoor recreation are closely related -- indeed tourism may be seen as one form of outdoor recreation -- we shall confine outselves to a discussion of **recreation**.

[2].Gill points out that tourism, which constitutes one part of outdoor recreation, is the sixth most important contributor to the provincial economy.

[3].Cory Gross, Facilities Coordinator, Canada Games, Personal communication, 9 September 1997.

[4].For details of the fisheries and habitat assessment see *Evaluation of the Proposed Dredging of Assiniboine River Shoreline at Brandon*. Report to Reid Crowther and Partners Ltd by TetrES Consultants Inc. November 1995 (Winnipeg: np).

[5].*Brandon 1997 Canada Games Waterski Facility Project, Heritage Resources Impact Assessment Final Report* prepared for Brandon 1997 Canada Games Society Inc. by Northern Lights Heritage Services, November 1996 (Brandon : np).

[6].Lake Wahtopanah, a bigger lake caused by another dam on the Little Saskatchewan River, does not have a history of water-based sports events and in this respect alone it was a less desirable location.

[7].See "Saving Minnedosa Lake" *The Tribune* (Minnedosa), 31 March 1997, 3.

[8].The main problem with Clear Lake would have been the difficulty of blocking off a part of the lake from the general public during the busy late summer season.

# The effect of suspended sediment control measures during the construction of a waterski facility, Assiniboine River, Brandon, Manitoba

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***Abstract:*** A suspended sediment monitoring programme was a term/condition of the Environmental Act Licence, issued to the Brandon 1997 Canada Games Society Incorporated, for development of a Water Skiing Facility on the Assiniboine River in Brandon Manitoba. A 420 m reach of the Assiniboine River had to be widened by 20 m to a depth of 2 m in order to accommodate venue requirements established by Water Ski Canada. A Floating Turbidity Barrier (sediment screen), was installed before dredging began on September 19, 1996. Construction was completed on November 5, 1996 after approximately 18,000 $m^3$ of material had been removed from the left bank of the Assiniboine River.

The sediment monitoring programme was to measure the suspended sediment load during the construction period and to assess the effectiveness of the sediment control measures implemented at the Waterski development site. Suspended sediment sampling occurred at three hydrometric cross-sections along the Assiniboine River; a control site located 14.9 km upstream of the development site (A-200), a second cross-section located just downstream of the development site (A-400), and a third cross-section 8.5 km further downstream (A-600). Daily suspended sediment concentrations, sampled at the three sites were subjected to the Wilcoxcon Matched Pairs Signed Ranks Test. Recorded suspended sediment loads at the A-200 site were significantly greater than those measured at either the A-400 or A-600 sites. The differences are attributed to the effect of a sediment screen at the construction site, an in channel weir located downstream of the development site but upstream of A-400, and the natural aggradation regime of the river during falling discharges.

## Introduction

A sediment control and monitoring programme was a term/ condition of Environmental Act, Licence issued to the Brandon 1997 Canada Games Society Incorporated for development of a water skiing facility on the Assiniboine River. The proposed waterski facility is located along the left (east) bank of the Assiniboine River, approximately 400 metres upstream of the 3rd Street Weir, adjacent to Dinsdale Park in the City of Brandon, Manitoba (Figure 1).

A 420 m reach of the river had to be widened by 20 m to a depth of 2 m in order to accommodate venue requirements established by Water Ski Canada. During construction, approximately 18,000 $m^3$ of material was removed from the left bank of the Assiniboine River.

## Purpose of the Sediment Monitoring Programme

The purpose of the sediment monitoring programme was to:

1. monitor the normal suspended sediment load in the Assiniboine River during the dredging period;
2. to estimate the amount of suspended sediment introduced into the river during dredging; and
3. to assess the effectiveness of the suspended sediment control measures implemented at the development site.

## Sediment Monitoring Programme Specifications

### Hydrometric Sampling Sites:

Suspended sediment sampling took place at three selected hydrometric cross-sections in the study area:

1) 4.8 km upstream of the development site; (A200),
2) 0.6 km downstream of the development site; (A400) and
3) 8.5 km downstream from the A400 site; (A600).

The first two suspended sediment sampling sites (A200 and A400) are located within the City of Brandon. The A600 site is located approximately 9.1 km downstream of the waterski venue at the eastern limits to the city (Figure 1).

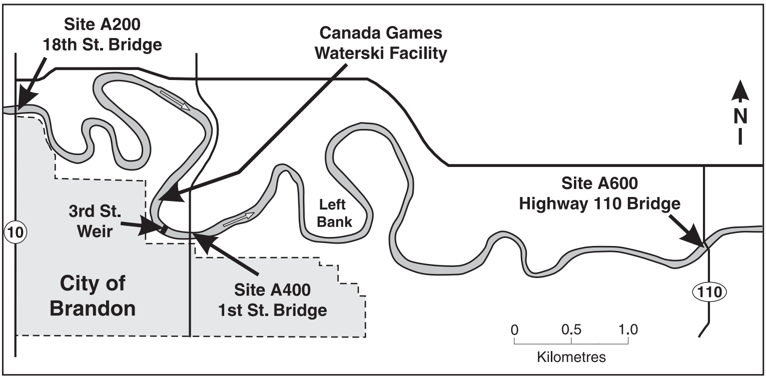


***Figure 1:*** *Assiniboine River: the study reach (Waterski Facility).*

**Sediment Mitigation:**

Contractors were required to complete the dredging of the left bank as quickly as possible during low flow conditions (Environmental Act, Licence 2159). A Floating Turbidity Barrier Type IA, was installed before subsurface dredging began. The sediment barrier consisted of 10 panels of reinforced polyester vinyl laminate, each 100 feet (32.8 m) in length and 7 feet (2.30 m) deep. This screen was set 7 metres out from the bank and anchored with twenty pound (7.69 kg) weights placed approximately every 10 m along the 1000 foot (304.8 m) length of the screen.

The 3rd St. weir, located approximately 400 m downstream of the proposed waterski facility, impounds the river and raises water levels approximately 1.8 m (Crowther et al., 1995). This weir probably trapped many of the larger sized suspended sediments.

**Sampling Procedures and Methodologies:**

Dredging of the left bank began on September 19, 1996. Construction proceeded, six days a week, until late October when soft ground brought dredging to a halt on October 30, 1996. After two weeks of freezing temperatures construction resumed and the project was completed in late November, 1996.

In July and August, 1996, well before construction and dredging began, detailed cross-sections were measured at each hydrometric sampling site. Stream discharge measurements were taken according to the method outlined by Terzi (1981). At the same time, suspended sediment concentrations were sampled using the Equi-Discharge Increment (EDI) methodology as outlined by Tassone, Lapointe and Zrymiak (1992). Stream discharge values and suspended sediment concentrations are used to calculate the total suspended sediment load (Penner et al. 1985).

Once construction had begun, single vertical suspended sediment sampling normally took place each day at the three hydrometric cross-sections. The EDI suspended sediment concentration data, collected prior to construction, were used to identified the sampling verticals. Daily discharge values recorded at gauging station 05MH013, located 14.9 km upstream of the A200 site were used for the calculation of total suspended sediment load. It is estimated that the discharge measured at the gauge would pass completely through the study reach in 25 hours. Therefore, no temporal corrections were applied to the data.

Five additional EDI's were conducted at the three sampling sites during the dredging period. These detailed measurements were used for verification of gauged discharge values and to assure that single vertical sampling was conducted at the appropriate sampling vertical.

Samples were sent to Enviro-Test Laboratories, Manitoba Technology Centre in Winnipeg, Manitoba. Suspended sediment concentrations ( g $L^{-1}$) were measured in the laboratory by the filtration method as prescribed by Environment Canada (Environment Canada, 1987).

## Discussions of Results

**Stream Discharge Regime:**

Figure 2 illustrates the mean daily discharge for the period July 3 to November 12, 1996. On July 3, 1996 mean daily discharge was 82 $m^3\ s^{-1}$. During the next two weeks mean daily discharge fell to 59.6 $m^3\ s^{-1}$. On July 20 an event hydrograph began to move through the study area and mean daily discharges rose. The crest

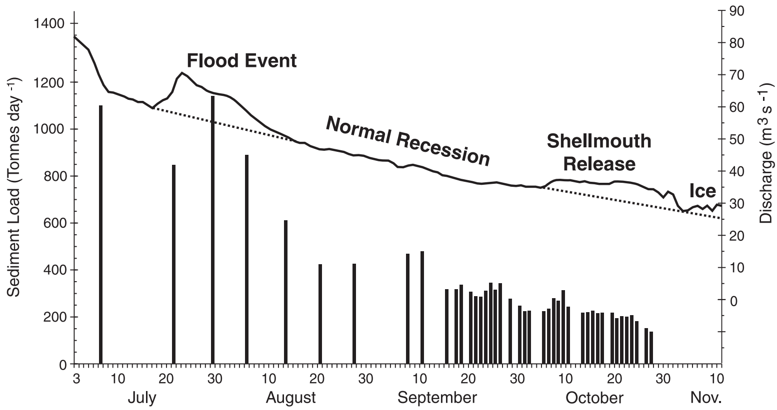


***Figure 2:*** *Assiniboine River (A200) stream discharge and suspended sediment load.*

of this event occurred July 25 when a mean daily discharge of 70.6 $m^3\ s^{-1}$ was recorded at the 05MH013 stream gauge. By August 15 mean daily discharges had returned to recession limb values and continued to decrease throughout the month. In the first week of October mean daily discharge values were at approximately 35 $m^3\ s^{-1}$. On October 7, 1996 a significant discharge release from the Shellmouth Reservoir began to move through the study reach. Discharges rose to 37 $m^3\ s^{-1}$ and remained at values in excess of 36 $m^3\ s^{-1}$ until the end of October. Ice conditions prevailed through the remainder of the study period and recorded discharges declined from 34 $m^3\ s^{-1}$ to approximately 30 $m^3\ s^{-1}$.

**Suspended Sediment Regime:**

Figure 2 illustrates the total suspended sediment loads which were measured at the A200 site for the period July 3 to November 12, 1996. Suspended sediment load is positively correlated with measured stream discharge.

Relatively high suspended sediment loads (1100 tonnes $day^{-1}$) are associated with the large discharges recorded in early July. These values had decreased to approximately 850 tonnes $day^{-1}$ by July 20. As the July 20 - August 15 event hydrograph moved through the study area, suspended sediment concentrations increased by approximately 50 g $L^{-1}$. The total load, recorded 12 days after the peak, had increased to 1142 tonnes day$^{-1}$. Decreasing suspended sediment loads paralleled the decline in discharge throughout August and September. By September 1, suspended sediment concentrations were approximately 100 g L$^{-1}$ and total loads were calculated to be about 425 tonnes day$^{-1}$. Local rainfall events probably account for the increase in suspended sediment concentrations on or about September 10 and 26, 1997. In the first week of October mean daily suspended sediment loads were calculated to be approximately 250 tones day$^{-1}$. As the discharge release from the Shellmouth Reservoir began to move through the study reach (October 7, 1997), suspended sediment concentrations increased to 313 tonnes day$^{-1}$. As discharges dropped to 34 m$^3$ s$^{-1}$ at the end of October, total suspended sediment loads fell to 135 tonnes day$^{-1}$.

Daily suspended sediment loads, measured at paired sites (A200 and A400), (A200 and A600) and (A400 and A600) were subjected to the Wilcoxon Matched Pairs Signed Ranks Test (Snedecor and Cochran, 1972).

**Statistical Results:**

Suspended sediment loads measured at the A400 and A600 site were expected to be less than those recorded at the A200 control site. This expectation is due to three factors:

1. The Floating Turbidity Barrier Type IA, installed at the waterski site, will limit the volume of sediment entering the Assiniboine River during dredging.
2. The 3rd St. Weir, located 200 km upstream of the A400 sampling site, acts as a small dam, impounding the Assiniboine River and slowing stream velocity. As stream competence is reduced, the larger suspended sediments are deposited in the settling basin which has formed upstream of the weir.
3. Decreasing mean daily discharges, common to the late summer and fall, result in reduced stream sediment capacity. As stream capacity declines, in channel sediment deposition occurs. Consequently, the aggrading stream sediment regime is expected to reduce suspended sediment loads in the downstream direction.

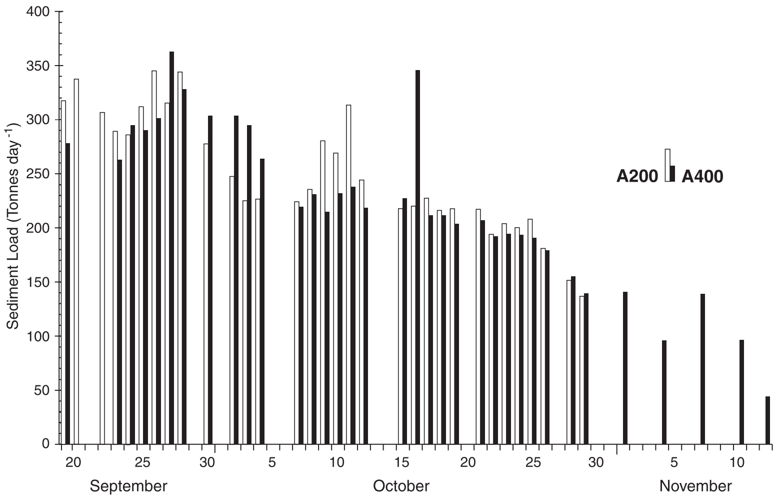


*Figure 3:* *Suspended Sediment Loads: A200 vs A400.*

## Results Of A200 vs A400:

Figure 3 illustrates the suspended sediment loads measured at the 18th St Bridge (A200) hydrometric cross-section and the 1st St. Bridge (A400) sampling site.

Comparative sampling occurred on thirty dates during the dredging period (September 19 - November 15, 1996). The Wilcoxon Matched Pairs Signed Ranks Test indicates that there was a significant difference in the suspended sediment loads ( = 0.01) recorded at the two sites. Suspended sediment loads were higher at the A200 control site on twenty of the sampling dates. This was expected. However, on 10 sampling dates, suspended sediment loads recorded at the A400 site were greater than the sediment loads measured at the control site. The difference between four of the matched pairs was within the range of measurement error (5 percent) and considered not significant. However six of the paired samplings indicate significantly greater suspended sediment loadings. In particular, the period from September 26 - October 4, recorded an average of 15% more sediment in suspension at the 1st St. Bridge site than was measured at the A200 control site located 5.6 km upstream. A second period of significantly higher suspended sediment loads at the A400 site was observed on

October 15 and 16. Particularly on October 16, there was a recorded 57 percent increase in the suspended sediment load measured at the 1st St. Bridge.

**Results of A200 vs A600:**

Comparative sampling occurred on 28 dates during the dredging period. The Wilcoxon Matched Pairs Signed Ranks Test indicates that there was a significant difference in the suspended sediment loads ( = 0.01) recorded at the two sites. Suspended sediment loads were higher at the A200 control site on 26 of the 28 sampling dates. Since A600 is located 13.9 km downstream of the 18th St Bridge (A200), the Assiniboine's aggrading sediment regime was expected to significantly reduce suspended sediment loads through this length of channel. In addition, the 3rd St. Weir is situated between the two sites and was expected to trap significant volumes of suspended sediment.

The two anomalous matched pairs were within the 5 percent measurement error and considered not significantly different.

**Results of A400 vs A600:**

The Wilcoxon Test indicates that there was a significant difference in the suspended sediment loads ( = 0.01) recorded at the two sites. Suspended sediment loads were higher at the A400 site on 25 of the 29 sampling dates. A600's location 8.5 km downstream of the 1st St Bridge (4200) and the Assiniboine's aggrading sediment regime effectively reduced suspended sediment loads through this length of channel.

There were only four dates when the suspended sediment loads recorded at the A600 site exceeded those measures at the A400 site. These differences were not considered to be significant as, in all matched pairs, they fell within the measurement error.

## Discussion

Figure 3 and the results of the Wilcoxon Matched Pairs Signed Ranks Test demonstrate that there is a general decline in suspended sediment loads through the study reach in a downstream direction.

Suspended sediment loads measured at the Highway 110 Bridge (A600) were always less than the suspended sediment loads calculated for the A400 and A200 sites. This indicates that a potential sediment plume generated at the dredging site was undetectable 9.0 km downstream.

At the A400 site six of the paired samplings indicated significantly greater suspended sediment loadings than those recorded at the A200 cross-section. In particular, the period from September 26 to October 4 recorded an average of 15% more suspended sediment at the A400 site than was measured 5.6 km upstream at the 18th St. Bridge. During this period, maximum differences exceeded 22 percent. Clearly, sediment was entering the river during dredging. A second period of significantly high suspended sediment loads, measured at the 1st St. Bridge site, was observed on October 15 and 16. October 16, in particular, registered a 57 percent increase in the suspended sediment load compared to the 18th St. Bridge site. It is speculated that during these two days the floating turbidity barrier was relocated to a downstream position. Relocation of the turbidity barrier was required since the 420 m dredging reach was longer than the total length of the turbidity barrier (approximately 305 m).

## Conclusion

From a statistical perspective, the construction of a waterski facility and the associated channel dredging appears to have had little impact on the normal suspended sediment regime in the Assiniboine River. Observed results are attributed to the effect of a floating turbidity barrier at the dredging site, an in channel weir located 400 m downstream of the dredging site but upstream of the A400 sampling location, and the normal aggrading regime of the river during falling discharges.

During channel bank dredging, the floating turbidity barrier could not prevent all the sediment from entering the Assiniboine River. For a nine day period in late September and early October suspended sediment loading increased by a mean of 15% and by as much as 22%. However, this increase in suspended sediment loading was not detectable at the Highway 110 Bridge 9.0 km downstream. A second sediment plume was detected on October 15 and 16 at the A400 site. Suspended sediment loads increased by 57%. It is suspected that the floating turbidity barrier was repositioned approximately 100 m downstream at this time. Removal of the turbidity barrier introduced significant volumes of trapped sediment into the flow. There was no evidence of this sediment plume extending to the A600 site and it is assumed that the dispersed material had been deposited in the river channel upstream of the Highway 110 Bridge.

Suspended sediment introduced into the Assiniboine River at the dredging site appears to have been deposited within the study reach. If this is the case, the construction of Brandon 1997 Canada Games Waterski Facility at the Dinsdale Park site had little or no impact on the riverine ecosystem beyond the study reach.

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# Optimum route location model for an all-weather road on the east side of Lake Winnipeg

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***Abstract:*** Development of all-weather roads in remote areas presents many problems. This is well illustrated by this study which attempts to determine the best road corridor for the east side of Lake Winnipeg. This corridor must connect the various resource-bases in native communities. This study also investigates the key engineering, environmental and social factors affecting road development to the region. They should not be considered in isolation from one another, as they are interrelated.

Any all-weather road development requires an environmental assessment of some form. Usually such developments are designed with engineering standards in mind, with little heed given to the environmental and social impacts in the early planning stages. The development of optimization models using Geographic Information System (GIS) can assist in the placement of a road by reducing human conflicts and environmental impacts.

The objectives of this study are twofold: firstly, to design an optimum path road network model for the east side of Lake Winnipeg, and secondly, to demonstrate the effectiveness of a GIS model in providing a corridor with the least cost of engineering, and minimal environmental and social impacts.

## Introduction

Development of all-weather roads in remote areas presents numerous problems and conflicts. The east side of Lake Winnipeg is a remote region of dispersed, isolated, small communities which currently rely on temporary, weather-dependent transportation systems. Transport Canada (1987) has recommended an all-weather road facility to assist in the placement of interim improvement facilities, which is to consider environmental and cultural factors.

The Provincial Overview Plan of 1987 (Manitoba Natural Resources, 1987) emphasized the need for multi-use corridors in this region to reduce the overall impact. "It is realized that some zones in the plan area are very sensitive to transportation corridors, the paramount importance of these corridors to isolated communities located within and beyond the plan area should not be neglected."

Any all-weather road development would require an environmental assessment of some form. These types of developments are generally designed to meet efficient engineering standards, with little consideration of environmental or social impacts in the early planning stages. The development of optimization models can assist in establishing a road alignment that would reduce potential conflict and environmental impacts. All-weather roads will link communities and facilitate the exchange of industrial goods, but they can also have a negative impact on caribou calving areas, hunting and fishing in the area.

The purpose of this study is to develop and demonstrate, on a micro- computer based system, an optimum route location model for initial siting of a corridor for road development which takes into account engineering, social and environmental considerations. This model could take into consideration lessons learned from Conflict Regulation by Boulding and Wehr (1979) for improving the overall efficiency and accuracy of conceptual plans. Another objective is to demonstrate the effectiveness of a GIS model in providing a corridor at the lowest cost while minimizing environmental and social impacts. Such a model will provide a beneficial mechanism for resolving conflicts in road development by attempting to take into account the majority of concerns and interests. It has three principal components: road engineering, environmental, and social criteria. Each component is broken into a number of layers which form the raw data for the model. The data is derived from existing maps, satellite imagery and community meetings.

## Study Area

The study area chosen is from the east side of Lake Winnipeg east to the Ontario border and from Hollow Water north to Pigeon

River (Figure 1). The east side of Lake Winnipeg is one of the few remaining regions under developed regions of Manitoba, with most of it accessible only by winter road, boat, or plane. This region of Manitoba is part of the Canadian Shield and is characterized by uplands with exposed bedrock and broad low lying areas. Muskeg and other types of low lying land predominate near the shore of Lake Winnipeg, while areas of bare rock are common along the Manitoba and Ontario border. There are pockets of lakes throughout the region. The region's rivers and lakes drain west into Lake Winnipeg. The shallow soils are a mixture of grey luvisols, organic and rock land covered by boreal forest composed mainly of black spruce, white spruce, jack pine and other coniferous species. The main inhabitants are Aboriginals, Metis, and a few white inhabitants. The total population of around 11,000 people. The majority of the area is Crown Land, which falls under provincial jurisdiction. The Indian Reserve land currently falls under federal jurisdiction.

There are pockets of lakes throughout the region (Table 1). The economy is primarily subsistence with some commercial activity. The unemployment rate is well over fifty percent and the region relies heavily on transfer payments and on southern subsidy (Manitoba Natural Resources, 1987). The population in the region is rising at a rate exceeding three per cent per year. The region may not have the capacity to support the population without continuing subsidy and southern goods (Table 1).

The east side of Lake Winnipeg is in a period of transition. However, the cumulative impact on the environment can be minimized with proper planning and decision making. The use of GIS, mapping database, and Remote Sensing, may help with these processes.

## Methods of Analysis

Modelling refers to the processing of duplicating processes and conditions in order to provide new information about the physical and sociological processes that make make up our world. Route location models have been used for many years. Roberts and Suhbier (1964) used preselected alternate routes and evaluated them

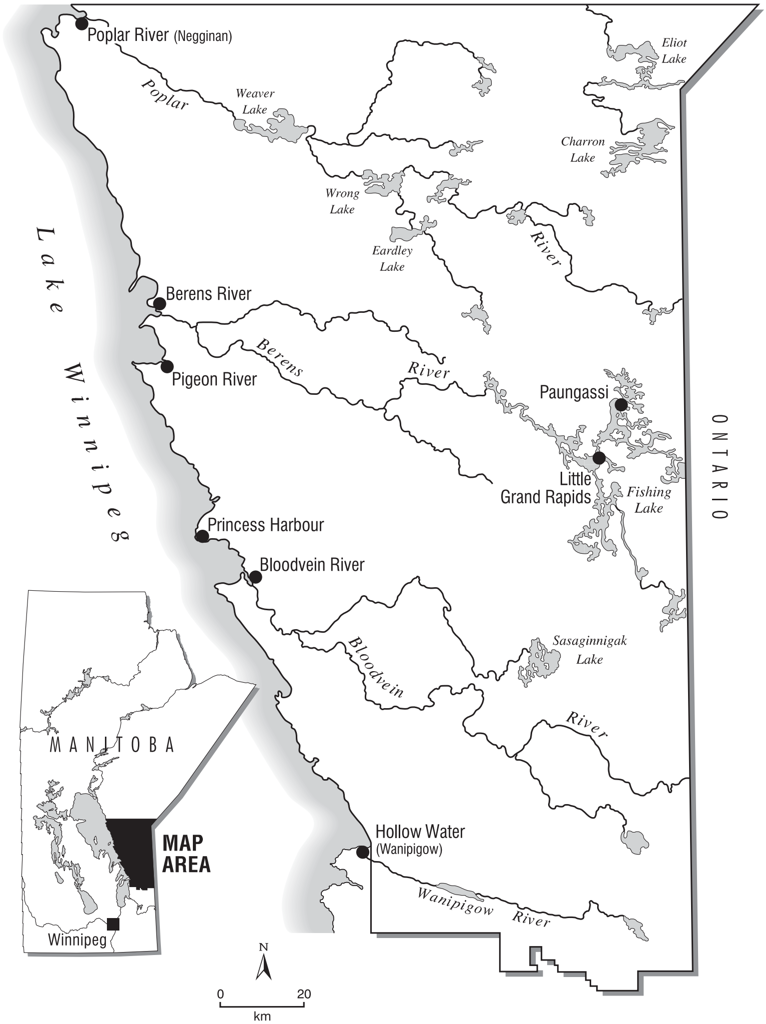


***Figure 1:*** *Location of the sudy area.*

***Table 1:*** *Native communities on east side of Lake Winnipeg.*

| COMMUNITIES | POPULATION | INDUSTRY | DOMINANT LANGUAGE |
|---|---|---|---|
| Bloodvein | 494 | 1,4,7,8,12 | English |
| Little Grand Rapids | 943 | 7,10,1,4 | Saulteaux |
| Paungassi | L.G.R. | 7,10,1,4 | Saulteaux |
| Berens River | 874 | 1,4,9,13 | English |
| Poplar River | 620 | 1,4,8 | Saulteaux |
| St. Theresa Point | 1720 | 1,8,7,4 | Cree |
| Wasagamack | 765 | 1,6,7,8 | Cree |
| Population Total | +5416 | | |

| Economic Activities | | | |
|---|---|---|---|
| 1. | Fishing | 9. | Commercial Industries |
| 4. | Forestry | 10. | Guiding |
| 6. | Hunting | 12. | Band Administration |
| 7. | Trapping | 13. | Government |
| 8. | Construction | 14. | Arts and Crafts |

with respect to several cost variables. This allowed for the rational selection of the best alternative.

Turner and Miles (1971) determined that there are many factors affecting the location of a road: route-dependent factors such as user costs, aesthetics, and the cost of structures. The first set of factors may be associated with the generation of alternatives while the second may be associated with the evaluation of alternatives to find an optimum route.

Both Minamikata (1984) and Nieuwenhuis (1986) developed a raster grid cells method to evaluate road costs. Douglas and Henderson (1988) expanded on these methods, developing a multi-parameter method which used a minimum total rating to obtain the optimum path. The criteria used were topography, land ownership and hazards. They suggested other criteria might be used such a location of sand and gravel, water and railway crossings.

The available database for the present study is derived from a variety of sources including satellite (supervised imagery), computer data bases, map data, statistical data and personal interviews. The map data available includes a mineral potential map (Azis, et al. 1972), land use zones map (Wall 1976), biophysical map of a portion of the region, fishing lodges and outcamps map (Indian and Northern Affairs 1984), topography map (Walton 1988) and surficial deposit map. Each of these sources is input as raw data into the model. The raw database is reclassified into three major categories, namely: engineering, environmental, and social; and various subcategories/ classes according to criteria set out in the optimum path/corridor for the road model. The economic criteria in this model are meant to examine the route of least conflict, although this may not be the least expensive route. The following is a brief description of the major categories and subcategories, along with their scores of the data base selected for the all-weather model;

1. Engineering criteria consists of:
- The percentage slope is classified and assigned a score (weighted value) of 0 value to regions of 0 - 10% slope, 5 value to 10% to 20% slope, and 10 value to 20 and up slope.
- Surface deposits are classified and assigned score of 10 for no deposits, 5 for potential deposits and 0 for commercial deposits.
- Hazards will form the third overlay based on existing barriers to road development. Water bodies or thick forest cover are classified and assigned a score of 0 for no barrier, 5 for partial, and 10 for complete cover barrier.

2. Environmental criteria consists of:
- The east side of Lake Winnipeg offers an opportunity to look at environmental factors which might be affected by the development of a road into a remote area. For example, a wilderness park affords some protection to the region.
- Land use zones are classified and assigned a score of 0 for land readily traversed by a road, while a score of 10 represents regions which should be left alone.
- Natural lake use zones are classified and assigned a score of 0 for a diverse biophysical zone and a score of 10 for a homogeneous zone.

3. Social criteria consists of:
- Lodges/fishing camps classified into and assigned a score of 0 for within 1.00 km buffer, 10 for > 1.00 km away from business

location. Fishing is a primary livelihood and is affected by a road development. While a buffer zone of 1.00 km is recommended around a fishing camp to protect the fishery, freezer plant locations should be placed close to the newly developed road (Manitoba Hydro 1989).

- Communities/residential areas are classified into and assigned a score of 0 for within 1.00 km buffer, and 10 for >1.0 km outside communities. They may provide the destination points for the road. In certain instances it is not desirable to be linked to the south, but regionally integrated (Chorley et al. 1967).
- Existing and potential mine sites are classified into weighted values of 0 for within 1.00 km and 10 for 1.00 km outside a mining area. The road may be able to link areas of potential mining to the region (Romanowski 1986).

The IDRISI software package (Clark University 1987) was used to process the above overlays as well as for importing and converting vector data into raster formats. As a raster based system it provides map overlays easily as well as execution of the model.

The Geography Information Model is designed to incorporate the majority of the factors listed above into a route selection model for the east side of Lake Winnipeg. The goal of the model is to find the optimum all-weather road route, bearing in mind all the related engineering, environmental, and social concerns (Eastman et al. 1993). From the engineering perspective, the most suitable location for all-weather roads is associated with no barriers while unsuitable is associated with barrier areas. To meet the environmental and social concerns, all-weather road routes are protected with a buffer zone of 1.00 km within the engineering suitable area. The total index factor is used to narrow down the suitable corridor for building all-weather roads. Land with the lowest index value is recommended for building. All of the individual layers, in this instance, are treated as equivalents (Barry, et al. 1985). It is also possible to set up a participatory setting where individuals involved can be assigned a relative importance factor. These factors are then weighted according to the results of the participatory group (Arnoff 1989).

Douglas and Henderson’s (1988) work created a least cost road suitability map equation based on each grid cell – having a total grid cell value from 0 - 100. The same results can be obtained using an IDRISI Cost module based on creating a cost surface in relation to a source point or cell, and identifying the current endpoint for the road just north of Hollow Water (see Figure 2). This seemed an appropriate starting point as environmental damage has occurred by development of a logging road.

"The Cost Module generates a distance/proximity surface where distance is measured as the least effort in moving over a friction surface. The unit of measure is 'grid cell equivalents' (gce)" (IDRISI 1996, p. 38). The COSTGROW option was used to deal with complex surfaces of the study region.

The Pathway Module (together with the cost surface module) is used to produce the least cost optimal road. This module requires the destination target cells be indicated as points or lines on an image. A road network cannot be created without repeating the procedure a number of times, because it simply finds a single least cost path to one target. The procedure must be used several times with individual targets to arrive at optimum paths to a number of locations. The width of the path is one grid cell.

## Results

Using the Pathway Module a path was created from the source point north of Hollow Water to Hollow Water. It was found to be extremely close to the road created by a lumber company. A second cost surface map was created with Little Grand Rapids as the source point using the same suitability map. The cost surface was input into the Pathway Module to derive the least cost path to Poplar Point. It was used a second time using the pathway from the source point north of Hollow Water to Poplar River. Figure 2 shows the final map representing a possible road network.

The resulting road network map takes a path close to the edge of Lake Winnipeg to link native communities. The link to Little Grand Rapids and Pauguassi seems to avoid the park lands and does not cross through caribou calving areas. The actual road corridor would come later after further intensive investigation by the local authority of the region as recommended by Simpson and McKecknie (1987). However, the initial process can involve all

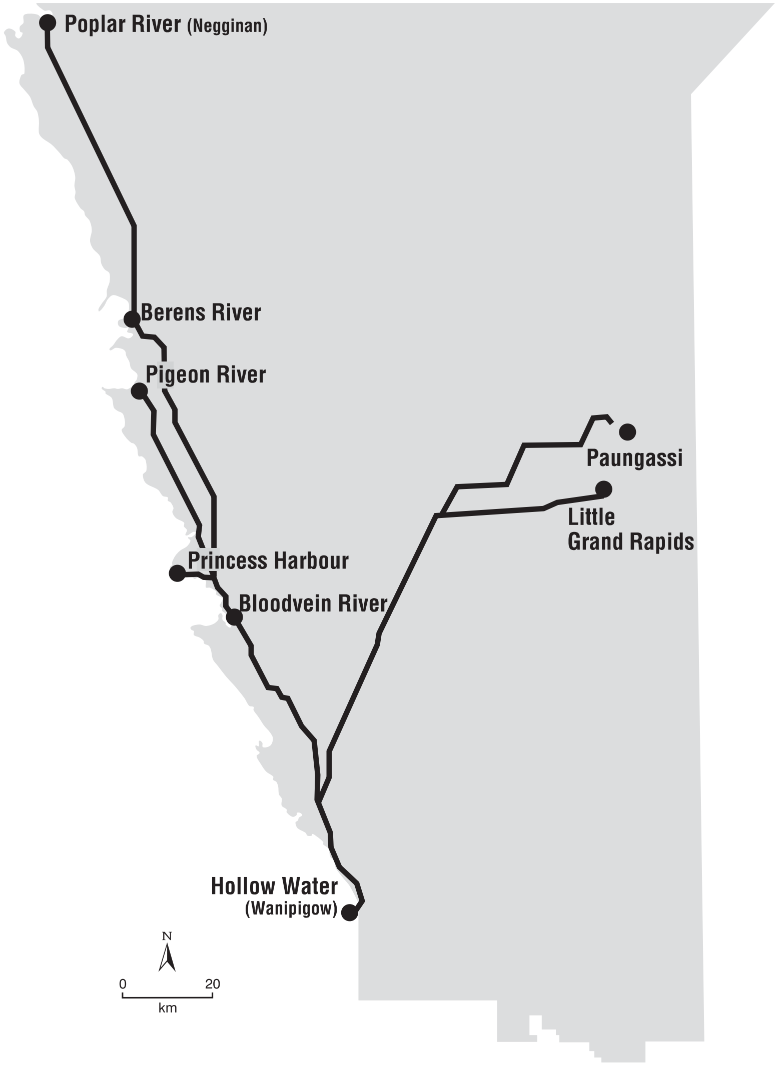


***Figure 2:*** *Location of proposed roads.*

parties in the process of social and environmental assessment prior to ground evaluation.

## Conclusion

In this study, a holistic approach to modelling a suitable corridor for all-weather road development was explored. It incorporated engineering, environmental and social aspects of the region. This type of model can take into account competing interests for a particular parcel of land.

Each portion of the development on the east side of Lake Winnipeg has multiple effects both direct and indirect. they are also cumulative in nature (Canadian Environmental Assessment Research Council 1987 and 1988). Recently the cumulative effects associated with complex developments have been recognized as a major challenge. Many of them can cause irreversible social, economic, and environmental effects. To assess such effects we must adopt a more comprehensive holistic approach to the environment. Each activity can not operate independently of the other. Predictive/simulation models similar to the present study can assist in achieving the most suitable development.

The tools of GIS and Remote Sensing are playing an integral role in this type of modelling, both in a predictive and historical perspective. This type of information will allow for the evaluation and prediction of change.

The east side of Lake Winnipeg holds the promise of some development. If developments such as multi-use corridors and roads are properly planned they will have a positive impact. The model is used to create the most suitable path between two points or a point and a road. Further work needs to be carried out to create a road network module which could form an extension of the Pathway module. This is a limitation of the current IDRISI program models, because they cannot handle the creation of a network. IDRISI also has limited capability in handling the input of routes through a region and determining optimum paths. However, the model can input environmental assessment audits. In fact, it may be in this way that one can further improve the overall model's effectiveness in planning road corridors.

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# Indicator species analysis: an alternative approach to ecosystems geography

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***Abstract:*** Ecosystems geography, or ecogeographic analysis, is the study of the distribution, pattern, structure, and identification of ecosystem boundaries at different levels of detail. Ecological regionalization frameworks are becoming increasingly popular as a logical means of spatially organizing the landscape for the conservation of natural resources, management of the environment, and analysis of spatially distributed ecological phenomena.

The objective of this research was to utilize the cartographic modeling, image analysis, and processing capabilities of geographic information systems (GIS) and remote sensing to conduct and ecogeographic analysis of the state of Indiana utilizing readily available ecological data. The purpose id to demonstrate the use of these technologies in the field of ecosystems geography and compare the resulting regionalization schemes with those developed through traditional methods of ecological regionalization; specifically those of Lindsey (1969) and Homoya et al. (1985).

Two alternative methods of ecogeographic analysis, referred to as indicator species analysis and multivariate cluster analysis, were evaluated. This paper focuses on the application of indicator species analysis, the calculation of an indicator species diversity index, and generation of an indicator species diversity surface in order to delineate ecological boundaries and convey information regarding the the breadth and magnitude of change between adjacent ecosystems. It is suggested that such methodologies may provide resource managers and researchers with a means of defining regionalization frameworks for the management, conservation, and analysis of spatially distributed ecological phenomena that are tailored to the specific management or research initiative at hand.

## Introduction

An increasingly popular application of regional systems is their use as a tool for the conservation, management, and analysis of spatially distributed ecological phenomena. Traditionally, government and private concerns have utilised political units as a template for the management, administration, and analysis of the environment and natural resources. Whereas this may be appropriate for infrastructures established within this context, it is surely an illogical approach for the management of naturally occurring systems. Recently, there has been an increasing awareness and interest in the distribution, pattern, structure, and identification of ecosystem boundaries at different scales of analysis, commonly referred to as ecosystems geography or ecogeographic analysis (Bailey 1996). Many government agencies have begun to develop management strategies based on the regionalization of natural areas or ecosystems for management, assessment, and reporting (Gallant et al. 1989).

The delineation of ecological regions is susceptible to common problems associated with the regionalization process. The boundaries of regions are often assumed to have determinable limits where the characteristics of one region are suddenly replaced by those of an adjacent region. However, few anthropogenic and likely fewer natural regions have hard boundaries. More often, the distinguishing characteristics of adjacent regions gradually change from one region to the next and specific values are chosen to define the boundaries between regions. These intermediate areas or transition zones are referred to as ecotones. An ecotone may be defined as the intersection between adjacent ecological systems having a unique set of biotic and abiotic characteristics described in terms of space, time, and the strength of interaction between adjacent ecological systems (Holland 1988). The delineation of hard boundaries, however, fails to express the breadth and magnitude of change between adjacent regions. Further, landscape boundaries defined in this manner do not indicate the strength of interaction between adjacent ecosystems and potentially valuable information is lost.

Existing ecological regionalization schemes (e.g. Bailey 1976; Omernik 1987) developed for specific applications are likely inappropriate for the variety of conservation, management, and analysis initiatives currently under consideration; particularly at regional or finer scales of analysis. Current ecogeographic literature supports the development of hierarchical, multipurpose regionalization schemes utilising the gestalt, map overlay, or controlling factors methods (Bailey 1996). These methods result in regionalization schemes that are intended to satisfy a variety of applications at various scales of ecological analysis. However, these approaches are essentially a form of manual cartographic analysis and tend to be labour intensive, inherently subjective, and impossible to replicate. Provincial, State, and local ecological regionalization schemes are often based on the expertise of key individuals having an intimate knowledge of the local ecology; an admittedly effective technique but highly subjective and lacking any structured methodology.

It is proposed that alternative methods of ecogeographic analysis utilising the cartographic modelling and image analysis capabilities of geographic information systems (GIS), remote sensing, and readily available ecological data may provide comparable results in a structured, efficient, and cost effective manner. Such methodologies would provide resource managers and researchers with a means of developing custom or user defined ecological regionalization schemes tailored to the specific management issue or research initiative at hand.

The objective of this research was to use the cartographic modelling, image analysis, and processing capabilities of GIS and remote sensing to conduct an ecogeographic analysis of the state of Indiana using readily available ecological criteria. The purpose was to demonstrate the use of these technologies in the field of ecosystems geography and compare the resulting regionalization schemes with existing natural divisions of the state developed through traditional methods of ecological regionalization; specifically those of Lindsey et al. (1969) and Homoya et al. (1985). Further, an alternative approach to the delineation and cartographic presentation of ecosystem boundaries is presented which provides a means of conveying information concerning the breadth and magnitude of change between adjacent ecological systems through the generation of an ecological surface.

Two alternative methods of ecological regionalization were examined. One was based on the spatial distribution of biotic criteria and referred to as indicator species analysis; and the other based on the distribution of a selection of abiotic components of the environment and incorporating multivariate cluster analysis. This paper describes the methods and results of indicator species analysis.

## Methodology

**Indicator Species Analysis:**

This method of ecological regionalization identifies boundaries through the development of broad vegetative regions based on the distribution of indicator species (Livingston 1903; Clements 1905; Curtis 1959; Dix and Smeins 1967). Indicator species are defined here as those species that reach the extent of their geographic distribution within the state of Indiana and, consequently, the limit of their geographic range represents a potential landscape boundary. Indicator species analysis was originally proposed by Livingston (1903) and Clements (1905) and was used by Curtis (1959) to identify floristic provinces in Wisconsin. The premise of this approach is that the distribution of species typical of a particular ecological region is a more useful indicator for determining ecological boundaries than the distribution of rare species. An assumption of this approach is that ecoregion boundaries or ecotones represent a zone of maximum regional indicator species diversity. In other words, ecotones are areas where a number of indicator species representative of adjacent ecoregions overlap. Curtis used distribution maps for 180 species to identify the zone of maximum regional indicator species diversity, or ecotone, between two floristic provinces in Wisconsin.

**GIS Development:**

A GIS vector coverage was created in Arc/Info depicting the total number of indicator species, number of indicator species representing each ecological system, and number of ecological systems occurring in each county for the state of Indiana. These data were recorded as point attributes located at the geographic centre of each county.

Indicator species were selected with reference to Parker (1936) and Freisner (1937). These authors have identifed over 150 trees, shrubs, herbs, flowering plants, ferns, and aquatic species that reach the limits of their range within the state of Indiana. These indicator species are representative of five broad ecological regions: 1) Northern Coniferous Forest; 2) Tall Grass Prairie; 3) Atlantic Coastal Plain; 4) Appalachian Plateau; and 5) Gulf Coastal Plain. The geographic distribution of 120 indicator species was determined using Deam's Trees of Indiana (1921) and Flora of Indiana (1970) as well as current distribution maps of the trees of Indiana developed by Jackson (1997).

Ecological boundaries were identified by mapping the distribution of indicator species representative of each of the five ecological systems occurring in the state. Boundaries were determined by generating isolines depicting the distribution of Atlantic, Appalachian, Northern, Prairie, and Southern species. Isarithmic maps were generated by first interpolating a lattice from the county based points coverage based on the number of species within each system occurring in that county. Three interpolation methods available within Arc/Info were considered: 1) kriging; 2) trend surface analysis; and 3) inverse distance weighting (IDW). Of the three, only the IDW method provided reasonable results and allowed the resulting lattice to be extrapolated beyond the extent of the input points coverage to the edge of the state boundary. Kriging provided reasonable results but did not allow for extrapolation and trend surface analysis resulted in unacceptable results since there was less than a critical number of points in the input coverage.

Isolines were then generated using the Arc lattice-contour function. Figure 1 illustrates the resulting isolines draped over a choropleth map showing relative indicator species abundance; similar maps were generated for each of the five ecological systems considered. The distribution of ecological systems was defined by the isoline representing one third of the total number of indicator species occurring in that system. It was reasoned that areas having

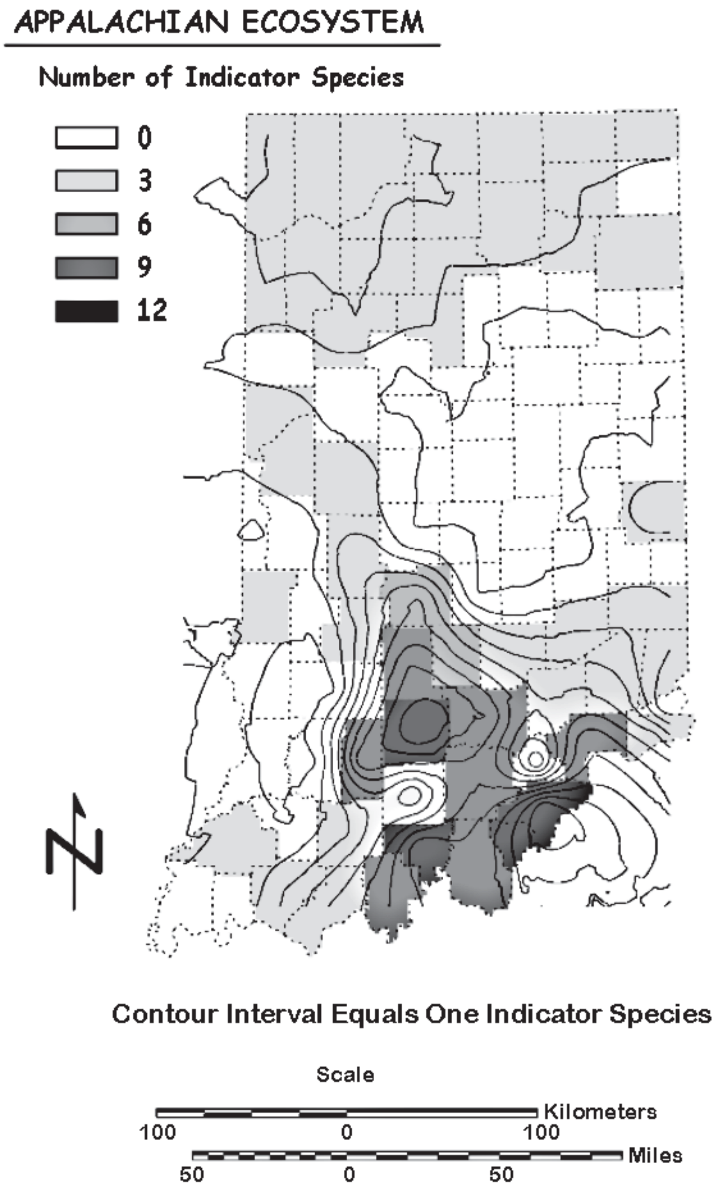


***Figure 1:*** *Isolines draped over choropleth map showing relative indicator species abundance for Appalachian ecosystem.*

one third or more indicator species could be confidently included within a particular ecosystem and that areas with less than this proportion of indicator species represented transitional zones between adjacent ecosystems.

An indicator species diversity surface (ISDS) was then generated by developing a measure of indicator species diversity referred to as the indicator species diversity index (ISDI). This index is a function of the number of systems represented, total number of indicator species, and variability of the number of species occurring within each ecological system.

$$\mathrm{ISDI} = \frac{\mathrm{ES}^2 \times \mathrm{TIS}}{\mathrm{SDIS} + \mathrm{TIS}} \times \mathrm{V}$$

where:

ES = number of ecological systems in that county,
TIS = total number of indicator species in that county,
SDIS = standard deviation of indicator species from each ecological system occurring in that county.
V = a scaling factor, in this case 10.

This index operates such that a county having an equal number of indicator species within three different ecological systems will have a higher index value than a county with a majority of species occurring in one ecological system and only a few in the other two. For example, consider a county with 5 indicator species occurring in each of 3 different ecological systems; the ISDI for this county is 9. If the same county had 3 indicator species occurring in two systems and 9 in the other, the ISDI would be 7.3. Finally, if 13 indicator species occurred in one ecological system, and only one in each of the other two, the ISDI would be 6.2. If only one ecological systems is represented the ISDI will always be 1, regardless of the number of indicator species present. This eliminates any sensitivity to the number of indicator species recorded in each county or within each ecological system.

The ISDS was then constructed by interpolating a surface based on the ISDI calculated for each county using the Arc/Info IDW function. This surface portrays the spatial distribution and ecological diversity of these five ecosystems within the state based

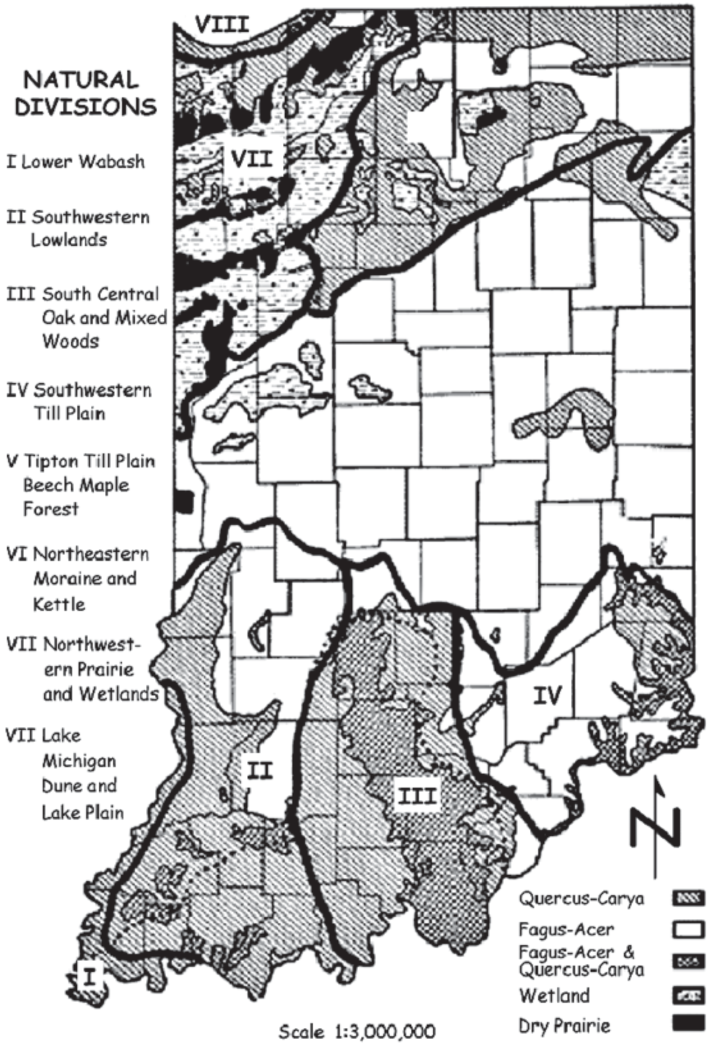


***Figure 2:*** *Natural regions of Indiana (Lindsay et al. 1969).*

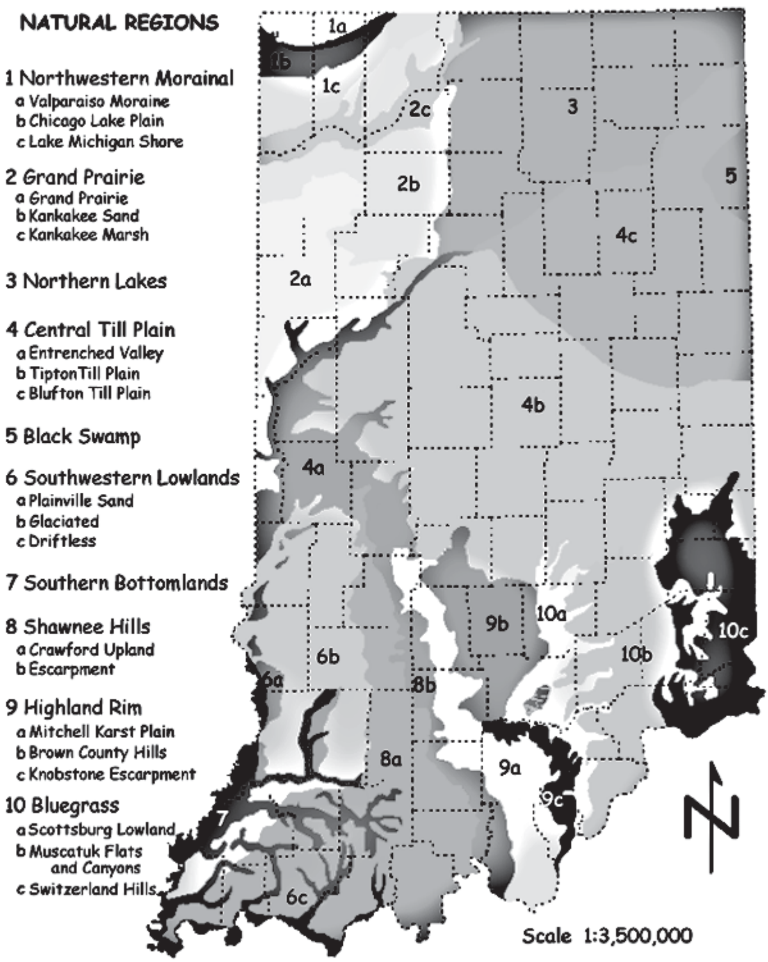


***Figure 3:*** *Natural regions of Indiana (Homoya et al. 1985).*

on the number of indicator species occurring within each system. The ecosystem boundaries previously constructed were then draped over this ISDS. The intent is to cartographically depict the distribution of these ecosystems and also convey additional information concerning the diversity within and between each ecological system.

## Results and Discussion of Indicator Species Analysis

The distribution and location of the regions discussed in the following text refer to the natural divisions of Lindsey et al. (1969) (figure 2) and natural regions of Homoya et al. (1985) (figure 3). Numbers and roman numerals in parentheses following division, region, and section names refer to the corresponding labels on figures 2 and 3. The performance of indicator species analysis was assessed by comparing the results with existing regionalization schemes developed through traditional methods of ecogeographic analysis. Consequently, some discussion of the ecological character of these regions is required, however, the reader is referred to Lindsey et al. (1969) and Homoya et al. (1985) for a thorough discussion of the ecological characteristics of the natural divisions and natural areas of Indiana.

**Interpretation of Indicator Species Diversity Surface:**

The resulting ecological regionalization scheme based on the distribution of indicator species is presented in figure 4. As indicated earlier, the distribution of each of the five ecological systems considered was determined by identifying the isoline representing one third of the total number of indicator species included in each ecosystem. These ecological boundaries have been draped over the resulting ISDS and the boundaries and core areas have been labeled accordingly.

The ISDS indicates that the highest indicator species diversity values occur in the northwestern portion of the state, primarily within the Northwestern Morainal (1) natural region, and in the south central Shawnee Hills (8) and Highland Rim (9) natural regions. These are areas with 25 to 60 indicator species representing 2 or 3 of the five ecological systems considered and with ISDS

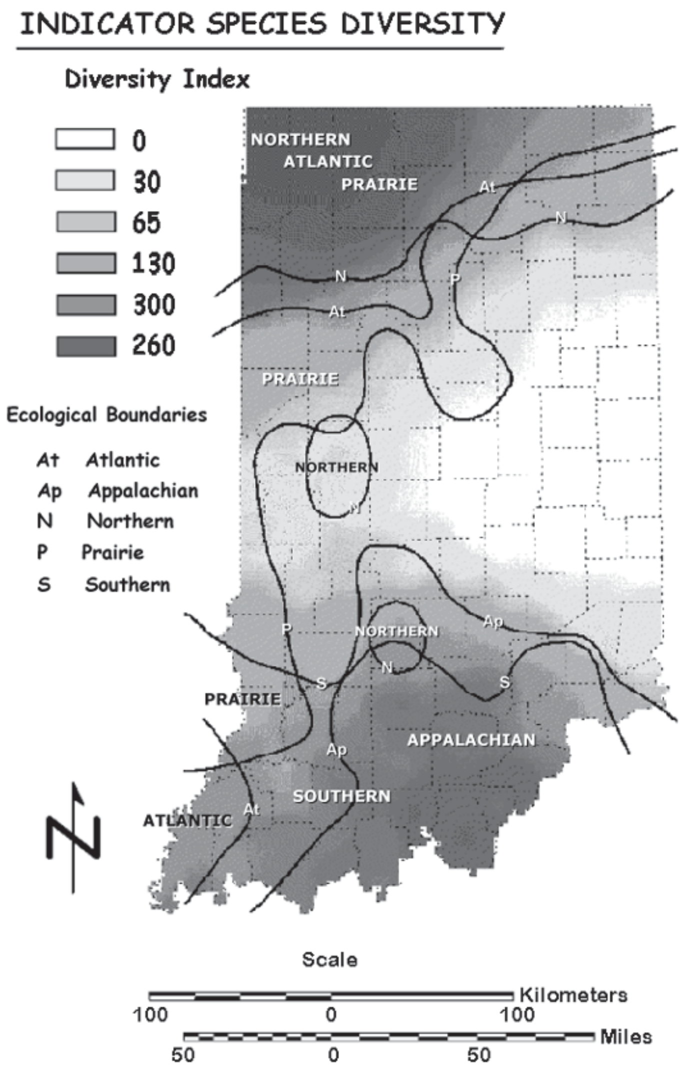


***Figure 4:*** *Resulting ecological regionalization scheme based on the distribution of indicator species.*

values greater than 200. In the northwest, Atlantic, Northern, and Prairie indicator species occur in abundance, while in the south-central region there are significant numbers of Appalachian and Southern species which result in these high ISDS values. ISDS values of 65 to 200 occur in areas with 5 to 24 indicator species representing one or two of the five ecological systems. For example, higher ISDS values occur in the southwest corner of the state where the Southern and Atlantic ecosystems overlap within the Southwestern Lowlands (6) and Southern Bottomlands (7) natural regions.

ISDS values less than 65 occur in areas where only one ecological system is represented or in areas where less than one third of the indicator species in all systems occur. In the west central portion of the state, within and adjacent to the Prairie system, ISDS values range between 30 and 65. In this area a significant but less than critical number of indicator species from each ecological system occur.Figure 4 here.The lowest ISDS values occur in the east central portion of the state where few if any indicator species representative of these ecological systems are present. This simply suggests that none of the five ecological systems considered is represented in this area and does not suggest that there is an overall lack of biodiversity; only a lack of diversity with regard to the indicator species selected from the ecological systems considered.

This area roughly coincides with the Central Till Plain (4) and Black Swamp (5) natural regions and may be characterised by the occurrence of intraneous species having state-wide distributions. In Indiana, species such as white oak (*Quercus alba*), box elder (*Acer negundo*), butternut hickory (*Carya cordiformis*), shagbark hickory (*Carya ovata*), walnut (*Juglans nigra*), American elm (*Ulmus americana*), beech (*Fagus grandifolia*), black cherry (*Prunus serotina*), and sugar maple (*Acer saccharum*) occur state-wide and are of little value for the identification of ecological boundaries through indicator species analysis. Based on the results of these analyses, this area represents a broad transition zone between the southern third of the state, which is dominated by the Appalachian and Southern ecosystems, and the northern third of the state, which is dominated by Atlantic, Northern, and Prairie ecosystems. Thus, relative to the distribution of the five ecological systems considered here, this area is unclassified and represents a broad ecotone, although in reality it may be included within the Eastern Broadleaf Forest system which incorporates the majority of the state at a coarser scale of ecogeographic analysis.

It was suggested earlier that ecotones represent regions of maximum indicator species diversity, where species from adjacent ecological systems overlap. However, unlike the results obtained by Curtis (1959) in Wisconsin, where two floristic regions overlapped within a relatively narrow transition zone, in the case of Indiana several of the ecological systems considered overlap over much of their distribution within the state. For example, the Atlantic, Northern, and Prairie systems share a similar distribution over the northern third of the state, with the exception of the south-western extension of the Prairie system. Consequently, although the maximum regional indicator species diversity does, in fact, occur within the region of overlap between these systems, it is not possible to identify this as an ecological transition zone at this scale of analysis. Since these five ecological systems represent broad continental scale biomes it may not be possible to identify the ecological transition zones between them within the state of Indiana alone. Similarly, the Appalachian and Southern systems share similar distributions in the southern third of the state and likewise a region of maximum indicator species diversity occurs within the area of overlap between these systems. This area may represent a portion of the ecotone between these systems within the state of Indiana but it is not possible to confirm this assumption at this scale of analysis.

The distribution of indicator species representative of these northern and southern ecosystems does not conveniently intersect somewhere in the middle of the state. Instead, we find a large region of low indicator species diversity characterised by intraneous species. It is possible that the addition of other indicator species or inclusion of an additional ecological system occurring within this area may alter the range of the five ecological systems considered and therefore the character of the ISDS. Alternatively, future research may attempt to include intraneous species in some manner such that we are able to account for regions that are otherwise undefined by the distribution of indicator species representative of the ecological systems considered.

**Distribution of Ecological Systems:**

In relation to the traditional state level regionalization schemes of Lindsey (1969) and Homoya et al. (1985) the distribution of these ecological systems is at a much coarser level of ecogeographic analysis and subsequently incorporates a number of the unique areas defined within these regionalization schemes. The Atlantic, Northern, and Prairie systems in the north occupy the majority of the Northwest Morainal (1), Grand Prairie (2), and Northern Lakes (3) natural regions of Homoya. These in turn correspond with the Northeastern Moraine and Kettle (VI), Northwestern Prairie and Wetland (VII), and Lake Michigan Dunes and Lake Plains (VIII) natural divisions of Lindsey. These regions fall within the Northern Moraine and Lake physiographic region characterised by intermittent lacustrine and outwash plain sediments over a vast area of till and end moraines.

The Appalachian and Southern systems in the south include Homoyas Soutwestern Lowlands (6), Southern Bottomlands (7), Shawnee Hills (8), Highland Rim (9), and Bluegrass (10) natural regions or Lindseys Lower Wabash (I), Southwestern Lowlands (II), South Central Oak and Mixed Woods (III), and Southeastern Till Plain Divisions (IV). The northern extent of the Southern and Appalachian systems corresponds well with the southern limits of Wisconsin and Illinoian glaciation respectively.

The southern extension of the Prairie system into the Southwestern Lowlands (6) natural area is identified by Homoya and is associated with edaphic factors affecting soil moisture capacity. The unclassified east central region of the state coincides with Homoyas Central Till Plain (4) and Black Swamp (5) natural regions and Lindseys Tipton Till Plain Beech-Maple (V) division.

## Conclusions

It appears that the use of indicator species as described here may provide a useful alternative to traditional methods of ecogeographic analysis when the identity and distribution of species representative of the desired ecological systems is known in advance. It is likely that a more comprehensive regionalization scheme would be provided if every ecological system occurring within the study area at the given scale of ecogeographic analysis were considered. Further, it appears that a consideration of the scale of ecogeographic analysis as compared to the geographic extent of the study area is crucial. For example, the regionalization of continental scale biomes within a comparatively small study area, such as the state of Indiana, may provide results difficult to interpret due to the limited scope of the study area. Provided that the data are available it is recommended that the scale of ecogeographic analysis is at least one order higher than that of the study area considered. It should also be noted that this index only provides a measure of diversity with regard to the ecological systems considered and is not an indication of overall biodiversity.

Indicator species analysis, the ISDI and resulting ISDS provide a useful method of identifying and conveying information concerning the character of the resulting ecological regionalization scheme. In addition, they provide a means of identifying areas of exceptionally high or low indicator species diversity and, therefore, communicate information regarding the breadth and strength of interaction between adjacent ecological systems.

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# Change in the size and functions of Regina's central business district, 1964-1997

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***Abstract*:** The paper employs Murphy and Vance's CBD delimitation method to map change in the extent of Regina's CBD. Analysis suggests that the CBD expanded by 25 percent over the study period and became relatively more efficient in serving the needs of city. Most growth can be attributed to office and government functions. Considerable vertical stacking of these functions has taken place in the CBD's core which is now dominated by large office towers. Decline of the CBD's retailing function has been linked to the development of large suburban shopping malls and warehouse-style stores. In contrast, tax exemption policies are indicated as a factor in the recent expansion of residential land use in the CBD. Speculation suggests that the CBD's size and dominant functions will not alter radically over the next several decades. The role of planning in regulating the location and form of land use in the CBD is stressed.

## Explaining Urban Development

In the North American city change in the form and function of urban areas reflects the interplay of development forces and urban planning. Change takes place within a predominantly free enterprise economic system in which development is both facilitated and constrained by prescribed planning processes, and by attendant land-use and zoning regulations. In this manner the precise form and function of development at any one location is judged to reflect the interests of both the development sector and the community at large. Typically, it is the central business district (CBD) and suburban fringe environments of the city which experience the most rapid change, and it is in these areas that development issues are most encountered. This paper outlines change in the form and functions of Regina's CBD between 1964 and 1997. The relationship between change in CBD functions and the growth of commercial activities in the suburbs is examined. An attempt is then made to assess the likely course of future developments in the CBD.

## Delimiting the CBD

Before examining change in the functions of Regina's CBD it is first necessary to determine its geographical extent. The most widely accepted method of delimiting CBDs is provided by Murphy and Vance (1954). The method employs four steps. First, characteristic CBD functions are identified. These include retailing, office and financial services and the accommodation sector, but not manufacturing and wholesaling activities, or government services and residential land use. Second, the floor area devoted to CBD functions is measured for all floors in each building on a block by block basis. Third, the intensity of CBD functions for each block is expressed in the form of two indices, the central business height index (CBHI) and the central business intensity index (CBII).

The CBHI indicates the extent to which CBD functions are vertically concentrated within each block. For each block, the CBHI is determined by dividing the cumulative floor area in CBD functions on all floors of each building by the total ground floor area of the block. A CBHI of 1.0 indicates that CBD functions cover an area equivalent to the entire ground floor area of the block. Indices greater than 1.0 signify varying intensities of vertical concentration or stacking of CBD functions. The central business intensity index (CBII) measures the floor area occupied by CBD functions in relation to total floor area. It too is determined by simple division of the two measurements. This index indicates the relative dominance of CBD functions in a block, with the value of 0.5 being selected as an indication of dominance. Finally, the two indices are used in combination to delimit the CBD. Essentially, the CBD is identified as an area of contiguous blocks in each of which the minimum values of the CBHI and CBII are 1.0 and 0.5 respectively. Other studies have refined these criteria to identify the core of the CBD (Horwood and Boyce 1959; Davies 1960). In this study identification of the CBD core follows the criteria set by Davies who judged that a CBHI of 4.0 and a CBII of 0.8 delimits its extent.

## Delimiting Regina's CBD

The above mentioned criteria have been applied at widely separate dates to delimit Regina's CBD (Wright 1964; Barriault 1993). Both studies modified Murphy and Vance's original criteria to include government or public administration as a characteristic function of the CBD. The rational for including this function was based on the knowledge that the CBDs of large Canadian cities are frequently the focus of considerable public sector employment. Arguably the provision of government services draws people into the CBD and thereby adds to the potential for retail and other businesses to benefit from persons making multi-purpose trips. Government employees themselves add to the demand for non-government services in the CBD. Beyond this, the construction of buildings to house government services can act as an important element, or even catalyst, in the expansion and renewal of the CBD. In the case of Regina, these factors are made evident by the city's role as a provincial capital and regional centre for federal government departments.

In delimiting Regina's CBD each of the aforementioned studies identified the peak value land intersection (PVLI) and then proceeded to measure the CBHI and CBII indices for each block within a designated study area (Figure 1). The latter was identified as being bounded by Saskatchewan Drive in the north, College Avenue in the south, Halifax Street in the east, and Rae Street in the west. It should be noted that neither study included the narrow strip of land located between Saskatchewan Drive and the mainline of the Canadian Pacific Railway (CPR). By 1997, that part of the study area to the north of 13$^{th}$ Avenue was clearly dominated by office and retailing functions. The city's business community promotes this area as Regina's Market Square. An overlapping area located south of Victoria Avenue and extending between Albert Street and Broad Street is identified for purposes of local administration as the Transition Area. The Transition Area has

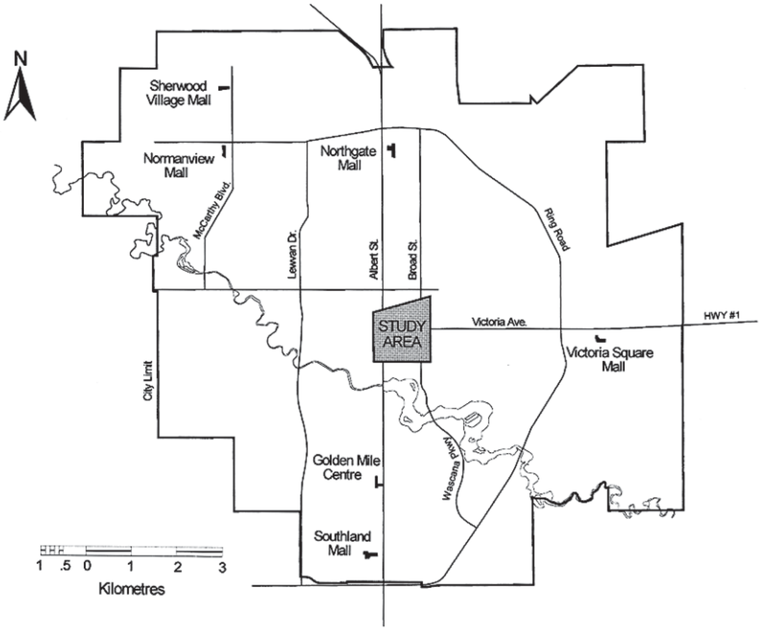


***Figure 1:*** *Location of study area and Regina's major suburban shopping malls.*

traditionally served as a residential neighbourhood, but in recent decades many of its house form structures have been replaced by office blocks and multi-unit condominium developments, or have been converted into offices providing professional services. Of all areas adjacent to the CBD, it best fits the description of *zone in assimilation*.

The results of the delimitation method are shown in Figures 2 and 3. In 1964 the PVLI was identified at the junction of 11th Avenue and Hamilton Street. Adjoining this location the CBD was confined to a 27-block area entirely within the area now designated as Regina's Market Square. Importantly, the extent of the CBD was somewhat exaggerated insofar as the 1964 study only considered the Victoria Avenue frontages of blocks 365 to 369, and thereby caused their CBHI and CBII values to be inflated. The northern boundary of the CBD coincided with the study area boundary along Saskatchewan Drive. Northward expansion beyond Saskatchewan Drive was effectively halted by the presence of the


***Figure 2:*** *Spatial extent of Regina's CBD and CBD core in 1964.*

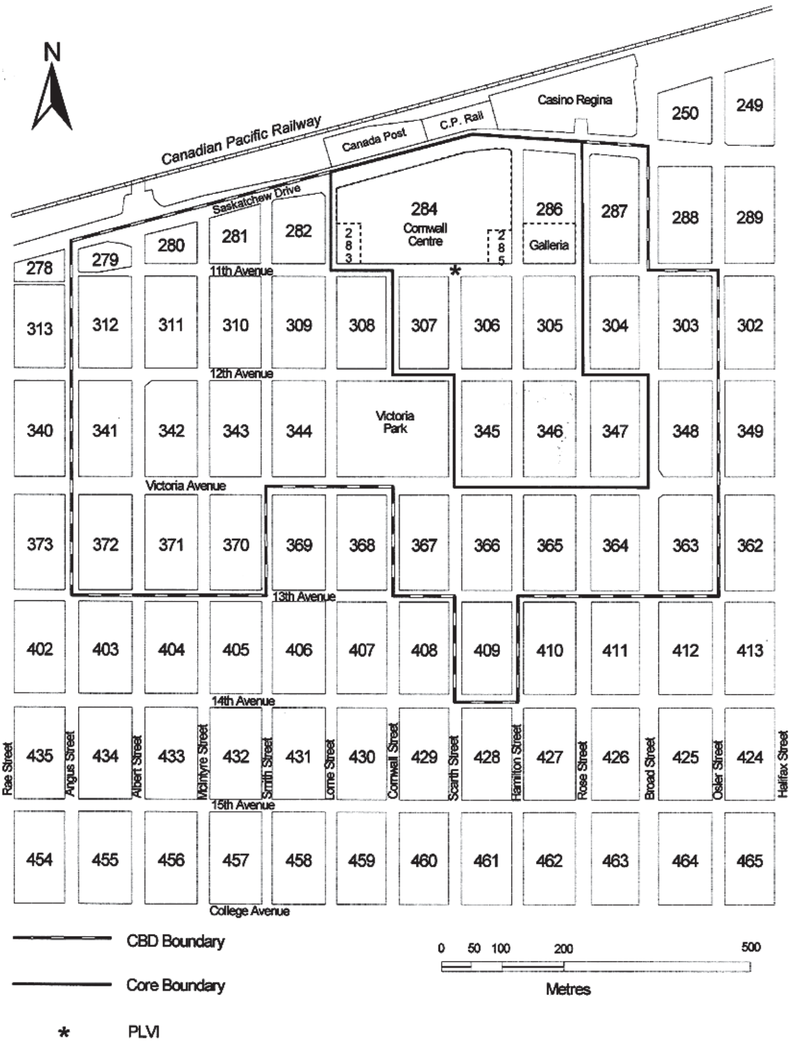


***Figure 3:*** *Spatial extent of Regina's CBD and CBD core in 1993.*

CPR mainline. In all other directions expansion of the CBD was determined by the interplay of market forces and planning regulations rather than by physical barriers. Within the eastern half of the CBD an 11-block core area was identified anchored around the PVLI. It should be noted, however, that the criteria for core area delimitation used by Wright (1964) were less demanding than those suggested by Davies (1960) and later adopted by Barriualt (1993). Had Wright employed the more stringent criteria, no block would have qualified for inclusion in a core area, a situation which would obviously have been unrealistic.

Between 1964-1993 the street and block pattern of the CBD changed slightly, first in the mid 1970s to accommodate the pedestrianisation of Scarth Street between 11th Avenue and 12th Avenue, and then in 1981 to facilitate development of the Cornwall Centre shopping mall. The latter development required the closing of Cornwall Street and Scarth Street between Saskatchewan Drive and 11th Avenue. More recently in the early 1990s, the Scarth Street Mall was subject to a series of improvements aimed at enhancing its appeal as a retailing environment. These improvements included the renovation of store frontages, the construction of a climate-controlled walkway linking the frontages of each store, and completion of a streetscaping programme.

By 1993 the PVLI had shifted one block west to the junction of 11th Avenue and Scarth Street. At the same time the CBD had expanded to encompass 35 city blocks, a 25 percent increase. This expansion was largely confined to blocks in the south of the study area and represented expansion of the CBD into the Transition Area. Again, Regina's inability to implement a rail relocation programme meant that the northern boundary of the CBD remained fixed, perhaps permanently. Somewhat paradoxically, whilst the area of the CBD expanded between 1964-1993, the area of the core decreased marginally and was confined to a compact 10-block area extending between the Cornwall Centre and the junction of Victoria Avenue and Broad Street. This said, it must be emphasised that the 1993 delimitation employed more stringent criteria in identifying the core area, and further, that a reasonable case for including Blocks 363, 366 and 409 can be made on the basis of their high indices and proximity to other blocks in the core.

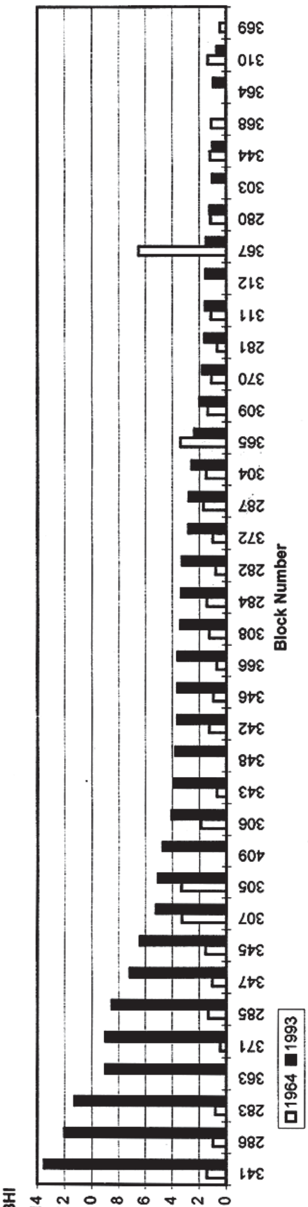


***Figure 4:*** *Change in the Central Business Height Index (CBHI) of Regina's CBD 1964-1993.*

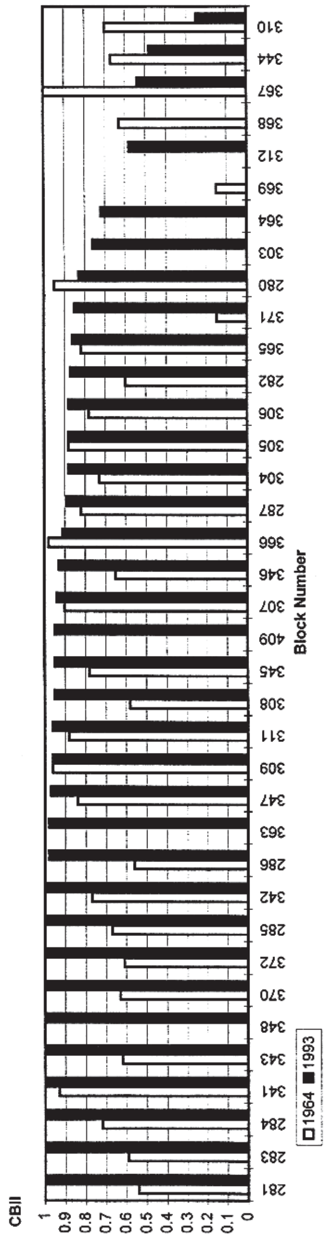


***Figure 5:*** *Change in the Central Business Intensity Index (CBII) of Regina's CBD 1964-1993.*

***Figure 6:*** *View of Regina's CBD from the south.*

## Beyond Delimitation

Simple delimitation of the CBD and core areas masks the true scale of change that has taken place in Regina's CBD since 1964. A more realistic impression of the increased concentration of CBD functions is provided by an examination of CBHI and CBII indices (Figures 4 and 5). If blocks 365 to 369 are excluded from analysis because of the method by which their 1964 indices were inflated, then all blocks identified in the CBD in 1964 registered an increase in their CBHI by 1993. In 1964 the maximum CBHI was just 3.3 (Block 305) and most blocks in the CBD had CBHIs of less than 1.5. In contrast, by 1993 the maximum CBHI had increased to 13.5 (Block 341), twelve blocks each had indices greater than 4.0, and only three blocks had indices of less than 1.5.

Similarly in 1964, with the exception of the part block occupied by Hotel Saskatchewan (block 367), no block had a CBII of 1.0. Also, only ten blocks had indices greater that 0.8. This situation contrasts with that observed in 1993. By then, eight blocks had CBIIs of 1.0 and a further 21 blocks registered indices in excess of 0.8. Quite clearly by 1993 the major change in the limits of Regina's CBD had occurred in the vertical rather than the horizontal dimension, and in the concentration rather than dispersal of CBD functions. Visible expression of these changes is now observed in

***Table 1:*** *Major real estate developments in Regina's CBD, 1964-1997.*

| Block No. | Building | Floor Area Square Fee | Date of Construction | Principal Function |
|---|---|---|---|---|
| 308 | Bank of Canada | 32,364 | 1964 | Office |
| 345 | Avord Tower | 37,339 | 1965 | Office |
| 348 | Regina Inn | 147,441 | 1966 | Hotel/Retail/Office |
| 372 | Saskatchewan Wheat Pool Building | 72,000 | 1967 | Office |
| 345 | TD Bank Building | 58,560 | 1973 | Office |
| 371 | Credit Union Central Phase I | 94,155 | 1975 | Office |
| 347 | Sands Hotel | 79,471 | 1976 | Hotel |
| 364 | London Life Place | 25,849 | 1976 | Office |
| 347 | Chateau Tower | 46,243 | 1977 | Office |
| 343 | Queen Elizabeth II Court (City Hall) | 66,264 | 1978 | Office |
| 283 | SGI Tower | 53,267 | 1979 | Office |
| 285 | Royal Bank Tower | 54,426 | 1979 | Office |
| 363 | South Broad Plaza | 72,195 | 1979 | Office |
| 308 | Sask. Telecommunications | 194,190 | 1952/1972/1979 | Office |
| 285 | Sask Tel | 185,744 | 1980 | Office |
| 286 | 2001 Cornwall | 55,311 | 1980 | Residential/Office |
| 307 | Bank of Montreal Building | 53,215 | 1980 | Office |
| 342 | North Canadian Oil | 24,708 | 1980 | Office |
| 284 | Cornwall Centre | 540,688 | 1981 | Retail |
| 346 | Sask. Energy Tower | 25,364 | 1981 | Office |
| 305 | Canada Trust Tower | 99,098 | 1983 | Office |
| 307 | McCullum Hill Centre Phase I | 180,956 | 1984 | Office |
| 312 | Sask. Place | 99,972 | 1985 | Office |
| 310 | Trianon Tower | 24,350 | 1987 | Residential |
| 286 | Ramada Plaza Hotel | 139,833 | 1988 | Hotel/Office |
| 286 | Galleria Shopping Centre | 158,746 | 1989 | Retail/Office |
| 286 | Scotia Tower | 36,836 | 1989 | Office |
| 363 | Wascana Energy | 86,786 | 1989 | Office |
| 306 | McCullum Hill Centre Phase II | 180,956 | 1991 | Office |
| 306 | CIBC Tower (new) | 203,653 | 1991 | Office |
| 341 | Sherwood Credit Union Phase II | 170,646 | 1992 | Office |
| 345 | Crown Life Place | 94,640 | 1992 | Office |
| 409 | Page Credit Union (Financial Building | 5,709 | 1992 | Office |
| 341 | CDSL Tower | 188,000 | 1953/1992 | Office |
| 371 | Credit Union Central Phase II | 81,553 | 1993 | Office |
| 305 | CIBC Tower (old) | 34,759 | 1997 | Residential |
| | **Total construction** | **3,705,287** | | |

the city's skyline signature of Modernist and Late Modernist tower blocks (Figure 6).

The background to these changes has been the more or less sustained program of construction in the CBD since 1964. Except for a six-year period starting in the late 1960s and in the period since 1993, one or more major construction projects have been started in most years (Table 1). Total construction of large projects excluding parking lots is estimated at approximately 3.7 million square feet, of which about 99 percent represents new construction rather than renovation or refurbishment. Of this same total, approximately 70 percent represents office construction.

## The Functions of Regina's CBD

Change in the concentration of CBD functions has been accompanied by shifts in their relative importance. In 1964, retailing was the most important function of the CBD and accounted for 26.1 percent of the total floor area (Table 2). Taken collectively, all CBD functions accounted for 77.9 percent of the total floor area. By 1993 this situation had changed dramatically. Office space now accounted for 46.5 percent of the floor area and occupied as much space as all other CBD functions combined. Although expanding in absolute terms, retailing had slipped to fourth place behind parking and hotels in order of floor area occupied. Increased functional specialisation of the CBD was indicated insofar as 92.9 percent of the total floor area was now occupied by CBD functions.

Growth of the CBD's hotel and accommodation function over the study period reflects promotion of the city as a centre for business and convent travel, and more recently as a location for casino gambling. Major developments have included the Regina Inn (block 348) and Sands Hotel (block 347) on Victoria Avenue, both of which compliment the long-established role of Hotel Saskatchewan (block 367). The city's tallest building, the Ramada Plaza Hotel (block 286), occupies a site on the northern fringe of the CBD and is advantageously place to serve visitors to Casino Regina (Figure 3).

As indicated above, government services and public administration were classified as CBD functions in the 1964 and 1993 studies. This sector grew substantially in absolute terms over the study period but declined in relation to the office and hotel sectors. Nevertheless, the data presented in Table 3 almost certainly disguise the sector's importance to the vitality of the real estate market in the CBD. Aside from the provincial Crown Corporations such as SGI (block 283) and SaskPower (block 366) which occupy properties in their own name, several federal and provincial

***Table 2:*** *Comparative change in the functions Regina's CBD, 1964-1997.*

| Function | Floor Area Square Feet 1964 | Floor Area Square Feet 1993 | % Change in Floor Area 1964-1993[1] | % Share of Floor Area 1964 | % Share of Floor Area 1993 |
|---|---|---|---|---|---|
| Office | 946,300 | 8,268,225 | 773 | 15.1 | 46.5 |
| Parking | 1,067,200 | 2,574,237 | 141 | 17.1 | 14.5 |
| Hotels | 544,050 | 2,362,992 | 334 | 8.7 | 13.3 |
| Retail | 1,634,210 | 1,764,477 | 8 | 26.1 | 9.9 |
| Government | 685,900 | 1,551,893 | 126 | 10.9 | 8.7 |
| Vacancies | 445,100 | 523,292 | 18 | 7.1 | 2.9 |
| Residential | 473,500 | 396,418 | (16) | 7.6 | 2.2 |
| Institutions | 319,900 | 342,678 | 7 | 5.1 | 1.9 |
| Wholesale | 134,800 | 0 | (100) | 2.2 | 0.0 |

[1] values in parentheses denote negative change

Source: Wright (1964); Barriault (1993)

government agencies rent space in the large tower blocks throughout the CBD. Examples include PFRA in the CIBC Tower (block 306) and Municipal Government in London Life Place (block 347).

Other notable changes in CBD land use have included a substantial increase in the space devoted to parking and the total demise of wholesaling. Except in areas south of Victoria Avenue and west of Lorne Street much of the additional parking space has been provided in the form of multi-storey car parks. Examples include those built in conjunction with the Cornwall Centre (block 284) and the Ramada Plaza Hotel (block 286). The demise of wholesaling reflects the lack of suitable space and the CBD's relatively high rents. Its demise is not exceptional, however. Wholesaling has never been a major function in Regina's CBD. Traditionally most wholesaling operations have been conducted in the Warehouse District immediately north of the CBD and CPR mainline. Other large wholesaling operations are located in Ross Industrial Park in the northeast of the city where access to road and rail services is optimised.

## Recent Developments

Since Barriault's study in 1993 the pace of new construction in Regina's CBD has slowed to a virtual standstill. Despite this, land-use functions in the CBD have continued to change. One indication of this is the further decline of retailing. Between 1964 and 1993 retailing experienced relative decline. However, the visibility and extensive pattern of vacancies revealed in a 1997 survey suggests that decline may now be absolute (Figure 7). Vacant properties included ones on Hamilton Street and others in the Galleria shopping mall, both of which are located within the area designated by planners as the CBD's prime retailing environment. The explanation for this decline is not hard to find. Despite its slow growth compared to most large Canadian cities, Regina has experienced considerable suburbanisation since the 1960s. Suburbanisation has been associated with the development of large suburban shopping malls, the first of which, the Golden Mile Centre, was built in 1959 (Table 3). These malls offer the convenience of ample free parking and climate-controlled shopping environments. As if to emphasise the declining fortunes of retailing in the CBD, several of the malls have undergone renovation and expansion programmes in the 1990s. More alarming still has been the recent development of several stand-alone warehouse-style stores along East Victoria Avenue in the vicinity of Victoria Square Mall (Figure 1). This area is well located to serve rapidly expanding suburbs in southeast Regina (e.g., Spruce Meadows and Windsor Park) and the exurban communities to the east of the city (e.g., Balgonie, White City and Pilot Butte).

In marked contrast to the decline in retailing the last two years have witnessed renewed interest in the CBD's residential function. This situation reflects a general process of societal change as witnessed in the increasing number and diversity of small households, some of which seek residence close to their place of work. Perhaps more importantly, the interest in 'living downtown' appears to be driven by speculative interests in the real estate market. In explanation, the sustained investment in office and hotel construction which terminated in the early 1990s created a surplus of rentable space, particularly in older office towers. Faced with


***Figure 7:*** *Distribution of vacant retail property in the vicinity of the CBD's retailing core,*

***Table 3:*** *Major suburban retailing developments, 1959-1997.*

| | Date of Construction | Floor Area Square Feet | | Date of Construction | Floor Area Square Feet |
|---|---|---|---|---|---|
| **Northgate Mall** | 1966 | 239,188 | **Normanview Mall** | 1976 | 203,371 |
| | 1977 | 120,224 | | 1996 | 8,224 |
| | 1993 | 6,468 | **Sub-total** | | **211,595** |
| | 1996 | 18,889 | | | |
| **Sub-total** | | **384,769** | | | |
| **Golden Mile Centre** | 1959 | 64,357 | **Victoria Square Mall** | 1982 | 221,936 |
| | 1975-1977 | 195,000 | | 1996 | 107,597 |
| | 1990-1992 | 11,405 | **Sub-total** | | **329,533** |
| **Sub-total** | | **270,762** | | | |
| **Southland Mall** | 1975 | 338,226 | **East Victoria Avenue** | | |
| | 1989 | 3,832 | Costco | 1992 | 127,067 |
| | 1995 | 14,106 | East Landing | 1994 | 40,993 |
| | 1996 | 56,645 | Mark's Work Warehouse | 1995 | 12,503 |
| **Sub-total** | | **412,809** | Peavey Mart | 1996 | 16,200 |
| | | | Liquor Store | 1996 | 13,000 |
| **Sherwood Village Mall** | 1980 | 178,000 | Staples | 1997 | 25,671 |
| **Sub-total** | | **178,000** | Home Depot | 1997 | 103,250 |
| | | | **Sub-total** | | **338,684** |
| | | | **TOTAL** | | **2,126,152** |

the prospect of these buildings remaining vacant or being demolished, the City has introduced a Downtown Residential Incentives Policy (DRIP). Under terms of the Policy developers are eligible to claim a five-year tax exemption on buildings and lands which are renovated or newly constructed for residential use. To date only the old CIBC tower (block 305) has been renovated for residential use, but others such as the Western Guaranteed Trust Building (block 285) and the Motherwell Building (block 365) are being planned or in process of renovation.

## Future Prospects

Speculating on the future condition of urban areas is risky, and yet the anticipation of urban futures is fundamental to planning for a 'sustainable' urban environment. With this in mind it is possible to draft a scenario of future urban development in Regina for the next several decades. Thus with respect to future expansion of the CBD, the most logical course of development would see further intensification of land use in the blocks surrounding the existing core. Planning policy supports this option. In this context the most likely candidates for intensification are the eight blocks located to the northwest of Victoria Park and the seven blocks immediately south of Victoria Avenue extending between Broad Street and McIntyre Street. Large parts of these blocks are currently occupied by low intensity land uses, including many street level parking lots, and might be considered to be held speculatively in anticipation of further expansion of the core.

Elsewhere the prospects for intensification or expansion seem less likely. Further expansion west of Angus Street is most unlikely in view of the substantial gentrification that is taking place in the neighbourhood. Blocks 403 and 434 are also excluded from consideration because of the recent completion of apartment and condominium units on these sites. One vacant (block 426) and several low intensity sites exist in the Transition Area south of 13$^{th}$ Avenue. However, recent developments on adjacent sites and current zoning suggest that future development in this area is likely to focus on apartment and condominium units. The most problematic area concerns most of the blocks east of Broad Street. Many of the business properties fronting Broad Street in the area north of 12$^{th}$ Avenue are either closed or obviously ailing. Typical business activities include pawnshops, missions catering to the poor and inexpensive restaurants. If Regina has a *zone in discard*, it is located here. Further east the area declines into an unattractive patchwork of parking lots, bulldozed sites and poor quality housing. Currently the City plans to develop a much needed neighbourhood park in several blocks immediately east of Halifax Street. For these reasons expansion of the CBD east of Broad Street remains problematic. It is possible that the City's commitment to neighbourhood improvement in the area may attract new business investment to the blocks fronting Broad Street, but this is still unlikely until the supply of more attractive sites elsewhere becomes exhausted.

With respect to land use functions in the CBD, there is no indication to suggest that the office function will experience the same suburbanisation that characterised the retailing sector in the last 40 years. Several decades of computer-based office technologies have not reduced the need or desirability for face to face contact in many business environments, and there is no reason to think that these circumstances will radically change in the future. Today much of the physical fabric of the CBD is still 'new.' Consequently, it is likely to be many decades before the office towers built since the 1960s become functionally obsolete. Furthermore, whatever Regina's growth rate over the next several decades, the city is unlikely to grow so expansively as to merit investment in suburban business parks of the type seen in large American cities. On the other hand, the range of zoning regulations and development standards currently guiding development in the CBD will almost certainly remain, and may be viewed by some to be too restrictive. For example, developments on some sites such as those adjacent to heritage and residential properties will remain subject to height and floor area ratio (FARs) restrictions in order to preserve the amenities of the original structures (Figure 8). In this case the sites most affected are Victoria Park and the heritage properties adjacent to it along with the residential area (DR) south of Victoria Avenue where commercial buildings, with the notable exception of hotels, are restricted by a FAR of 2.0.

In the case of retailing, it is difficult to imagine a set of circumstances under which it will revive in the CBD. The essentially *laissez faire* environment in which suburban retailing has prospered in response to the wider pattern of suburban growth is unlikely to change. In Regina, much urban planning is synonymous with facilitating expansive suburban development whether residential or commercial, rather than with limiting growth. In suburbia at least, the development sector appears to largely dictate the pattern and pace of development, and there is little or no expression of a desire or need to change this arrangement. Arguably then, suburbia will continue to expand. Currently, Regina's population is not large enough to support department stores in both the CBD and suburban areas. Thus Eatons, Sears and the Bay are each located in the CBD but have not established outlets in the suburban malls. However, in view of the increasing suburbanisation of the city's population it is evident that these stores are becoming increasingly distanced from much of their market. Consequently, it may not be long before one or more of the stores is obliged to relocate to the suburbs in order to prevent further slippage of its

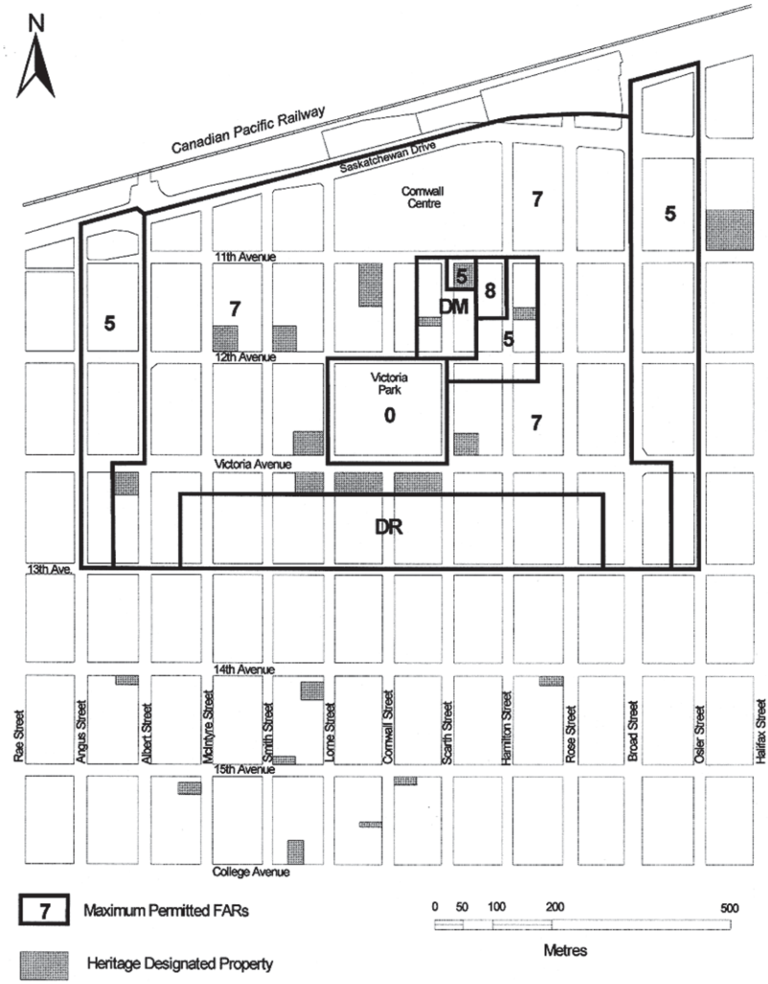


***Figure 8:*** *Heritage properties and maximum permitted floor area ratios (FARs) in Regina's CBD.*

market share. If this happens, the others may follow with the consequence that retailing in the CBD will be relegated to a minor status. More hopefully, the growth of a residential population in the CBD may help to stabilise the retailing sector.

## The Role of Planning

Finally, the role of planning in facilitating and guiding development must be considered. Change in the size and functions of Regina's CBD has not been achieved without significant input in terms of formal planning. Over the study period this input has been registered in the form development plans and zoning bylaws (e.g., Regina 1979; 1984; 1985; 1991a). Other studies have addressed particular aspects of the CBD or Downtown environment including urban design standards, the suitability of residential development, and the feasibility of climate controlled walkways (e.g., Regina 1982; 1989; 1991b). Currently the most important instrument in regulating development in the CBD is Zoning Bylaw 9250 (Regina 1992). The overall philosophy behind this instrument is neatly expressed in the 1991 Development Plan wherein the city's economic development is required to promote 'the continued development of the Downtown as Regina's primary business, office, retail, cultural and administrative centre' (Regina 1991a, 69).

In practical terms this philosophy is implemented through specific regulations and development standards contained in Bylaw 9250 (Regina 1992, 205-222). Prominent among these are ones governing building heights, floor area ratios (FARs), permitted wind velocities, sun-shadow impacts, the provision of public amenities and parking, and the preservation of heritage properties, all of which can influence the exact form and location of developments. Generally, these regulations have become more numerous over time. In so far as the CBD flourishes, it can be claimed that regulations and development standards have remained sensitive to the expectations of developers and those who work, shop and recreate in the CBD.

## Acknowledgement

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# Location, location, location: selling sex in the suburbs

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**Steven Kohm, University of Toronto**

***Abstract:*** Conventional understanding of the sex trade in cities has identified it as an inner city phenomenon. However, a broader interpretation of the topic suggests that the sale of sex involves more than street prostitution and it is more widespread than hitherto acknowledged. When sex is openly employed to sell other services or products, it is a moot point as to whether the sex is not an integral component of the product package. Marketing literature would certainly have us believe it to be so. When off-street sex is examined, it also becomes apparent that technology is permitting sex to be sold in a variety of forms and in a variety of locations. Evidence drawn from Winnipeg, western Canada, and Perth, Western Australia, suggests that, to an increasing degree, sex is not only being marketed to a suburban-based clientele, it is becoming more widely available for sale in the suburbs.

## Introduction

Just as population has moved to the suburbs, to be followed by industry and other forms of commerce, so have businesses that sell sex, or who use sex to sell other products and services. The extent to which the sex trade has penetrated the suburbs is very difficult to ascertain without more intensive research than permitted under current budgetary and other constraints. However, it is safe to say that both clients and the varied sex related benefits they seek are widely distributed through the city (Kohm 1997; Kohm and Selwood 1997; Selwood and Batzel 1988). The providers are quite evidently well aware of the basic principles of contemporary marketing and offer a wide range of products and services in targeting a variety of market segments who are largely resident in suburbs.

The purveyors of sex appreciate that they are selling products that comprise, to quote from a basic marketing textbook: a "complex bundle of benefits that satisfy [consumers'] needs" (Kotler *et al* 1996, 291). Products thus boast a potentially wide range of attributes that can be conceived of as operating at three levels (Figure 1). These levels consist of the core product's benefits as sought by the by the consumer, the actual product and the augmented product. The core product addresses what the consumer is *really buying*. That is, it can satisfy a variety of basic needs and wants. In the case of a bar or beverage room, that may include the slaking of a thirst, reinforcement of a macho image, soothing of a libido, a desire for company, or whatever. The product's specific tangible and intangible features are referred to as the actual product. These will include the quality of the liquid, what it is contained in, and who is carrying it.. Finally, the augmented product would include the entertainment provided in the bar. However, the augmented component quickly becomes an important and expected part of the total product. In a beverage room featuring exotic dancers, the stripper's sexy gyrations are just as much part of the purchase as is the drink itself. According to Kotler *et al* (1996, 291):

> Today, most competition occurs at the product augmentation level. Successful companies add benefits to their offers that not only will *satisfy*, but will also *delight* the customer.

Massage parlours, escort services, strip bars and burlesque clubs, adult video and magazine outlets and adult sex shops are among the outlets that provide sex related products and services (Kohm and Selwood 1997). In this paper we will be focusing on one aspect of the "soft sex" trade: that is, the legally sanctioned provision of adult entertainment in drinking establishments, including strip clubs, bars and restaurants. Because these places are not always accepted without protest by segments of the wider community, they do not always have a highly visible impact on the townscape, but they nevertheless adhere to the basic rule for

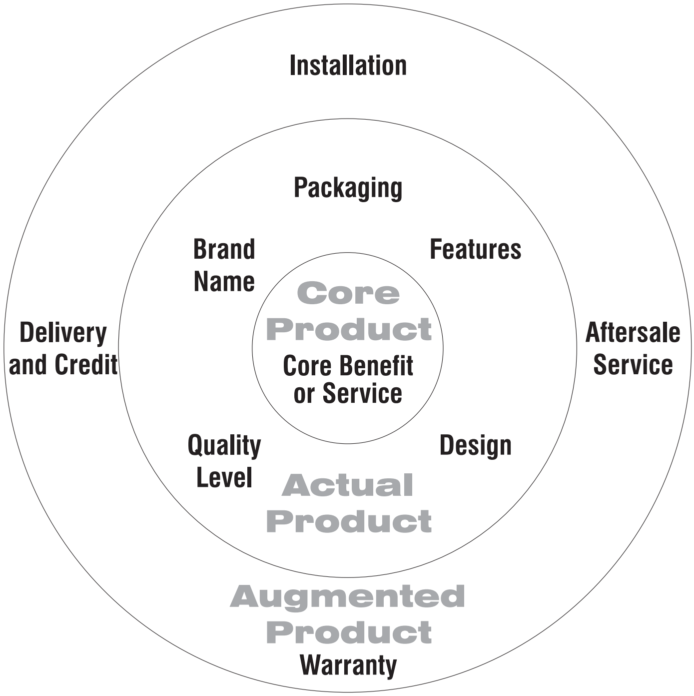


***Figure 1:*** *The attributes of a product (Source: Kotler, et al. 1996, p. 291).*

marketing consumer goods: location, location, location. Winnipeg, Canada, and Perth, Western Australia, provide the case study material for the paper.

## The Hooters Phenomenon

One of the more obvious manifestations of the sale of sex in the suburbs is the "Hooters" chain of restaurant, with the Hooters Girls being an integral part of the product concept. Although Hooters' management insist that they are running a "neighbourhood restaurant." According to their website promotion, the

> . . . concept stresses great food, great service, reasonable prices, a relaxed atmosphere and, of course, the now famous

> Hooters Girls. These elements combine to make Hooters the place to go for families, celebrities, sports figures, and anyone who enjoys food and FUN, FUN, FUN! (http://www.hooters.com)

That's not quite so. Gary Score, manager of Fargo's Hooters, says that the restaurant "is a blue-collar place that caters mostly to men aged 25 to 40. It's a place where they can eat and drink . . . and enjoy the scenery" (Owen 1997 16 February). Bruce Owen, staff reporter for the Winnipeg Free Press, notes that in Winnipeg, "most of the clients are men, from college guys to lone retirees."(*ibid*).

Winnipeg's Hooters is located in Madison Square, a parasitic shopping complex, almost adjacent to Polo Park, Winnipeg's first suburban, regional shopping centre. It is also located conveniently near Winnipeg's football stadium and arena, both venues being important sources of Hooters' customers. It might also be noted that St. James, the suburb containing Hooters, is commonly stereotyped as being the home of a lower middle class population, not renowned for its placing high stock on culture, but rather on the materialistic values of the mass market. Hooters' website would also be accessible to a high percentage of St. James dwellings.

Hooters' suburban Winnipeg location is no coincidence. Their other Canadian locations are also firmly planted in the suburbs. Toronto's Hooters is in North York and the Edmonton outlet is on Bourbon Street in the West Edmonton mega mall (http://www.hooters.com). Vancouver's Hooters is in Surrey, a suburb some forty minutes drive from downtown.

This obvious commodification of the female body has been the subject of repeated controversy, something on which the restaurant chain of course thrives. Only this week (September 22-28 1997) Vancouver's Hooters hit the pages of *The Winnipeg Sun* and the *Winnipeg Free Press* (Lakritz N. 1997; Joyce 1997 23 September), which reported the dethronement of one Gabriella Petivoky, Miss Canadian International, a Hooters Girl, because of her promotional work with the restaurant chain. The Manitoba Action Committee on the Status of Women, along with other women's rights groups, raised objections to Hooters' arrival in

Winnipeg even before the restaurant's opening (St. Germain 1996: Owen 1997) and the debate continues to feature in letters to the press (see, for example, Harris 1997). However, as Carl Matheson, a philosophy professor at the University of Manitoba, has observed: ". . . the Hooters chain is no better or worse than other aspects of Western culture . . . , so why pick on Hooters?" Hooters' blatant commercial use of women's bodies is perhaps controversial, but it exists, and it exists in the suburbs to service a largely suburban clientele.

## Strip Bars and Burlesque Clubs

Although there is a concentration of strip bars and self-styled burlesque clubs in the inner city, they are also found in more suburban locations. The more highly visible burlesque clubs tend to locate near blue collar, working class neighbourhoods and in association with industrial land. The Chalet Hotel, home to "Teasers" and "Studs" (the former featuring female dancers and the latter males), is located on the borders of a largely inactive industrial part of St. Boniface (see figure 2). The burlesque club and a large adult video store both make their home in close proximity to the abattoirs. On the other side of the city, "Centerfolds", a burlesque club catering to male patrons, is located in another working class suburb of the city, close to the CPR Weston Shops. "Club Fantasy", a recently revamped burlesque club in Winnipeg (*Winnipeg Sun*, 27 March, 1995), is located in an inner city area characterized by a diverse mix of retail, light industrial and working class to poor quality housing.

However, live nude entertainment is by no means confined to the burlesque clubs. The Liquor Control Act also permits licenced "Beverage Rooms" and in some cases "Banquet Halls," to provide exotic dancers as entertainment (*Manitoba Liquor Control Commission Licensee Field Manual*, 1990). Burlesque or nude entertainment is therefore associated almost exclusively with hotel beverage rooms, since bars not associated with hotels are generally classed as "Cabarets" where nude entertainment is not permitted under the Act's regulations. Where nude entertainment is permitted, the Liquor Control Act has set out strict rules of conduct. Among

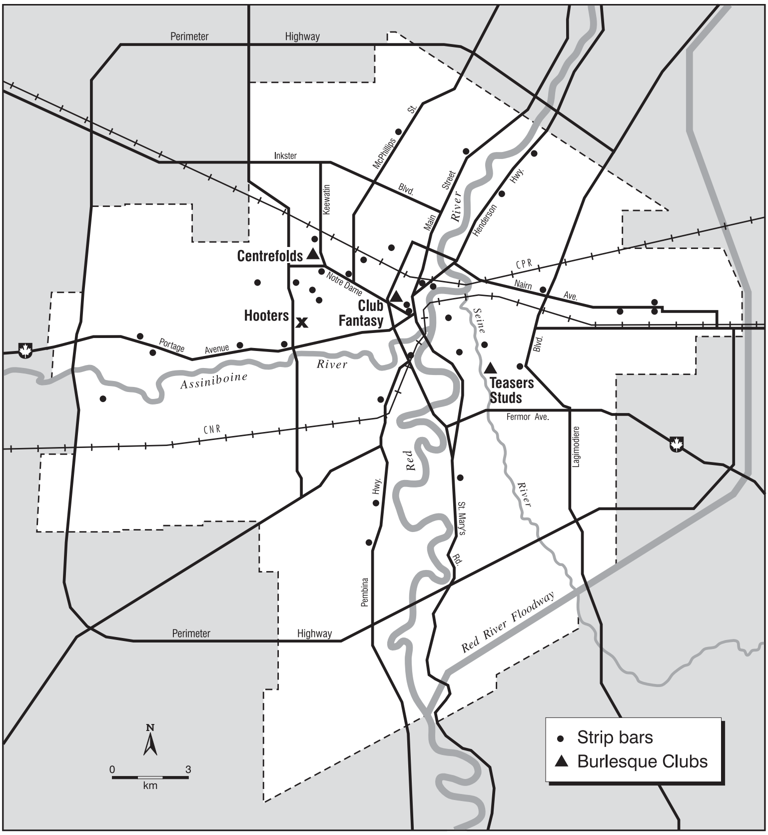


***Figure 2:*** *Winnipeg's soft sex sales outlets.*

other things, the regulations state that there may be "no audience participation" and that "only one exotic dancer is permitted to be in the stage area at any one time" (*ibid.*). The rules seem to be aimed at preventing any sort of sexual contact from occurring, whether it directly involves the audience or not. While there are occasions where there is some contact between the dancer and a patron, it is a far cry from the lap dancers of Ontario, or the "ten dollar" dancers of Montreal. However, the Liquor Control Act does not govern the location of bars providing exotic dancers.

This is controlled by Winnipeg's zoning regulations which generally treat hotels containing beverage rooms as permitted uses in commercial districts. Zoning does not discriminate between an ordinary beverage room with no burlesque entertainment and a bar which is offering strippers as a form of entertainment (pers. comm.). Commercial use zones are widely distributed throughout the city.

A survey of Winnipeg's hotels revealed that their representatives were often reluctant to acknowledge that strip shows were featured at the establishment. Whereas hotels that did not offer this type of service seemed to be more than happy to make this information public, those establishments that did offer the service were often quick to qualify their affirmative response. In one case, the hotel management refused to make this information available over the phone, fearing they might be exposed to "feminists." In many cases, it was pointed out that strippers were only offered as entertainment for the lunchtime and after work crowds. The management of one bar in particular, when asked why their bar had strippers in the afternoon but not the evening, offered this response: "We're a family-type bar."

It seems that there is a hierarchy among bars and hotels in the city. At the top of the pyramid are such "higher order" family oriented hotels and chains, such as the Holiday Inn or Quality Inn, which consider having strippers on the premises "substandard" (pers. comm.). Next, are those bars which do offer nude entertainment, but only as a sideline to the lunchtime business crowd, or on the weekends. Finally, there are those bars which offer burlesque entertainment exclusively, both in the day and in the evening hours. Of the eighty-nine hotels in Winnipeg that have some sort of nightclub or bar, just over forty-one per cent said they had strippers on at least a part-time basis. The spatial distribution of hotels with this type of service is widespread and extends into most districts in Winnipeg (see figure 2). Virtually all are located on arterial streets with a significant amount of commercial activity, and most are in the suburbs. Twelve such bars are located in the CBD or zone of transition, but the remaining twenty-five are in the suburbs. It is very apparent that the latter are serving up sex to a suburban clientele.

## Some Australian Comparisons

The sex trade is alive and well in Australia and provides some interesting parallels and contrasts with its Canadian counterpart. As in Canada, the industry is regulated by different levels of government, but in Australia the Commonwealth, or Federal government has less direct involvement. For example, whereas prostitution, although not in itself illegal, is effectively banned throughout Canada because of the national Criminal Code, it is legally sanctioned in various parts of Australia, including the Capital Territory and the two most populous states of New South Wales and Victoria. In this paper we will use examples of the sale of sex in restaurants, burlesque houses and bars of Perth, Western Australia in comparing the two systems.

## The Raunchy Restaurant

The Raunchy Restaurant in Fremantle, Perth's port city, is a far cry from Hooters. The present location is more central in that Fremantle has its own CBD. However, it was formerly located in North Perth, one of Perth's inner suburbs, until forced to move because of local opposition and political expediency (pers. comm. 1997). The name carries the message without innuendo employed by Hooters and the product package is far more explicitly sexual in content. At The Raunchy Restaurant, patrons are served by "semi-clad waitresses" (Duffy 1997) with such added delectables as:

> A-La-Lap - Topless or Naked Hostess Perched on *your lap* feeding you fresh fruit and cream.
> Slic-A-Chic - Essential warm *oil massage* topless or naked hostess of your choice.

Or, the *piece-de-resistance*:

> Tutti-Frutti - The most *tantalising* dessert in the world! Choose your naked hostess, she will *lay* (sic) *naked* on your table covered only in fresh fruit and cream.

The patron is then invited to lick the platter clean down to the plastic wrap body covering. Touted as the “ideal venue” for “bucks shows, Birthdays and special Occasions, Social and Sporting Clubs, Private and Corporate Functions” (<http://www.wasex.com.au>). The Raunchy Restaurant is hardly the place for a family meal, but it continues to be associated with the suburbs by the local police (Duffy 1997).

## Perth's Strip Bars and Burlesque Clubs

Clearly, The Raunchy Restaurant fits more appropriately into the category of the burlesque house or strip joint than it merits being called a restaurant. Eating in this case is the augmented component of the sex product. Raunchy’s current location is also more in line with that of Perth’s other strip clubs or nightclubs holding a “Cabaret” licence permitting full nudity. The “Kit Kat” club, is located in Fremantle, designed no doubt to attract visiting sailors as well as local customers. Others, like “Gobbles,” “Submission” and “The Site” are on the fringes of Perth’s principal night entertainment district. Again, such locations are designed as much to cater to the tourist as to the local clientele.

However, as in Winnipeg, Perth’s suburban bars and pubs have also incorporated the sexual component into their sales of beer and liquor. Many outlets now feature “skimpy” barmaids, particularly at lunch and supper hours when there is strong competition for the customers’ dollar. Starting in the 1980s, Perth’s bars began to feature “see through” barmaids, then during the America’s Cup challenge, barmaids went topless (Hall, Selwood and McKewon 1995), but more modest dress codes were imposed in the aftermath of the Cup loss. Nevertheless, there is considerable discretion used in the interpretation of the code as spelled out in the licencing conditions of the Liquor and Gaming Act and administered by the police Liquor and Gaming Branch. Although many have applied, only four pubs have been granted special licences permitting toplessness. These are all in distinctly working class, suburban, commercial districts, where local councils and nearby businesses raised no serious objections.

Elsewhere, the "skimpy" bars offer a variety of options. Some barmaids are dressed quite decorously, similarly to the Hooters Girls, but others, depending on the workplace, their employer, their personal inclination and the demands of the local inspector, will be dressed very skimpily indeed, wearing little more than a g-string and not much more on top. One criterion used by inspectors is whether "buns" are exposed - this being permitted by some, disallowed by others (pers. comm. 1997). A few of the larger pubs also employ exotic dancers, either as singles or in teams, who put on shows at peak times. Some dancers are male, managed by "Collars and Cuffs," "Moving Violations," or "Toyboys," but the great majority are female associated with such operations as "Living Dolls," "Teasers," or "Sunset Strip." According to one employer, the dancers are not supposed to bare themselves or to make contact with patrons, but will at times do so in the excitement of the dance (pers. comm. 1997). Time did not permit a systematic survey of Perth locations featuring skimpy barmaids and exotic dancers, but they are numerous and scattered through the suburbs, generally operating unobtrusively and, in the higher class suburbs, relying only on word of mouth for their publicity.

## Discussion and Conclusion

In comparing the provision of "soft sex" in the two countries, it is readily apparent that there are some common threads. First, it is clear that both are selling sex as part of a more complex product, commodifying the human body and marketing bits of its anatomy along with other attributes of the product. Burlesque houses, strip clubs and pubs are involved in the business, including neighbourhood pubs located in the suburbs. In general, the more extreme forms are contained in working class districts. However, that is by no means universally the case. Sex is for sale in higher class suburbs too, albeit with less fanfare.

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THE RAUNCHY RESTAURANT 1997 <http://www.wasex.com/Raunchy>

# Two large family farms in Manitoba

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## Introduction

The family farm is alive and well in Manitoba although this is not readily apparent from the census of agriculture (Carlyle 1983). For example, about 2,000 of the 24,000 census farms in the province are classified as corporate farms. Some people have become alarmed by this statistic, fearing that large corporations have been squeezing out family farms. Yet, closer inspection of the census reveals that the overwhelming majority of corporate farms in Manitoba are, in fact, incorporated family farms. Connery's Riverdale Farms Ltd., a vegetable and fruit farm located near Portage la Prairie, is one such family corporate farm (Figure 1).

Statistics Canada (1997) classifies Hutterite colonies under the heading of "institutional, community pasture and other" farms. Hutterite colonies are, however, nothing if not a type of family farm, and they have been aptly classified as being large multi-family farmsteads by geographer Hans Schlictmann, (1977). Thus, the second type of family farm considered in this paper is Sommerfeld Hutterite colony which is located about 20 km east of Portage la Prairie (Figure 1).

## Connery's Riverdale Farms Ltd.

The Connery farm is an incorporated family farm owned and managed by Ed Connery and his two sons, Doug and Jeff, and their families. It is one of the largest of the twelve major commercial vegetable farms in Manitoba, four of which are located in the Portage district (Manitoba Agriculture 1997).

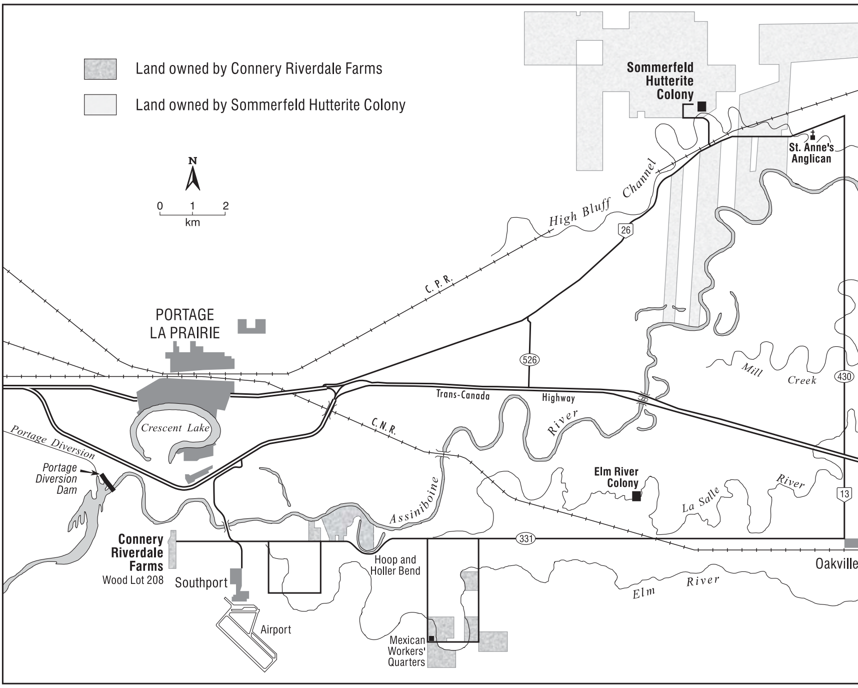


***Figure 1:*** *Location of Connery's Riverdale Farms Ltd. and the Sommerfeld Hutterite Colony.*

Several conditions favour commercial vegetable production in the area. The frost-free and growing seasons are longer than in most parts of Manitoba (Dunlop and Shaykewich 1982), and the soils are loamy alluvial ones varying in texture from silty clay to fine sandy loam (Ehrlich, Poyser, and Pratt 1957), a type ideal for vegetables in general and root crops in particular. Irrigation water is readily available from the Assiniboine River and several other rivers in the district, most of which flow in former channels (paleochannels) of the Assiniboine River, such as the Elm and La Salle (Figure 1) (Rannie 1990; Rannie, Thorleifson, and Teller 1989). In addition, the district is close to Winnipeg, the main market.

The Connery family formerly operated a market garden and nursery in the St. Vital area of Winnipeg, but moved to the Portage la Prairie district in 1960, lured by the favourable physical conditions discussed above and by the encroachment of urban land uses as Winnipeg expanded.

The present-day farm comprises some 352 ha (870 acres), of which about two-thirds is owned by the Connerys, and it consists of several parcels (Figure 1). The northernmost group of parcels is located along the south bank of the Assiniboine River, which provides irrigation water for this group. The other main group of parcels is along, and irrigated by, the Elm River (Figure 1). The offices and cleaning/warehousing sheds are located on Wood Lot 208, which is part of the riverlot survey of the Red River Settlement that preceded the Dominion Lands Survey of townships and ranges (Figure 1). Water for washing the vegetables and transporting them through flumes is obtained by pipeline from wells on a neighbour's property near the Assiniboine River

Although the farm's area is not large in Manitoba terms, vegetable farming is intensive, so that the gross farm income is sizeable – more than $3 million annually.

Ranked by area devoted to each, the crops grown by the Connerys are carrots, broccoli, asparagus, cooking onions, and green onions. In addition to vegetables, the Connerys sow some land to wheat and alfalfa, which are grown in rotation mainly to interrupt pest and disease cycles, and they have a field of strawberries.

Provincial regulations require that only carrots among the crops produced by the Connerys be marketed through Peak Vegetable Sales (formerly Manitoba Vegetable Producers Marketing Board) under the name of Peak of the Market. The Connerys, however, choose to market all their vegetables through Peak.

The Connerys are the main producers in Manitoba of broccoli, green onions, and asparagus, and they are probably second ranked in carrots (Connery family 1997 and Manitoba Agriculture 1998).

There is one spring sowing of carrots, and they are harvested from late July or early August onwards into the autumn. Some of the carrots are shipped directly to market. The remainder are stored in enormous Fil-A-Cel sheds at Wood Lot 208 for shipping out from October to March. These carrots must be stored at 0°C (32°F), requiring that they be refrigerated even during the winter because of the heat they generate in storage.

Broccoli is planted weekly from May to July, and hand cut beginning in July. The heads are sized, sorted, and boxed in the field using a broccoli trailer, then packed in slush ice produced by a slush ice maker at the warehouse.

Asparagus is a perennial crop which can produce for decades without replanting. It occupies a large portion of the 40 ha (100 acre) "island," which is nestled in a former meander bend of the Assiniboine River, amusingly named Hoop and Holler Bend (Figure 1). This and several other meander bends in the district have been artificially cut off from the Assiniboine River in an attempt to reduce flooding in the Portage area by hastening the flow of the river (Figure 1). The asparagus is cut by hand from three-person buggies during May and June.

Cooking onions are planted during one spring sowing, harvested in September, and packed out until April. They are mechanically harvested, then cured in a heated Fil-A-Cel shed. Green onions are planted weekly from spring to July, hand pulled, and packed in ice for shipment. Harvest begins in early July. Strawberry plants produce for two years and then are replaced. Picking – u-pick or pre-pick – begins in early July.

Vegetable farming is very labour intensive despite the increasing mechanization of some operations, and about half of the Connerys' annual expenses of $2.8 million is for hiring farm labourers. They employ 40 to 50 people during the winter and, at the peak of the harvest, this figure rises to 130 to 140. Hired labourers come from Winnipeg, the Sandy Bay Indian Reserve on the west shore of Lake Manitoba, the Portage district, and from Mexico. The Mexicans are brought to Manitoba under a federal program for migrant workers, and they are used for "stoop" labour. They are provided with living quarters on the farm (Figure 1).

## Sommerfeld Hutterite Colony

Almost all of the 35,000 to 40,000 Hutterites living on colonies in the United States and Canada are descended from the 443 Hutterites on colonies recorded in the United States census of 1880 (Hostetler 1974). This statement excludes several thousand people following many teachings of the Hutterian faith living on colonies

*The church on Sommerfeld Colony (photo by John Lehr).*

*Some of the residences on Sommerfeld Colony (photo by John Lehr).*

(bruderhof) in the northeastern United States which, however, are not considered to be true Hutterites by the Hutterian church (Preston 1992). Being descended from such a small founding group, today's Hutterites have only about fifteen different surnames. Among the Schmeideleut Hutterites, the group or "clan" to which all Manitoba Hutterites belong, studies have shown that the "average" husband and wife are more closely related than second cousins but not as closely related as first cousins once removed (Hostetler 1974).

This extended family nature of the Hutterites is reflected by the fact that the 20 families totalling about 100 people living on Sommerfeld colony have only two surnames, Hofer and Gross.

The colony "Boss," John Hofer, and his wife Susanna, moved to Sommerfeld colony when it was founded in 1977 from Sommerfeld's "mother" colony, Rock Lake. As is Hutterite practice, Susanna moved to Rock Lake colony from Rainbow colony when Susanna and John were married, which was before Sommerfeld colony was founded.

Following traditional practice, most important management positions on the colony are filled by adult men (see below). The key positions are the Colony Boss, the Colony Minister(s), and the Farm Boss. They meet daily to discuss colony operations (Ryan 1977).

Colony Boss – John Hofer
Colony Minister – Michael Hofer (brother of the colony boss)
Second Minister and German teacher – Clarence Gross
Farm Boss (crops) – Levi Hofer (brother of the colony boss)
Pig Boss 1 – David Hofer (brother of the colony boss)
Pig Boss 2 – Arnold Gross
Chicken Broiler Boss – Jonathon Gross
Chicken Layer Boss – Jacob Gross
Blacksmith – Jacob Hofer (brother of the colony boss)
Carpenter – Joseph Hofer (brother of the colony boss)
Electrician – Peter Hofer (brother of the colony boss)
Head Cook – Annie Gross

Sommerfeld Colony comprises some 3000 ha (7400 acres), of which the colony owns about two-thirds and rents the remainder. I don't know how secure the tenure is on land rented by the Colony.

Some of the land is located on land surveyed under the Dominion Lands Survey system and some is located on land surveyed under the earlier riverlot system (Figure 1). Considering that the average Manitoba farm family of four or five people farms about 320 ha (790 acres), Sommerfeld colony, and indeed most Hutterite colonies in Manitoba, has to make intensive use of its resources.

The economic mainstay of Sommerfeld colony is hogs. There are two separate operations, each with its own boss (see above). A total of about 1,000 sows is kept (soon to be 1,400) each of which produces some 24 hogs a year, for a total annual output of 24,000 hogs. Two holding tanks, one of 5.5 million litres (1.2 million gallons) capacity and the other of 13.6 million litres (3 million gallons) capacity, are used to store waste from the hog barns and to produce manure fertilizer for the crops.

The colony also relies heavily on poultry. It has 7,500 laying hens which produce about 6,000 eggs per day or 2.2 million eggs a year. The chicken broiler operation yields 1,500 broilers every 6 to 7 weeks.

The hogs, laying hens, and broilers are all raised under factory-farming conditions in barns and sheds where there is close monitoring and control of temperature and moisture conditions, types and amounts of feed, and exposure to diseases.

Four dairy cows are kept for colony use, and a vegetable garden and orchard of about 2 ha (5 acres) yields vegetables and fruit for colony consumption.

Canola, wheat, and barley are the main crops grown, with most of the barley being fed to the pigs and chickens on the colony.

With such a large human and livestock population on the colony, obtaining sufficient supplies of water is a high priority. When the colony was being founded, drilling for water at the colony site was unsuccessful despite the fact that some drill holes penetrated 120 m (400 feet) below the surface. Ample quantities of water were, however, eventually found in 9 m (30 feet) of sand along an Assiniboine River paleochannel (High Bluff channel, Figure 1) about 0.8 kms (0.5 miles) away, from whence it is pumped to the colony.

Hutterite life is firmly grounded in their faith, the essence of which is a belief in oneness in Christ, which manifests itself in communal living on colonies. To maintain this faith, services are held frequently at the church on the colony.

Education is also a concern of the Hutterites. On Sommerfeld, and generally among Manitoba Hutterites, formal schooling is limited to grades 1 to 8 at a public school on the colony. Some children on Sommerfeld do take grades 9 and 10, but they do so on the colony through teleconferencing with schools in Portage la Prairie.

The operation of a Hutterite colony is a complex one, involving skills ranging from metal working and electrical wiring to using computer software. Knowledge of this type is gained from manuals and books, and extension courses offered by colleges and universities. Once gained it is passed down from one generation of Hutterites to another.

## Conclusion

The two farms examined in this paper are unusual in that they are minority types in Manitoba. The Connery farm is one of only twelve commercial vegetable farms, excluding potato farms, in Manitoba and Sommerfeld is one of about ninety Hutterite colonies in the province. They do, however, represent part of the vast spectrum of family farms in Manitoba, no two of which are exactly alike.

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