The University of Manitoba

WINNIPEG FLOOD HAZARD MANAGEMENT

BY

XUEYONG ZHANG

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfilment of the Requirements
for the Degree

MASTER OF ARTS

Department of Geography
Winnipeg, Manitoba
Canada

September, 1996

ISBN 0-612-16389-X

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

COPYRIGHT PERMISSION

WINNIPEG FLOOD HAZARD MANAGEMENT

BY

XUEYONG ZHANG

A Thesis/Practicum submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of

MASTER OF ARTS

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to my academic advisor, Dr. W.J. Brown, for his invaluable advice and guidance throughout the preparation of this thesis.

I would also like to thank Mr. Alf A. Warkentin, Mr. E. Kozera and Mr. Neil Harden of the Water Resources Branch of the Manitoba Natural Resources, Mr. D.D. McNEIL and Mr. Aurele E.D. Delaurier of the Water and Waste Department, Mr. Mark Bennett of the Emergency Program Office, Mr. Eddie Kaganka of the Streets and Transportation Department of the City of Winnipeg, and Mr. Ken Grant of the Manitoba Emergency Measures Organization, who in various ways assisted in providing support towards the completion of this thesis.

Special thanks to Dr. M. Carvalho, Department of City Planning, and Dr. L.P. Stene, Department of Geography, at the University of Manitoba, for their helpful comments and suggestions.

ABSTRACT

Flood hazard management is a broad activity. This thesis is concerned with four aspects of Winnipeg flood hazard management: flood hazard analysis, mitigation measures, disaster preparedness, and disaster response organization.

In the flood hazard analysis, the causes of flooding and historical floods have been investigated. Based on the historical flood data, flood frequency analysis was conducted in order to determine the recurrence of flooding.

Flood hazard adjustments in Winnipeg consist of structural works and non-structural measures. The four flood control works and the flood protection systems in Winnipeg have been extensively used since their installation, and they have protected the City from major flood damages in 1974, 1979 and 1996 when the flood threat was greatest. There is a need to elevate primary dykes after many years of operation, and to convert some temporary dykes into permanent structures. It has been ascertained that the true discharge for a 160-year flood is higher than that originally computed using the Redwood Bridge flood data. A range of non-structural measures has been examined in this thesis. Of them, the FDRP and flood forecasting were successfully implemented. Government legislation has been important through exercising control over urban development. In view of an increasing flood damage potential, an insurance program involving public funds and the

private insurance industry could be introduced in order to provide financial assistance to property owners.

Regarding disaster preparedness in Winnipeg, planning, training, education, exercise, warning, and the JEPP program have been reviewed. Flood disaster preparedness training and education of the general public is very low, and more information materials need to be developed and distributed. Electronic media and other educational methods should be employed, especially in the spring time, to educate the public.

In terms of Winnipeg's flood disaster management system, appropriate government departments and relevant legislation have been studied. Winnipeg flood manuals and guidelines have to be revised periodically in order to reflect changes in operation. Inter-agency communication and coordination should be augmented in order to provide more efficient disaster management. To prepare for a future flood response, a volunteer system should be established by the City of Winnipeg in conjunction with Human Resources Development Canada.

1. INTRODUCTION

1.1 STATEMENT OF THE PROBLEM

1.1.1 Background of the Study

The United Nations proclaimed the 1990s as the International Decade for Natural Disaster Reduction (IDNDR). The unanimous passage of General Assembly resolution 42/169 on 11 December 1987 was based on the belief that natural hazards are continuing to pose escalating costs on human societies through death, destruction, damage and disruption (Jones, 1993; Plate and Kron, 1994). In the context of the IDNDR, there is a great need to reassess natural hazards, to promote their control, and to formulate preparedness plans for them.

Of all the natural hazards threatening human society, "flooding is the most common environmental hazard throughout the world." (Smith, 1993: 182). This is because of the relatively high frequency of flood events, the widespread geographical distribution of floodplains, and the long-standing human occupance of the latter.

Unlike the United States, where high flood frequencies and resulting heavy damages are associated with wet temperate climates, the flood hazard in Canada is relatively restricted, but a recurring problem. However, of more than 60 kinds of natural and human-made disasters which could occur in Canada, "floods are the number-one natural disaster in Canada in terms of property damage." (Emergency Preparedness Canada, 1996; p.1). Over two hundred Canadian towns and cities, from British Columbia to Newfoundland, face potential flooding (Foster, 1981). Major disasters struck Vancouver in 1948, Winnipeg in 1950, and Toronto in 1954, but significant damages are experienced every year (Quinn, 1976).

Winnipeg is a Canadian city with a serious flood hazard problem. In the spring of 1950, Winnipeg experienced its largest flood of the twentieth century, perhaps the most spectacular example of flooding in Canada. Following that flood disaster event, Federal and Manitoba Provincial agencies began investigation of the nature of the flood problem and of possible ways of reducing the hazard. In the following decades, a series of structural and non-structural measures was applied in the flood-prone areas, especially around the City of Winnipeg.

After decades of flood reduction efforts for Winnipeg, three major questions may be posed. Firstly, what flood control programs have been completed? Secondly, how effective are these programs? Finally, how will the City of Winnipeg meet the challenge still posed by its flood hazard? All of these issues will be investigated in this research.

1.1.2 Objectives of the Study

Flood hazard management in Winnipeg has been selected for this study on two bases:

(1) Flooding is the most frequent, damaging natural hazard in Manitoba, and has been particularly severe in the Red River Valley. In the light of the IDNDR, it is opportune to reassess the flood risk and the range of measures for coping with this natural hazard.

(2) Winnipeg, the capital city of Manitoba, is at the confluence of the Red and Assiniboine Rivers, hence has a major potential flood hazard. As Winnipeg is Manitoba's largest city and its political-economic centre, research into its flood hazard management becomes more imperative.

The research has several objectives in terms of theoretical and practical contributions:

(1) to provide an informed analysis of Winnipeg's flood hazard.

(2) to survey the range of coping strategies employed in flood hazard reduction in Winnipeg.

(3) to examine the existing flood hazard preparedness programs for Winnipeg.

(4) to discuss aspects of Winnipeg's current flood disaster management system.

(5) to promote conceptualization of natural hazard reduction in which preparedness and disaster management are crucial components of the system.

1.2 LITERATURE REVIEW

Flood hazard research literature that is Canadian or international is selectively reviewed in this section. The focus is on the flood studies in Canada and Manitoba relating to this research project.

1.2.1 Flood Hazard Research

Flood hazard research has a history of over 50 years, having originated in the United States and having primarily developed from the 'Chicago school'. In Britain, Canada, Australia and other countries, researchers undertook flood hazard studies influenced by the American work (Parker and Penning-Rowsell, 1983).

Smith (1993) stated that, during the early decades of this century, almost exclusive reliance was placed on structural measures aimed at the physical control of river floods. Since the 1960s, flood-loss reduction strategies have become progressively more regulatory in approach employing a combination of measures. The latter are dominated by floodplain management including land-use planning, designed to reduce the hazard vulnerability of floodplain residents. Measures include flood warning and insurance. Entering the 1990s, the development of disaster prevention and preparedness plans, and access to warning systems, become the major goals of flood hazard research as proposed by the IDNDR.

1.2.2 Canadian Flood Hazard Research

Canadian flood hazard research developed early as a direct outgrowth from the Chicago natural hazard studies of flooding (Burton, 1965; Sewell, 1965; Hewitt and Burton, 1971). The cooperative federal-provincial "Flood Damage Reduction Program" was initiated in 1975, with emphasis on non-structural measures (Mitchell, Gardner, Cook and Veale, 1978; Handmer, 1980; Page, 1980; Andrews, 1993): it involved a major effort by all levels of government. One of the excellent research contributions in this period was the investigation of the flood hazard in the Grand River Watershed, Ontario: this work combined studies of physical adjustments and institutional measures (Mitchell et al, 1978). Later studies of Ontario's historic flood damage are by Shrubsole, Kreutzwiser, Mitchell, Dickinson and Joy (1993) and by Millerd, Dufournaud and Schaefer (1994). As a contribution to the IDNDR, Andrews (1993) edited and presented an authoritative report, Flooding: Canada Water Book, which gives a full and historical account of flooding cause, consequence and mitigation policy in Canada.

1.2.3 Manitoba and Winnipeg Flood Hazard Research

In addition to Ontario, Manitoba is another focus of flood hazard research in Canada. Regarding the historic flood hazards before 1950, few studies were undertaken (Anderson, 1873; Atwood, 1923; Hurst, 1949). After the disastrous flooding of 1950, flood hazard research was started in earnest, and a wave of government investigation reports and individual research on flood damages emerged (Clark, 1950; Government of Canada Prairie Command, 1950; United States Geological Survey, 1950; Department of Resources and Development Canada, 1952; Rutherford and Baracos, 1951, 1953; Red River Basin Investigation, 1953; Baracos, 1954; Hurst, 1957).

In the 1960s and 1970s, attention shifted to flood control structures constructed during this period (Department of Agriculture and Conservation, 1963; Weber, 1967; Rich, 1974). In the following decade, studies with emphases on the operation and management of these flood control systems were produced (Rannie, 1980; Mudry, MacKay, and Austford, 1981; Carlyle, 1984; Agyare, 1992). Agyare (1992) proposed a decision support system for flood control management with a focus on flood damage analysis, which incorporated geographical information systems (GIS) techniques. To date in the 1990s, apparently there have not been any major research projects on the flood hazard in Manitoba. However, a recent article by MacDonald (1994) provided a retrospective description of floods in the Red River Valley.

In regard to Winnipeg flood disaster/emergency management, relatively little research has been undertaken (Hannigan and Kueneman, 1978; Goulter and Hannan, 1984; Bumsted, 1987). Hannigan and Kueneman (1978) concentrated their sociological studies on individual awareness of flood hazards in flood-prone southern Manitoba. Goulter and Hannan

(1984) reviewed the Manitoba flood forecasting system and the response of the government agencies.

1.3 SCOPE OF THE STUDY

This study is to investigate the flood hazards in Winnipeg, and to analyze its flood hazard management system.

Chapter 2 gives a brief description of Winnipeg's development. Particularly addressed is Winnipeg's dependence on its main rivers, in terms of their uses for settlement, transportation, water supply and recreation.

Chapter 3 analyzes the flood hazard in Winnipeg. This chapter gives a summary of the historical floods and provides a flood frequency analysis, based on historic flood data.

Chapter 4 surveys the human adjustments to the flood hazard. The structural works and non-structural measures are described, and the benefits and limitations of these are assessed.

Chapter 5 examines the preparedness programs in Winnipeg. This chapter describes the planning, training, education, and exercise programs related to flood disaster preparedness.

Chapter 6 presents the legislation and institutions pertinent to the flood disaster management in Winnipeg. It discusses the disaster organizations and the flood disaster management systems.

2. WINNIPEG DEVELOPMENT

2.1 DESCRIPTION OF WINNIPEG

2.1.1 Geographical Location

Winnipeg is located at the junction of the Red River and Assiniboine River. It is approximately 100km north of the Canada-U.S.A. border, and it is almost at the geographical centre of North America. The City has been referred to traditionally as the "Gateway to the West", as it is situated near the eastern limit of the Canadian Prairies.

2.1.2 Historical Development

In 1738 Pierre de La Verendrye established a fur trading settlement called Fort Rouge at the "forks", the junction of the Red and Assiniboine Rivers (Marsh, 1988). In the early nineteenth century in this locality, the Red River Colony was established by the Earl of Selkirk (1812): this settlement was a hub of the fur trade until the 1880s, when grain production became the principal industry in Western Canada. The rivers were the heart of the Red River Colony; farms were laid in narrow strips along the riverbanks for irrigation and easy transport. Incorporated as a city in 1873, Winnipeg became the main commercial centre for Canada's grain trade, serving as headquarters for many grain companies and the Canadian Wheat

Board (Morton, 1957; Weir, 1974; Bumsted, 1988; Krenz and Leitch, 1993).

Winnipeg's strategic location made it the natural focus for the western extension of the Canadian transcontinental railways. With the completion of the Canadian Pacific Railway (1885), a new era of expansion and prosperity in Winnipeg began. Artibise (1988) stated that very many immigrants, high wheat prices, and plentiful capital contributed to rapid growth. By 1911 Winnipeg ranked as the third largest city in Canada and the fourth in manufacturing.

After 1914, Winnipeg entered a recession. "The Winnipeg General Strike (1919) left scars, and the Great Depression plunged business, manufacturing, wholesale trade and the mail-order business into sharp decline." (Artibise, 1988: p.2316). Decades later the development of petroleum, natural gas, coal and potash shifted the economic power westward from here. Winnipeg's monopoly of the marketing of agricultural products and of the distribution of goods was challenged by Regina, Saskatoon, Edmonton and Calgary. The two Albertan metropolises have grown rapidly relative to Winnipeg in the past forty years. Today, Winnipeg is still a center of transportation, distribution, banking and insurance. Metropolitan Winnipeg contains more than one half of Manitoba's population of 1.133 million (in 1992) and it dominates the provincial economy.

2.2 RIVER DEPENDENCE

Humans have always been dependent on rivers. The rich flood plains adjacent to them are used for agricultural purposes. Also, cities and towns have been located along rivers that can be used for transportation, trade, and power generation. Without doubt, the Red and Assiniboine rivers were instrumental in the development of the City of Winnipeg, and even the province of Manitoba.

Actually, the name of Winnipeg comes from the Indian Cree word meaning "Muddy Waters" (Parks & Recreation Department, 1982). It implies that the site of Winnipeg and its early development were dependent on the muddy river waters which flowed through it.

2.2.1 River-Oriented Settlement

A study of the historic development of settlement along the Red River reveals the significance of the river. Winnipeg has a long functional association with the Assiniboine and Red. The Forks, at the confluence of the Red and Assiniboine, was a commercial site, the best place to control the fur trade. At the Forks, the village of Winnipeg grew up along the banks of the Red and Assiniboine. Since these rivers were the main arteries of communication, the buildings of various villages, such as St. James and St. Charles on the Assiniboine River, and St. Boniface and St. Vital on the Red River, were situated along the banks (Morton, 1957). The rivers carried people and materials, and provided water, fish, and power for the local people.

2.2.2 Waterway Transportation

From earliest times the waterways were essential to transportation in Winnipeg's development. The Red River was part of the fur transportation route linking northern lakes, rivers and Hudson Bay. The Assiniboine River was the fur traders' route to the western plains. Therefore, Winnipeg was a readily accessible settlement for fur trading. In the steamboat days of the late nineteenth century, Winnipeg was a riverport for settlers heading west to their homesteads. Morton (1957) referred to a regular steamboat service along the Assiniboine between Winnipeg and Portage la Prairie after 1876.

Boats were the primary methods of transportation of freight and people. The *Anson Northrup*, named after its owner, was the first steamboat on the Red River in 1859. Between 1859 and 1871, it was the only steamer moving goods on its north-south route (Krenz and Leitch, 1993). Six additional boats were built between 1871 and 1875. The steamboats brought settlers, supplies, and construction materials from the United States to Winnipeg. After 1876, they shipped grain from Winnipeg to Minnesota for export to Europe (Parks & Recreation Department, 1982). Steamboating on the Red River lasted 53 years, ending in 1912 (Krenz and Leitch, 1993). With the coming of the railroad from St. Paul, Minnesota, to Winnipeg in 1878, and Canadian Pacific railroad to Winnipeg in 1881, the need for water transportation was lessened. The rivers were used for shipping cargo on barges even after the turn of the century, and, in fact, up until 1970. Nowadays water transportation is restricted to the Red River between Winnipeg and Lake Winnipeg (Green, 1995).

2.2.3 Water Supply and Water Quality

The first settlements were along the well drained levees of the Red and Assiniboine Rivers. One of the major factors in the choice of site was the access by water. The early land drainage works were agricultural; later they were for the settlement of Winnipeg (Graham, 1984).

The Red and Assiniboine rivers cross intensively-used agricultural land, from which fertilizers, pesticides and organic materials enter the rivers in run-off. Upstream water quality usually meets the *Manitoba Surface Water Quality Objectives* for fish and other aquatic life. However the combination of natural and human upstream activities create poorer water conditions as the rivers reach Winnipeg. The high phosphate content from fertilizers, the poor physical condition for recreation (high suspended solids content and low clarity), and unaesthetic characteristics for drinking (poor taste, odour and water hardness), all fail to meet the Manitoba Objectives (Works and Operations Division, 1991a).

At present, many licenses exist for the use of river water for agriculture. Only a few industries employ river water for such purposes as equipment cooling, and these uses have no specific requirements for water quality. However, the Red and Assiniboine rivers are not a main source of drinking water in Winnipeg. They are currently used as receiving water for sewage lagoon and treatment plant discharge. Both rivers have similar water quality, and extensive treatment is required (Works and Operations Division, 1991b).

The existing water supply system for Winnipeg includes the Shoal Lake water source, the Shoal Lake Aqueduct, the Deacon Reservoir and the City's water distribution system. To meet the increasing water demand, according to the *Winnipeg Development Plan Review* (James F. MacLaren Ltd., 1979), the Assiniboine River would provide more adequate water to the existing supply system rather than the Red River for the reasons:

(1) An Assiniboine river source would be better located for integration into the existing supply and distribution systems.

(2) The South End and North End Water Pollution Control Centers discharge into the Red River. Consequently, the use of the Assiniboine River would receive greater public acceptance.

(3) Flow control in the upper reaches of the Red River occurs within the U.S.A. making this river a less reliable water

source.

2.2.4 Water-Based Recreation

The demand for recreational facilities in Winnipeg is growing with the increase in population and increasing leisure time. The Red and Assiniboine are valuable resources for water sports, especially canoeing, boating, skiing and fishing, as well as for riverine camping. Only during the past three decades have these rivers become important for recreation and tourism (Green, 1995). The Red River is the largest single recreation resource for much of the Red River Valley.

Sport fishing is a popular activity along the Red River north of Lockport in both summer and winter, although it is a significant recreation within Winnipeg. Within the past few years, the development of The Forks complex at the confluence of the Red and Assiniboine rivers has proved to be a major tourist facility. Associated with this complex, a riverwalk has been constructed along the north bank of the Assiniboine from The Forks to the Manitoba Legislature. A riverwalk also extends from The Forks downriver on the west bank of the Red. This aesthetic riverine resource is an important recreational facility.

There are five major marina/boat launching areas operating within Winnipeg. River boats from two commercial boat-touring operations regularly ply the waters of the Red as it winds its way through the City past more than 30 park and recreation areas between the north perimeter and south perimeter highway bridges (Manitoba Clean Environment Commission, 1980). River cruises enable sightseeing along the Red and Assiniboine Rivers. Up to five commercial cruise boats ply the rivers regularly. The first river boat used for cruises in this city was the M.S. Paddlewheel Queen, constructed in 1965 (Green, 1995). Power boating is popular along the Red between the floodway entrance control structure at St. Norbert and the town of Selkirk. Estimates range between 11,000 and 70,000 boaters on the rivers in Winnipeg, with about 60 per cent being regular river users who moor their boats at private docks or marinas (Works and Operations Division, 1991b).

Swimming activity within Winnipeg's rivers is uncommon, due to their natural murky appearance and their contamination. The steep and muddy banks are unappealing to swimmers and pose safety hazards. Winter skiing on the wider and straighter stretches of the river is quite common.

3. FLOOD HAZARD ANALYSIS

3.1 RIVER SYSTEM

Winnipeg is situated within the two major drainage basins of the Red River and Assiniboine River (Figure 3-1).

3.1.1 Red River

The Red River, 877km long, rises in Lake Traverse on the Minnesota-South Dakota border as the Bois de Sioux River; it flows directly north past Fargo and Grand Forks, crossing the Canadian border near Emerson, Manitoba. The Red receives its largest tributary, the Assiniboine, in Winnipeg. Eventually it flows into Lake Winnipeg. The Red flows northwards across the broad flat floor of pro-glacial Lake Agassiz. Overlying lacustrine sediments are alluvial deposits. In times of severe drought (e.g. 1934) the river can virtually dry up (Marsh, 1988). By contrast, a late spring thaw after heavy snows can cause the Red to flood. The flood threat is exacerbated because the north-flowing Red has upper reaches that thaw before the lower reaches do.

The Red River drainage basin upstream from St. Norbert is 124,300km^2 (48,000 sq. mi.), of which 11 per cent of the area is in Manitoba (Manitoba Clean Environment Commission, 1980; Krenz and Leitch, 1993). The Red's elevation at Wahpeton

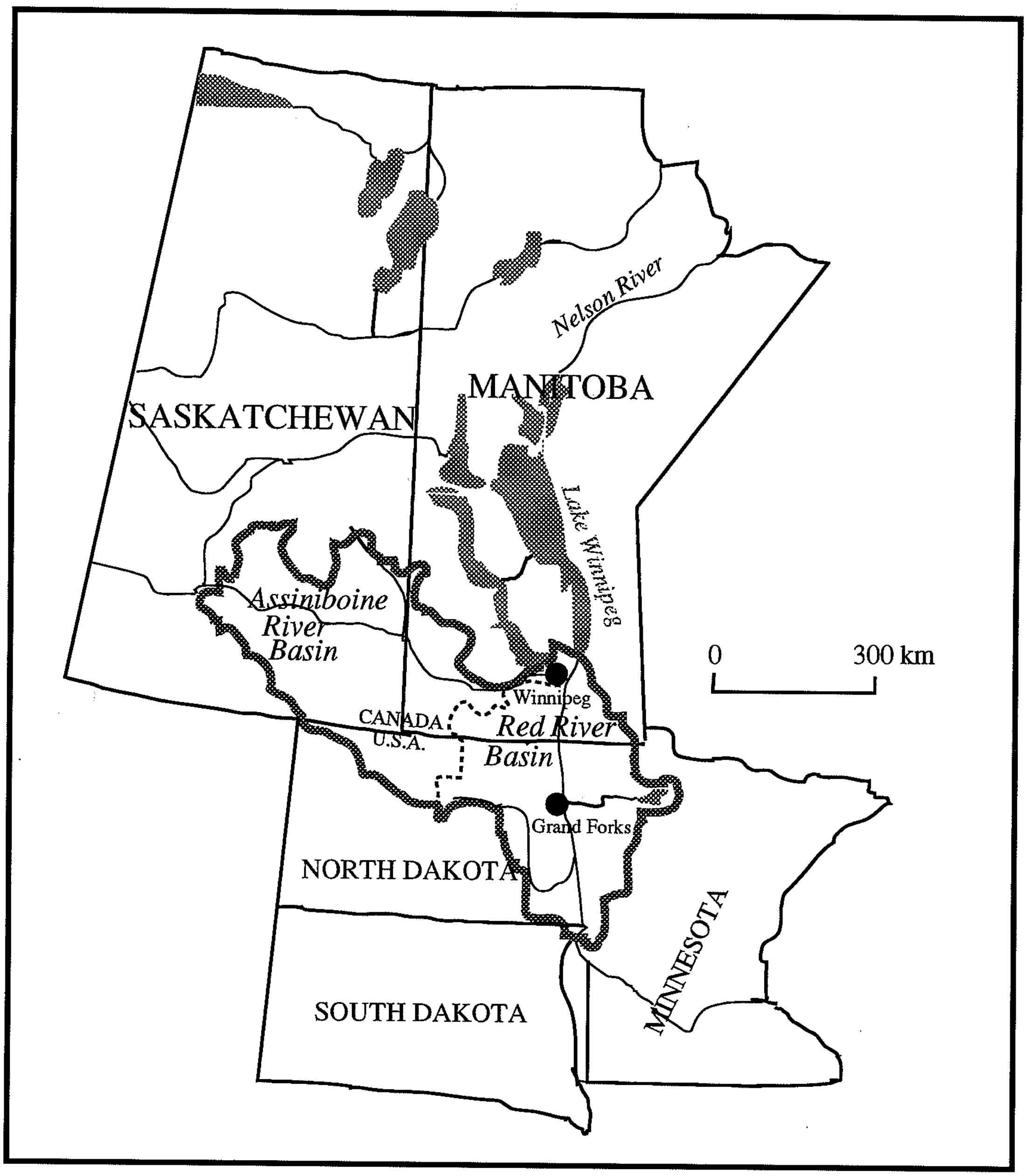


Figure 3-1 The Red and Assiniboine River Basins

Source: MacDonald (1994).

(North Dakota) is 287m (943 ft.) above sea level, and Lake Winnipeg is about 218m (714 ft.) above sea level. The difference in elevation between these two points is approximately 70m (229 ft.) over a distance of 885km (550 mi.). The longitudinal slope of the Red River between these locations averages about 0.075m/km. This extremely low gradient is conducive to flooding of the Red River plain.

3.1.2 Assiniboine River

The Assiniboine River, 1070km long, rises in southeast Saskatchewan. It enters the Lake of the Prairies near the Manitoba border, and downstream it is joined by the Qu'Appelle River. Southeast of Brandon, the Souris River joins the Assiniboine. The latter has eroded a broad valley through the Manitoba Escarpment before crossing the proglacial Lake Agassiz plain to Winnipeg.

3.1.3 Hydrological Characteristics

Within Manitoba, the Roseau, Rat and Seine rivers enter the Red River from the east, whereas La Salle, Morris and Assiniboine rivers enter from the west. Some tributaries of the Red in the U.S.A. and Manitoba have a fairly rapid descent into the Red River valley, where their gradients are reduced to a little more than that of the Red River. The western tributary streams are characterized by frequent low discharges compared with those of the eastern tributaries, due to slightly lower precipitation, the lack of regulating lakes and swamps, and the existence of many undrained areas (Red River Basin Investigation, 1953).

The stream flows in the Red River basin are highly variable. The lowest annual discharge for the Red River at Emerson over the period of record (from 1912) was $3.0 \times 10^8 m^3$ recorded in 1934. The highest annual discharge at the same location was $111.0 \times 10^8 m^3$ recorded in 1950. Normally the minimum monthly flow occurs in February, with an average discharge of $20 m^3/s$. The highest monthly discharge is usually in April. The average April flow over the period of record is $340 m^3/s$. At Redwood Bridge in Winnipeg, discharge rates range from a low of $159 m^3/s$ in February 1981, to a maximum of $3058 m^3/s$ in May 1950 (Manitoba Clean Environment Commission, 1980). Mean spring flow is $850 m^3/s$ at Redwood Bridge.

3.2 THE CAUSES OF FLOODING

Most flooding in the region occurs as the result of spring snowmelt. However, occasional floods do occur as a consequence of large summer rainfalls. Factors influencing river flooding potential fall into three categories: climate, topography, and ground conditions.

3.2.1 Climate

Seasonal flooding may be produced by spring snowmelt in areas of abundant snow accumulation and marked seasonal temperature changes. The meteorological conditions that aggravate flooding within the Red River over this region are heavy autumnal precipitation, severe frost before snowfall, abundant snowfall particularly during the latter portion of winter, a late and sudden melt of the snowpack, and heavy rainfall and wet snow during the spring breakup of river ice (Carlyle, 1984).

Floods in the lower reaches of the Red and Assiniboine have always been associated with spring snowmelt. It is estimated that snow only constitutes about 17 per cent of the total yearly precipitation in the lower Red River basin, yet melt of accumulated snow, in combination with other factors, has been the main cause of river flooding (Red River Basin Investigation, 1953). Andrews (1993, p.58) summarizes the major factors affecting snowmelt runoff in this area:

- extent, and moisture content, of snow cover.
- rate of melting of the snow.
- rain coincident with snowmelt.
- soil moisture and temperature.
- absorptive capacity of the clay soils.

Flood hydrographs associated with snowmelt runoff into large rivers are typically characterized by slow rising limbs, prolonged high flows and gradual recessions (Red River Basin Investigation, 1953).

The Red River and some of its tributaries may increase the flood hazard due to ice jams, depending on the prevailing temperatures at break-up. Where warm air is moving from the southwest, the runoff from the southern portion of the basin may be partially blocked by ice in the northerly reaches of the rivers (Red River Basin Investigation, 1953c). Ice jams occur occasionally, particularly on the Red's tributaries, and these locally may cause river level rises of 2.4m to 2.7m (8-9 ft.) in a day. A sudden thaw accompanied by heavy rainfall promotes a spring flood too.

3.2.2 Topography

Carlyle (1984) observed that "[t]he valley of the Red River is structurally and geomorphologically predisposed to flooding." (p.331). The topography of the region is obviously responsible for its natural tendency to flooding. The Red River flows across the virtually flat bed of former Lake Agassiz. The average longitudinal slope is slightly greater than 0.09m/km between Fargo and Grand Forks, and is about 0.045m/km from the latter point to Winnipeg (Red River Basin Investigation, 1953a). As a result, the Red easily spills over its low banks onto the surrounding flat prairie.

The course of the Red River and the pattern of its tributaries influence the magnitude and duration of flooding. Sometimes, there is a situation where peak flows from the Red's confluent streams coincide with the flood crest moving northward along the main river (Red River Basin Investigation, 1953c).

3.2.3 Natural Channel Conditions

The normal channels of the Red and Assiniboine rivers are inadequate to carry excess snowmelt flows. For instance, the natural channel of the Red can accommodate only about one-third to one-half the peak discharge that occurred in May 1950. Consequently, the cities and towns of Manitoba and North Dakota bordering the Red and Assiniboine have a long record of flood experience (Red River Basin Investigation, 1953b). Table 3.1 gives the approximate channel dimensions and flow capacities at selected stations. It can be seen, by comparing Table 3.3 and 3.1, that the natural channel at Winnipeg can only carry a flood discharge with an approximate return period of 7 years.

Table 3.1 Channel Characteristics of the Red River

Location	Height above Lake Winnipeg (m)	Width of Stream (m)	Depth (m)	Approximate Channel Capacity (m^3/s)
Wahpeton, N.D.	167	46	3	42
Fargo, N.D.	137	76	6	91
Grand Forks, N.D.	91	122	9	510
Emerson, MB	47	152	9	1076
Winnipeg, MB	14	198	9	1954
North of Selkirk, MB	1.8	274	4.6	--affected by water level of Lake Winnipeg

Source: Red River Basin Investigation, 1953a.

3.2.4 Ground Conditions

Vegetation also affects flood potential. Historically, there were tall grasslands, creeks and marshlands along the Red and Assiniboine rivers which retained large amounts of rain water. Today the same places have become open fields, and many marshes have disappeared with the creation of drainage ditches. These land-use changes promote flood formation because rain water is quickly transferred into the rivers. As a general rule, open ditch drainage increases the rate of runoff. However, the characteristics of stream flow depends on many factors. Compared with other factors determining the magnitudes and frequencies of flood discharges, the impact of open ditch drainage is insignificant (Red River Basin Investigation, 1953c).

3.2.5 Contribution to Flooding

The Assiniboine River, with a basin area of about 163,000km^2 (63,000 sq. mi.), is the largest tributary of the Red. Compared with the Red, the Assiniboine has lower discharges and its peak flows are usually smaller, as its basin lies largely within a drier climatic region. Rannie (1980) estimated that the Assiniboine River contributes only 31 percent (or 25 percent according to Water Resources Branch, 1981) of the water flowing through Winnipeg. Forty-five percent of the combined flow of the Assiniboine and Red is derived from Manitoba, 46 percent from the United States, and 9 percent from Saskatchewan (Manitoba Clean Environment Commission, 1992).

Water Resources Branch (1981) established a correlation between Red River flood peaks and Assiniboine River contributions to them:

$$Y_0 = 2770 + 0.186X_0$$

in which Y_0 is the estimated Assiniboine River contribution (in cfs), X_0 is the Red River flood peak at Redwood Bridge. The correlation coefficient is $\gamma=0.71$, and standard deviation is $\sigma=23,029$ respectively.

By using the linear correlation and confidence limits ($\pm1.645\sigma$, at $\alpha=90\%$), three Assiniboine River contributions were estimated for various Red River peak discharges. The three values representing the upper, the average and the lower limits, are referred to as the maximum, the average and the minimum contribution respectively to the Red River peaks (Table 3.2).

Most of the runoff in the Red and Assiniboine watershed occurs during the spring. However, the timing of peak flows on the two rivers does not normally coincide. Clark (1950) found that in only 15 percent of cases the peak discharge on the Assiniboine River coincided with the flood crest on the Red River. In 75 percent of cases, the peak of the Assiniboine River was later than that of the Red. The other 10 percent of all cases involved the Assiniboine cresting prior to the Red.

Until the completion of the flood control works at Portage la Prairie, Assiniboine floodwaters sometimes caused serious damage between there and Winnipeg. However, normally, the Assiniboine was only a contributing, rather than a causal, factor of flooding in Winnipeg itself.

Table 3.2 Assiniboine River Contribution to the Red River Peaks at James Avenue (in cfs)

Red River Peak in Winnipeg	Assiniboine River Contribution		
	Minimum	Average	Maximum
10,000		4,600	
20,000		6,500	
30,000	1,200	8,400	15,500
40,000	3,100	10,200	17,300
50,000	5,000	12,100	19,200
60,000	6,800	13,900	21,100
70,000	8,600	15,800	23,000
80,000	10,400	17,700	24,900
90,000	12,200	19,500	26,900
100,000	13,900	21,400	28,800
110,000	15,700	23,200	30,800
120,000	17,400	25,100	32,800
130,000	19,100	27,000	34,800
140,000	20,800	28,800	36,800
150,000	22,400	30,700	38,900
160,000	24,100	32,500	41,000
170,000	25,800	34,400	43,000
180,000	27,400	36,300	45,100
190,000	29,000	38,100	47,200
200,000	30,600	40,000	49,300
210,000	32,300	41,800	51,400
220,000	33,900	43,700	53,500
230,000	35,500	45,600	55,600
240,000	37,000	47,400	57,800
250,000	38,600	49,300	59,900
260,000	40,200	51,100	62,900
270,000	41,800	53,000	64,200
280,000	43,300	54,900	66,400
290,000	44,900	56,700	68,500

Source: Water Resources Branch, 1981.
Note: to keep the accuracy of the original text, the imperial system is adopted here.

3.3 HISTORICAL FLOOD EVENTS

3.3.1 Hydrological Records

The earliest continuous records of river stages and discharges in the Red River Basin may date back to 1882 when gauges were installed by the Corps of Engineers, United States Army, on the Red River at and above Grand Forks. Observations of the peak flood stages of the Red River at Winnipeg were taken by the City Engineer's Office from 1874, with the exception of seven years (1879 and 1886-1891). Daily stage records at Emerson and Winnipeg have been kept continuously since 1912 and published by Water Resources Division of the Manitoba Government (Red River Basin Investigation, 1953). For the period of 1912 to 1971, the gauging station was at the Redwood Bridge in Winnipeg. In 1971 the gauge was relocated to the James Avenue Pumping Station. Published stage data at these stations since 1968 reflect regulation by flood control works (Water Resources Branch, 1981).

3.3.2 Historical Floods

Little is known about flood events prior to organized settlement of the Red River Colony, although temporary trading posts were established in this area as early as 1738 (Red River Basin Investigation, 1953 and 1953b; Andrews, 1993). Following the colonization of the Red River valley in 1812, there was no mention of flooding at Winnipeg, but historical accounts indicate that there was very high water near Pembina (North Dakota) in 1815 (Red River Basin Investigation, 1953).

The three large floods in early times occurred in 1826, 1852 and 1861 (Red River Basin Investigation, 1953). Much of the site of present-day Winnipeg was covered with water, and the whole Red River valley appeared rather like a lake. The greatest flood in the period of organized settlement occurred in the spring of 1826; it resulted from wet weather in the previous autumn, a winter of heavy snow, and a late spring with a sudden thaw in early May coinciding with heavy rainfalls (Andrews, 1993). The Red rose rapidly, driving the inhabitants of Winnipeg westward to Sturgeon Creek for refuge. At Fort Garry, the Red River rose 2.7m in 24 hours. The estimated maximum discharge through the town was 6371m^3/s, and occurred on 21st May 1826. The recurrence interval of a flood of this magnitude is about 667 years (MacDonald, 1994). Flood waters forced the abandonment of Fort Garry and virtually destroyed every building there. Almost all of the present-day built-up area of Greater Winnipeg (with the exception of the westernmost suburbs) was inundated (see Figure 3-2).

The second and third largest floods occurred in 1852 and 1861 respectively. As in 1826, the floods were due to a wet autumn, heavy winter snows, a late and sudden spring thaw, and rainfall during the snowmelt runoff period. These floods were accurately documented by several observers. The flood of 1852 was 0.6m lower than the 1826 peak. At the junction of the Red and Assiniboine, the water rose to an elevation of 232.4m, and the peak discharge, which occurred on 21st May 1852, reached about 4672m^3/s. The estimated recurrence interval is 150 years. As Figure 3-2 reveals, flooding was not as extensive as

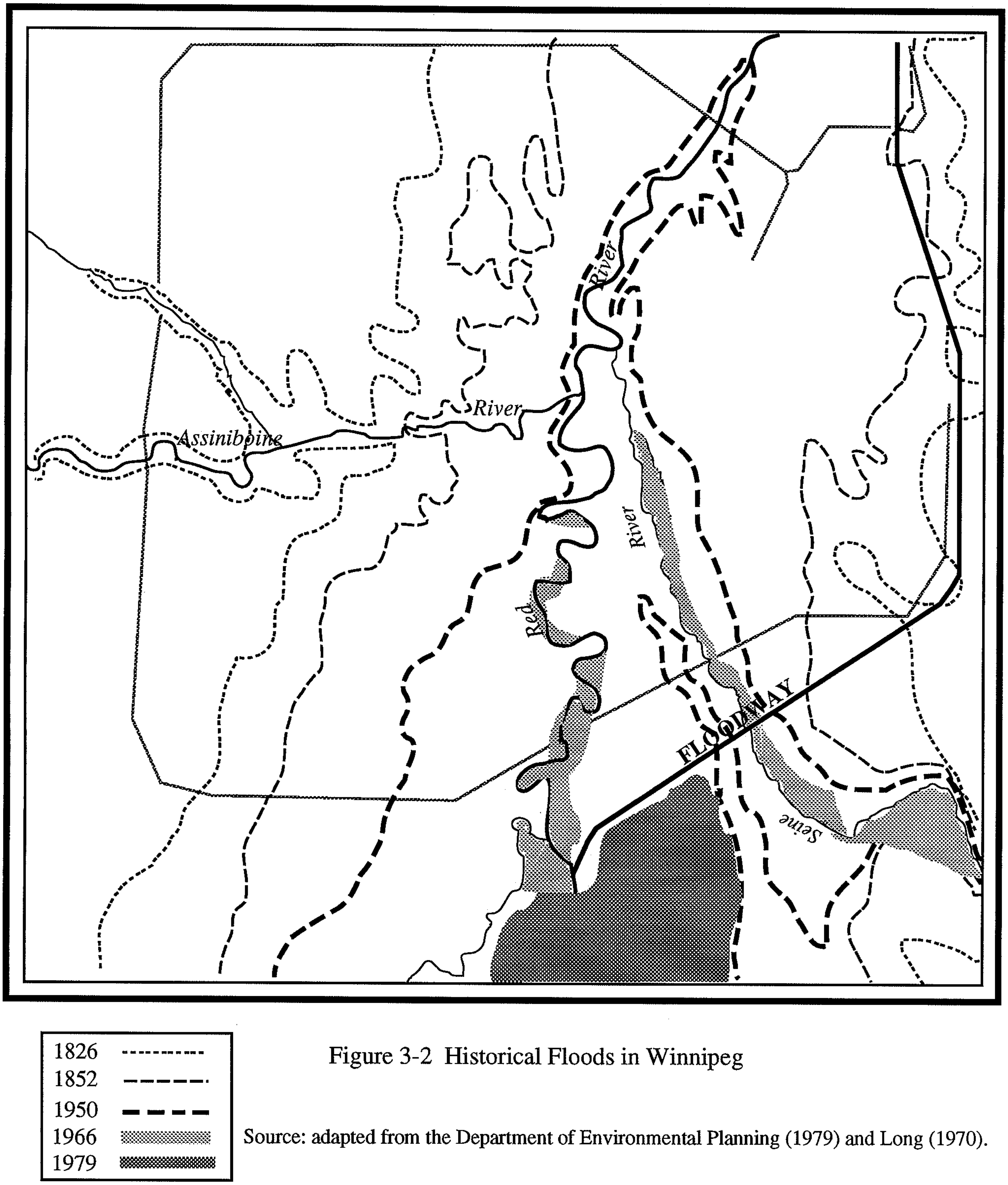


Figure 3-2 Historical Floods in Winnipeg

Source: adapted from the Department of Environmental Planning (1979) and Long (1970).

in 1826. Most of present-day west Winnipeg was not flooded. However, compared with 1826, more damage resulted due to the interim increase in settlement. About 3500 people, representing 75 per cent of the population, abandoned their homes, and at least one person drowned (Andrews, 1993; Red River Basin Investigation, 1953).

The 1861 flood peak ($3540m^3/s$) occurred on 8th May, and was 1.2m lower than the 1826 peak. The Nor-Wester, Winnipeg's first newspaper (bi-monthly), provided a graphic description of the flood. The maximum elevation reached by the water at The Forks is estimated at 231.8m (Red River Basin Investigation, 1953). The flood forced many settlers to abandon their homes and to seek refuge on higher land. However, damage was significantly less than that in the 1852 event because floodwaters were much less extensive (Andrews, 1993).

3.3.3 Recent Floods

For most of the first half of the twentieth century, few major floods occurred. Only in 1904, 1916 and 1948 did peak discharges of over $2000m^3/s$ exist. There were numerous moderate peak discharges during this period. Nevertheless, the flood damage threat grew as development of the City of Winnipeg took place.

The most extensive and prolonged Winnipeg flood thus far in the twentieth century occurred during the period of April, May and June of 1950, the fourth largest flood event on record (Figure 3-2). This event was widely reported (Clark, 1950; G.O.C. Prairie Command, 1950; Hurst, 1957; Red River Basin Investigation, 1953; Rasky, 1961; US G.S., 1967; Gardner, 1976; Bumsted, 1993). The flood was caused by an unusual combination of factors: relatively high water content of the snow, a sequence of cold and warm air temperatures, and intense rains during the flood (Zelinsky and Kosinski, 1991). The late spring and heavy snowfall of the preceding winter caused the waters of the Red to reach flood proportions about the middle of April. A heavy rainfall, twice the normal precipitation for the month, occurred on May 4 and 5; this exacerbated the flood problem (Hurst, 1950; Red River Basin Investigation, 1953). The river reached flood level by April 22. The water level continued rise until May 19th, when it reached a crest of 9.24m (30.3 ft.) due to heavy rainfall. A near-peak stage (about 30 ft.) lasted from May 14 to May 20 (Clark, 1950). The Red's peak discharge was 3058m^3/s, with a return period of 28 years; this discharge is less than half the peak flow of the 1826 flood.

According to the Department of Resources and Development Canada (1952), "[t]he flood on the Red River of the North caused the greatest damage to Winnipeg that the city has ever experienced." (p.116). During the flood, the water was zero to about 4.6m (15 ft.) deep in some of the low-lying districts near the rivers, particularly in the Fort Garry and St. Vital areas. Water covered about one tenth of the City by May 14. Some 8,200 homes in Greater Winnipeg were flooded, including 5,500 in which water reached above the first floor (Clark, 1950). In Winnipeg, the river was above the flood stage of 18 feet for 51 days (from April 21 to June 10) (Wild, 1996b), and forced between 70,000 and 100,000 persons to evacuate their homes. During the flooding two dykes (Wildwood Dyke and Riverview Dyke) were breached, and one volunteer pump operator drowned (Clark, 1950; Zelinsky and Kosinski, 1991; Andrews, 1993). The property damage was estimated at $75 million, about $500 million today (Wild, 1996b).

The flood of 1966 along the Red River was severe in terms of its damage cost, with a total of $12.2 million ($49.2 in 1991 dollars) (Andrews, 1993), the highest loss since 1950. This flood resulted from an above average accumulation of snow following a wet autumn in 1965. Early forecasts indicated that flooding in 1966 would be as serious as that of 1950, which had a peak stage of 9.24m. However, no significant rainstorms preceded the 1966 flood peak, which reached only 8.02m (26.31 ft.) (Long, 1970). Flooding affected a relatively small area within Winnipeg (see Fig. 3-2). Nonetheless, this event involved the second largest emergency operation in the City's history (Rannie, 1980), it caused much damage, and it resulted in large-scale disruption of normal urban activity.

In the spring of 1979, a large accumulated snowpack, late and exceedingly rapid melt, and heavy April rainfall in the upper part of the Red's drainage basin combined to produce a severe flood condition in the Red River valley (Rannie, 1980). The natural 1979 maximum flood discharge (3,030m^3/s) was close to that of the 1950 flood (3,058m^3/s). However, the 1979 flood event occurred after the construction of the Winnipeg flood control system. As a consequence, property damage in 1979 was limited to south of the Floodway, and City activity was scarcely affected (Manitoba Government Services, 1980; Andrews, 1993) (Figure 3-2).

The only other post-Floodway flood event that possessed a greater natural peak discharge than the 1966 flood was that of 1974 (approximately 2,700m^3/s); in Winnipeg, its effect was negligible due to the operation of the major flood control works.

Unlike the springtime river floods, due to rapid snowmelt and heavy rains, a recent flood event in Winnipeg occurred in the summer of 1993, the wettest summer in 120 years in the lower Red River valley. This rainstorm flood event resulted from three major downpours on July 24-25, August 8 and August 14, which exceeded the design input of the City's sewer system at many locations (CNC-IDNDR, 1994). By mid-August, Winnipeg had received 427.8mm of rain since June 1, compared to the historical average of 231mm for the three summer months. Gardens, yards and streets in the St. Vital and Fort Garry areas were inundated, and many basements were flooded (anon., 1993a). Homeowners along the Red River suffered millions of dollars damage from water backup from sewers and from rainwater incursion into basements. The Red rose 3.3m above its normal summer levels and submerged some low-lying areas. Sturgeon Creek and other tributaries of the Assiniboine and Red had flash flood conditions. Basically the flooding was caused by unusually heavy rainfalls that saturated the heavy clays in the Red River valley and resulted in standing water that soon overloaded the urban sewer system. The flood damage and cleanup costs in the 1993 event were estimated at $50 million, while the total insurance claim for damage due to storm sewer backup was an additional $160 million (CNC-IDNDR, 1994).

3.3.4 Summary

Table 3.3 shows the estimated maximum discharges in order of relative flood magnitudes at Winnipeg. It can be seen that all floods occurred in late April or May. The Red River peak flood level for the 1993 summer rainstorms event is added to the table for comparative purposes.

Table 3.3 Worst Floods on the Red River at Winnipeg

Date of Maximum Discharge	Estimated Maximum Discharge (m^3/sec.)	Likelihood of Recurrence (in years)
1826 May 21	6,371	667
1852 May 21	4,672	150
1861 May 8	3,540	45
1950 May 19	3,058	28
1966 April 14	2,497	14
1916 April 24	2,427	13
1882 May 3	2,421	13
1904 April 24	2,209	9
1948 May 1	2,124	8
1956 April 27	1,974	7
1960 April 18	1,965	7
1892 April 19	1,957	7
1897 April 27	1,954	7
After the Floodway was built (1969): *		
1979 May 10	3,030	27
1974 April 25	2,718	19
1987 April 9	2,350	12
1970 April 30	2,251	10
1969 May 2	2,143	8
1993 August 15	1,303	3
Normal Flow:		
Spring	850	
Summer	50	

Source: MacDonald, 1994. Data from A.A. Warkentin, Water Resources Branch, Manitoba Department of Natural Resources.

Note: * Computed natural flows without existing flood control works.

3.4 FLOOD FREQUENCY ANALYSIS

3.4.1 Flood Data Series

In frequency analysis, two data series of peak flows are often defined: the annual maximum series and the partial duration series. It is known that the two series form different probability distributions, but for return periods of 10 years and more, the differences are minimal, and the annual maximum series is the one most usually analyzed (Shaw, 1983). The annual maximum series takes the single peak discharge in each year of record; as a consequence, the data set is equal to the length of record. The annual maximum discharges on the Red River at Redwood Bridge are recored in Table 3.4.

Table 3.4 Annual Maximum Flow Discharges at Redwood Bridge, Winnipeg (m^3/s) *

Year	Data	Year	Data	Year	Data	Year	Data
1826	6371	1901	977	1931	688	1961	481
1852	4672	1902	1404	1932	1062	1962	1687
1861	3540	1903	819	1933	1096	1963	660
1875	1042	1904	2209	1934	442	1964	1002
1876	807	1905	614	1935	425	1965	1809
1877	1068	1906	866	1936	1067	1966	2497
1878	382	1907	980	1937	219	1967	1727
...		1908	909	1938	436	1968	510
1880	1178	1909	578	1939	357	1969	2143
1881	1291	1910	980	1940	498	1970	2251
1882	2421	1911	345	1941	1183	1971	1526
1883	1422	1912	586	1942	1291	1972	1588
1884	1345	1913	1277	1943	1195	1973	529
1885	1008	1914	442	1944	493	1974	2718
...		1915	326	1945	1486	1975	1671
1892	1957	1916	2427	1946	1079	1976	1807
1893	1897	1917	1124	1947	1039	1977	187
1894	1303	1918	405	1948	2124	1978	1750
1895	957	1919	665	1949	1362	1979	3030
1896	1741	1920	1090	1950	3058	1980	881
1897	1954	1921	628	1951	1064	1981	159
1898	1458	1922	821	1952	1008	1982	1458
1899	345	1923	1809	1953	357	1983	1393
1900	331	1924	654	1954	524	1984	1048
		1925	1190	1955	1520	1985	991
		1926	379	1956	1974	1986	1812
		1927	1455	1957	654	1987	2350
		1928	912	1958	524	1988	564
		1929	912	1959	991	1989	1390
		1930	1042	1960	1965	1990	396
						1991	280
						1992	1400
						1993	1303
						1994	1130
						1995	1880

Source: compiled from various sources. Water Resource Branch, Manitoba Department of Natural Resources.

* Discharges were recorded at Redwood Bridge (1912-1970) and James Avenue Pumping Station (1971-1995).

* Computed natural flows are utilized in all calculations, hence the effects of existing flood control works are eliminated.

In analyzing single historical sequences of hydrologic variables, the predictive value of fitted distributions is limited because the records are generally short and the sampling errors are correspondingly large. Additional and more reliable information can often be obtained within a homogeneous region by correlating dependent hydrologic variables with other causative factors. In such ways, hydrologic characteristics within the region can be summarized, and estimates of statistical parameters can be derived from general regional relations.

The length of the period of record used in a frequency analysis significantly affects the results. Regression techniques are often used to extend short records at a station if significant correlation exists between that place and a nearby station with a longer record.

3.4.2 Flood Prediction and Forecasting

In estimating future floods, two different approaches, forecasting and prediction, are used. Keith Smith (1971), author of the book *Water in Britain: A study in applied hydrology and resource geography*, recognized their difference:

> Flood prediction proper makes use of a long time-period, usually the total span of records, and concentrates on the more extreme events. It is largely based on mathematical theory, and attempts to predict the statistical frequency of flood occurrence. The results are expressed in terms of average probability or return period, but there is no indication of when a flood of a particular magnitude will occur.
>
> Flood forecasting, on the other hand, deals with

specific events in the short-term as they arise, and, by using current information on weather conditions, state of the ground, etc., an attempt can be made to provide a warning not only of the magnitude of the river peak but also the timing of the event (p.116).

The purpose of both flood prediction and forecasting is to provide as much advance warning as possible of an impending flood. Over time, the demands for flood forecasts have changed from a simple indication of the likelihood or severity of flooding to an accurate prediction of magnitude and timing of flood passage (Andrews, 1993). In the scientific literature, the possibility of selecting simple adaptive models for real time flood forecasting has been widely discussed. Flood hydrology has advanced to the point where storm rainfall and runoff conditions can be simulated to high levels of accuracy. With the use of satellites to track storm movements, there is now genuine real time flood forecasting which can greatly diminish the lead time for warnings (Smith, 1992). Manitoba flood forecast methods will be discussed in Chapter 4.2.

3.4.3 Flood Prediction

In respect to flood prediction, two parameters should be determined, namely, flood magnitude and return period. There are two methods of fitting distributions: one is a straightforward plotting technique for the cumulative distribution, and the other considers the use of frequency factors.

The cumulative distribution provides a rapid means of determining the probability of the event equal to or less than some specified quantity. This attribute is used to obtain recurrence intervals for observed data. As a general rule, frequency analysis should be avoided when working with records shorter than 10 years and in estimating frequencies of expected hydrologic events greater than twice the record length (Kite, 1988). The probability of flood events can be obtained by use of a "plotting position." This technique in all cases is to arrange the data in increasing or decreasing order of magnitude and to assign order number ***m*** to the ranked values. Of the several formulae in use, Shaw (1983) recognized that Gringorten's formula is the best,

$$P(X) = \frac{m-0.44}{N+0.12}$$

where ***m*** is the rank of the flood event X and N is the total number of flood occurrences. However, the most efficient formula for computing plotting positions for unspecified distributions, and the one now commonly used for most sample data, is the Weibull formula, also sometimes known as the Gumbel formula (Kite, 1988; Sharp and Sawden, 1984; Shaw, 1983),

$$P(X) = \frac{m}{N+1}$$

The plotting of data on a graph is undertaken using the Gumbel scale for recurrence intervals. However, this method gives conservative results in that the return period conforms closely to the period of record. Actually, both Gringorten and Weibull formulae give similar results, with only a major divergence at both ends of the plotting position. Flood frequency analysis using the Weibull formula for the Red River at Winnipeg for recurrence interval determination, produces the results given in Table 3.5, based on the 104 annual maximum discharges for the continuous record 1892-1995.

Table 3.5 Flood Frequency Analysis

Year of Record	Annual Peak Flow	Rank	P(X)	T(X)
1950	3058	1	.0095	105
1979	3030	2	.019	52.5
1974	2718	3	.029	35
1966	2497	4	.038	26.3
1916	2427	5	.048	21
1987	2350	6	.057	17.5
1970	2251	7	.067	15
1904	2209	8	.076	13.1
1969	2143	9	.088	11.7
1948	2124	10	.095	10.5
1956	1974	11	.105	9.6
1960	1965	12	.011	8.8
1892	1957	13	.124	8.1
1897	1954	14	.133	7.5
1893	1897	15	.143	7.0
1995	1880	16	.152	6.6
1986	1812	17	.162	6.2
1923	1809	18	.171	5.8
1965	1809	18	.171	5.8
1976	1807	20	.190	5.3
1978	1750	21	.200	5.0
1896	1741	22	.209	4.8
1967	1727	23	.219	4.6
1962	1687	24	.228	4.4
1975	1671	25	.238	4.2
1972	1588	26	.248	4.0
1971	1526	27	.257	3.9
1955	1520	28	.267	3.8
1945	1486	29	.276	3.6
1898	1458	30	.286	3.5
1982	1458	30	.286	3.5
1927	1455	32	.305	3.3
1902	1404	33	.314	3.2
1992	1400	34	.324	3.1
1983	1393	35	.333	3.0
1989	1390	36	.343	2.9
1949	1362	37	.352	2.8
1894	1303	38	.362	2.8
1993	1303	38	.362	2.8
1942	1291	40	.381	2.6
1913	1277	41	.390	2.6
1943	1195	42	.400	2.5
1925	1190	43	.410	2.4
1941	1183	44	.419	2.4
1994	1130	45	.429	2.3
1917	1124	46	.438	2.3
1933	1096	47	.448	2.2
1920	1090	48	.457	2.2
1946	1079	49	.467	2.1
1936	1067	50	.476	2.1
1951	1064	51	.486	2.1
1932	1062	52	.495	2.0
1984	1048	53	.505	2.0
1930	1042	54	.514	1.9
1947	1039	55	.524	1.9
1952	1008	56	.533	1.9
1964	1002	57	.543	1.8

Table 3.5 Flood Frequency Analysis (cont.)

Year of Record	Annual Peak Flow	Rank	P(X)	T(X)
1959	991	58	.552	1.8
1985	991	58	.552	1.8
1807	980	60	.571	1.8
1910	980	60	.571	1.8
1901	977	62	.590	1.7
1895	957	63	.600	1.7
1928	912	64	.610	1.6
1929	912	64	.610	1.6
1908	909	66	.629	1.6
1980	881	67	.638	1.6
1906	866	68	.648	1.5
1922	821	69	.657	1.5
1903	819	70	.667	1.5
1931	688	71	.676	1.5
1919	665	72	.686	1.5
1963	660	73	.695	1.4
1924	654	74	.705	1.4
1957	654	74	.705	1.4
1921	628	76	.724	1.4
1905	614	77	.733	1.4
1912	586	78	.743	1.3
1909	578	79	.752	1.3
1988	564	80	.762	1.3
1973	529	81	.771	1.3
1954	524	82	.781	1.3
1958	524	82	.781	1.3
1968	510	84	.800	1.3
1940	498	85	.810	1.2
1944	493	86	.819	1.2
1961	481	87	.829	1.2
1914	442	88	.838	1.2
1934	442	88	.838	1.2
1938	436	90	.857	1.2
1935	425	91	.867	1.2
1918	405	92	.876	1.1
1990	396	93	.886	1.1
1926	379	94	.895	1.1
1939	357	95	.905	1.1
1953	357	95	.905	1.1
1899	345	97	.924	1.1
1911	345	97	.924	1.1
1900	331	99	.943	1.1
1915	326	100	.952	1.1
1991	280	101	.962	1.0
1937	219	102	.971	1.0
1977	187	103	.981	1.0
1981	159	104	.990	1.0

$\bar{Q}$ = 1153.4 (T= 2.3)

S_Q = 659.0219

On the other hand, the Gumbel extreme value distribution (Type I) can be used to estimate the *T*-year flood. Estimates of a specified annual maximum Q_T may be obtained from the following formula:

$$Q_T = \overline{Q} + K(T)\, S_Q$$

This formula is a simplified transform by taking the logarithm of the Gumbel distribution function. Shaw (1983) provided values of the frequency factor, *K(T)*, in relation to recurrence intervals for the Gumbel Type I distribution (see Table 3.6).

Table 3.6 The T - K(T) Relationship for the Gumbel Distribution

T	K(T)	T	K(T)	T	K(T)
1	$-\infty$	10	1.30	80	2.94
2	-0.16	15	1.64	90	3.07
3	0.25	20	1.86	100	3.14
4	0.52	25	2.04	200	3.68
5	0.72	30	2.20	400	4.08
6	0.88	40	2.40		
7	1.01	50	2.61		
8	1.12	60	2.73		
9	1.21	70	2.88		

Source: Shaw, 1983; p.310.

Assuming a Gumbel Type I distribution of annual maximum peak flow data for the Red at Winnipeg [with mean and standard deviation computed for the discharges - see Table 3.5], estimates of the peak discharges for required return periods can be calculated (see Table 3.7).

Table 3.7 T-Year Flood Discharges for the Red River at Winnipeg (m^3/s) (N=104)

T	2	5	10	20	50	100	200
Q_T	1047	1628	2010	2379	2873	3223	3579

3.4.4 Updated Flood Frequencies

N. Harden[1] selected the annual flood series of 1776-1996, with a total number of 119 years, for frequency analysis. He used the Log Perason Type III formula to calculate frequencies, and plotted flood probabilities on a graph (Figure 3-3). The results of the flood frequency analysis undertaken by the Water Resources Branch are presented in Table 3.8 in terms of selected recurrence intervals and their corresponding peak discharges.

Table 3.8 T-Year Flood Discharges at Redwood Bridge (N=119)

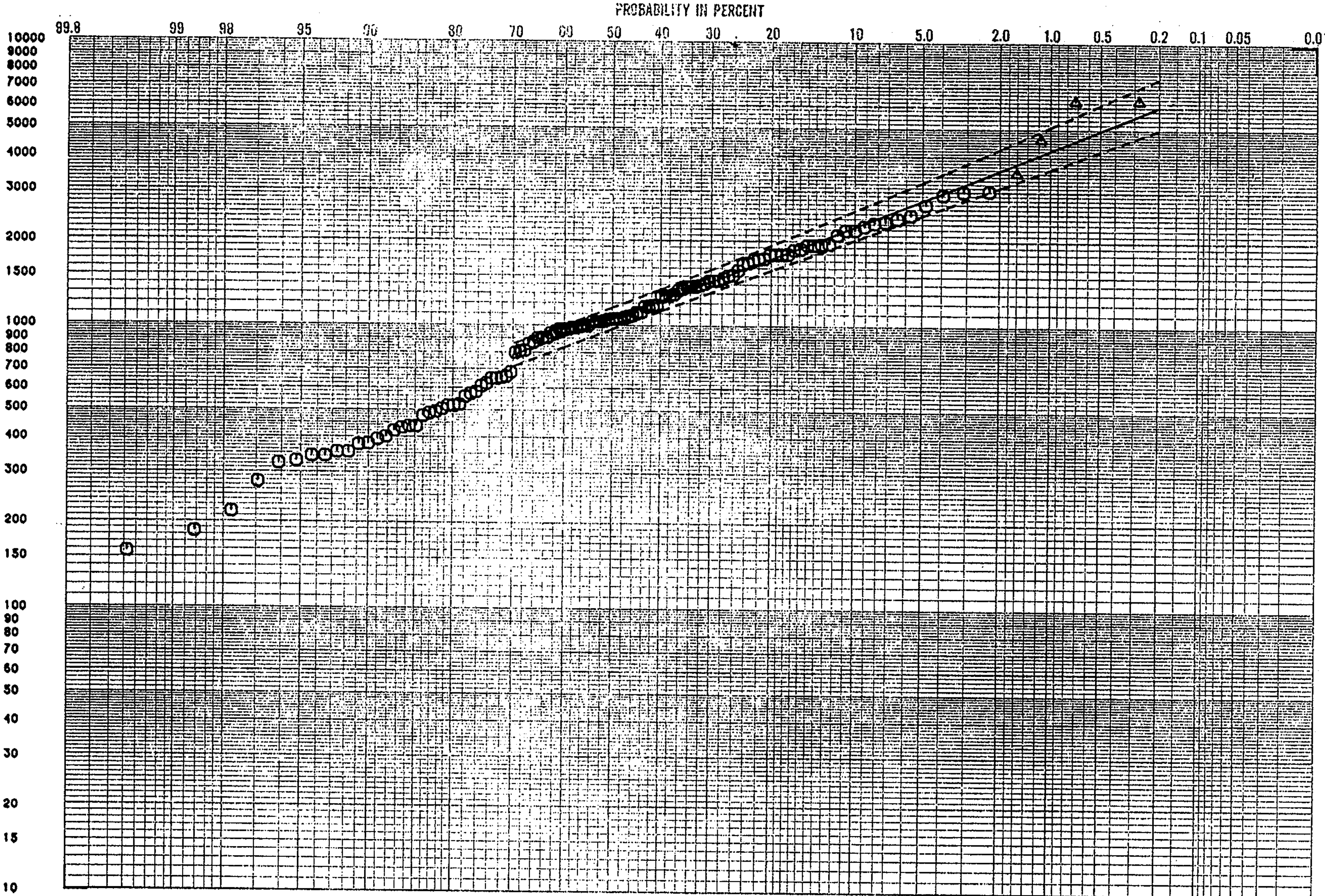
T	2	2.5	5	10	20	25	40	50	100	200	500
Q_T	1068	1237	1747	2271	2829	3017	3429	3633	4300	5024	6076

Source: Neil Harden, Water Resources Branch, 1996.

3.4.5 Discussions

In flood frequency analysis, many different probability distributions have been investigated for possible application. Lye, Sinha and Booy (1988) compared Bayesian analysis and maximum likelihood estimates (MLE), and obtained the T-year flood estimates at the Redwood Bridge in Winnipeg (see Table 3.9).

[1] N. Harden, Water Resources Branch. Personal Communication, September 1996.



NATURAL FLOWS RED RIVER AT REDWOOD BRIDGE HISTORICAL FLOWS INCLUDED

LEGEND

PLOT POSITION : CUNNANE
- O RECORDED
- Δ HISTORIC
- + ESTIMATED

SKEW COEFFICIENT (G) = 0.10 ———
95 % CONFIDENCE BAND - - - - -
STD.DEV. (S) 0.25
MEAN VALUE (ARITH) 1078.5 M**3/S

PROVINCE OF MANITOBA
DEPARTMENT OF NATURAL RESOURCES
WATER RESOURCES BRANCH

FREQUENCY CURVE

RED RIVER AT REDWOOD BRIDGE

NATURAL FLOWS INCL HISTORICAL FLOODS

PERIOD OF RECORD:	1875-1996	PREPARED BY: HARDEN	DATE: JUL-96
NO. OF YEARS: 119	STA.NO.: 05OJ001	DR.AREA:284899 SQ.KM.	ZONE: M.S.

Figure 3-3 Frequency Curve

Table 3.9 T-Year Flood with Standard Errors
(N=93)

T	2	5	10	20	50	100
MLE	991 (65)	1587 (102)	1995 (147)	2401 (208)	2938 (309)	3353 (400)
Bayes	1002 (64)	1604 (101)	2013 (147)	2413 (208)	2942 (309)	3350 (400)

Source: Adapted from Lye et al, 1988; p.85.
In parentheses are standard errors.

It is thus possible to fit several distributions to the sample flood data and to arrive at several different estimates of the T-year event. This is demonstrated for the flood data at Winnipeg in Tables 3.7, 3.8 and 3.9. Regarding different probability distributions, the main divergence is located in the tails of the distributions, which of course is the major concern for design flood.

It should be noted that "[t]here is no general agreement amongst hydrologists as to which of the many theoretical distributions available are most suitable to describe natural events, no agreement has been reached on the best techniques of fitting a distribution." (Kite, 1988; 249).

The accuracy of flood frequency estimation is largely dependent on the length of the flood record as well as on the selection of the frequency or probability distributions. A record is particularly valuable if it is long, continuous, homogeneous and has no missing peaks. With respect to the analysis of flood frequencies in Winnipeg, the Water Resources Branch has revised its recurrence intervals periodically, with the extension of the annual series of peak discharges over time. This is exemplified in Table 3.10 with respect to four of Winnipeg's largest floods.

Table 3.10 Comparison of Frequencies

Recurrence Intervals (T)	1852 Q=4,672	1950 Q=3,058	1974 Q=2,718	1979 Q=3,030
Water Resources Branch 1) (1979)	200	25	25	35
A. Warkentin 2) Water Resources Branch (1993)	150	28	19	27
N. Harden 3) Water Resources Branch (1996)	85	43	22	31

Sources: 1) Department of Environmental Planning, 1979.
2) MacDonald, 1994.
3) N. Harden, 1996.

Note: 1974 and 1979 are computed natural peak discharges at Redwood Bridge.

3.5 FLOOD RISK ANALYSIS

The concept of recurrence interval states that the T-year event is the average chance of exceedance once every T years over a long record. If $P(X)$ is the probability of an annual maximum equalling or exceeding X in any given year, the recurrence interval for X is:

$$T(X) = \frac{1}{P(X)}$$

However, it is also important to know the actual probability of exceedance of the T-year flood in a specific period of n years. This is called the risk, R.

Shaw (1983) stated that, if $F(X)$ is the probability of X

not being equalled or exceeded in any one year, then clearly, $F(X)=1-P(X)$. Assuming that annual maxima are independent, the probability of no annual maximum exceeding X in the whole n years is given by $(F(X))^n$. The probability of exceedance of X at least once in n successive years is then $1-(F(X))^n$, which may be represented by $R(X) = 1-(1-P(X))^n$, or simply,

$$R=1-(1-\frac{1}{T})^{n}$$

Therefore, various levels of risks associated with recurrence intervals can be calculated in theory (Table 3.11).

Table 3.11 The Expected Design Life Associated with Various Degrees of Risk and Different Recurrence Intervals

	Recurrence Interval (yrs)							
Risk	2	5	10	15	20	25	50	100
0.99	1.1	1.7	2.7	3.8	4.9	5.9	11.4	22.2
0.95	1.3	2.2	3.9	5.5	7.2	8.9	17.2	33.9
0.80	1.8	3.6	6.7	9.8	12.9	16.0	31.6	62.6
0.75	2.00	4.02	6.69	11.0	14.9	18.0	35.6	72.7
0.70	2.2	4.7	8.8	13.0	17.1	21.3	42.0	83.6
0.50	3.43	7.74	14.9	22.1	29.4	36.6	72.6	144.8
0.40	4.44	10.3	20.1	29.9	39.7	49.5	98.4	196.3
0.30	6.12	14.5	28.5	42.6	56.5	70.6	140.7	281
0.25	7.46	17.9	35.3	52.6	70.0	87.4	174.3	348
0.20	9.47	22.9	45.3	67.7	90.1	112.5	224.6	449
0.15	12.8	31.3	62.0	90.8	123.6	154.3	308	616
0.10	19.5	48.1	95.4	142.9	190.3	238	475	950
0.05	39.5	98.0	195.5	292.9	390	488	976	1949
0.02	99.5	248	496	743	990	1238	2475	4950
0.01	198.4	498	996	1492	1992	2488	4975	9953

Sources: Compiled from Viessman, Lewis, and Knapp 1989; and Sharp and Sawden 1984.

Note: The figures presented in the matrix are the expected design life values expressed in years.

Accordingly, for 5-year duration and 10-year duration periods in Winnipeg, the risks that events having selected recurrence intervals will occur have been computed in Table 3.12 as shown below.

Table 3.12 Risk Probability

Duration (n)	T/2	5	10	20	30	50	100	150
5-year	0.97	0.67	0.41	0.23	0.16	0.10	0.05	0.03
10-year	1.00	0.89	0.65	0.40	0.29	0.18	0.10	0.07

The above risk concept is actually a definition from the viewpoint of engineers who are involved in the design of flood alleviation schemes. For some other groups, such as emergency planners, psychology researchers, and the general public, the selection and definition of risks from flooding may vary significantly (Green, Tunstall, and Fordham, 1990).

4. FLOOD HAZARD ADJUSTMENTS

Humans exist in an essentially ecological relationship with their environment, and have to live with a variety of natural hazards which threaten both life and property. In a sense, the history of human evolution is one of the humankind struggle against natural hazards. In the context of river flooding, humans have attempted to reduce the flood hazard by a variety of means. A theoretical array of responses to the flood hazard is provided by Ward (1978). Represented diagrammatically, these responses may be differentiated into non-structural adjustments (e.g. land use regulation, insurance) or structural responses (i.e. flood control). As shown in Figure 4-1, Ward distinguished between two types of flood control: firstly, abatement (in which watershed modification is undertaken) and, secondly, protection (in which river channel modification is implemented).

Traditionally, flood problems were coped with through the implementation of large-scale structural measures of flood control. However, over the past fifty years, the emphasis has gradually moved away from abatement and protection towards reducing human vulnerability through non-structural approaches.

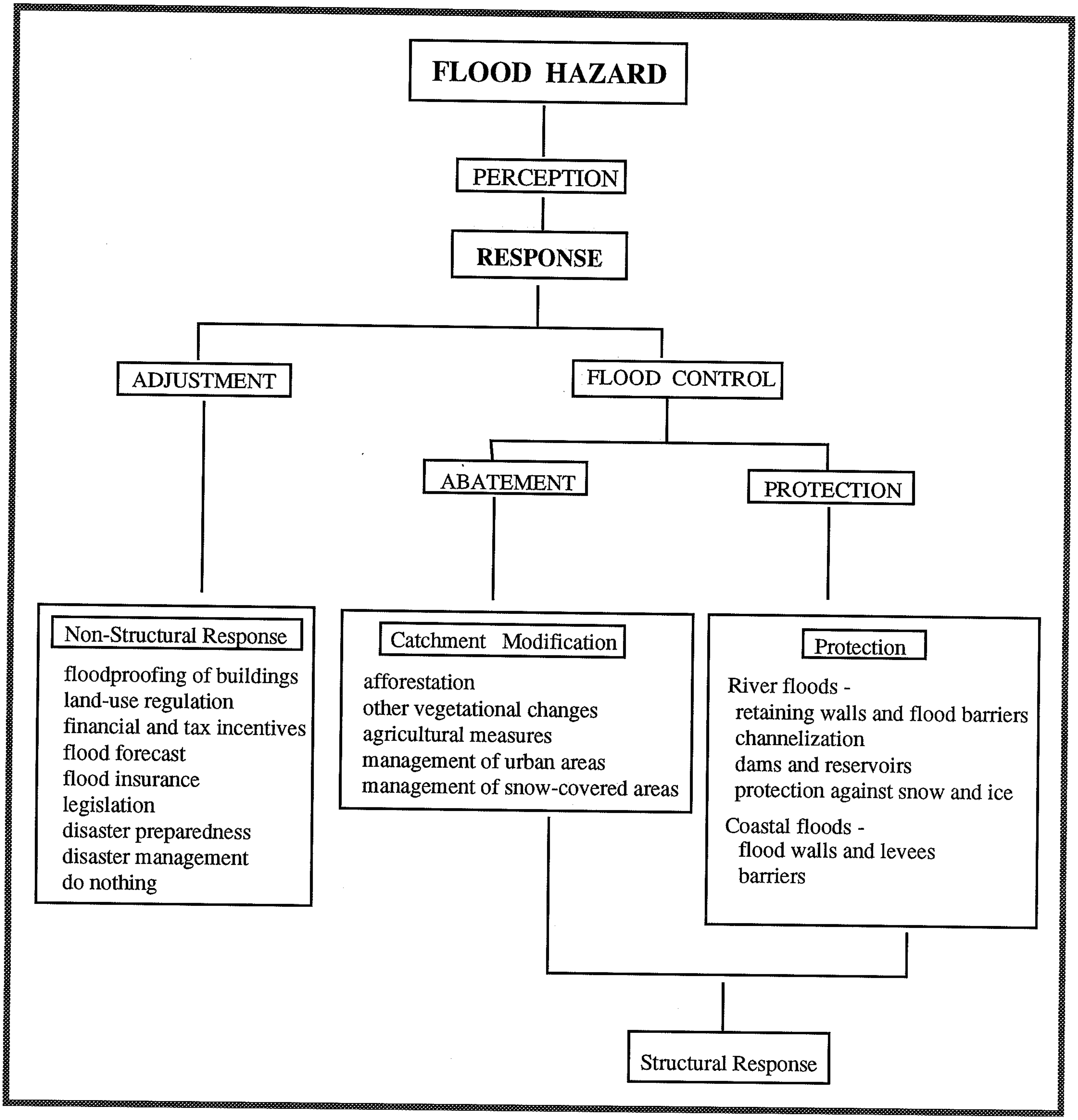


Figure 4-1 Response to Flood Hazard

Source: adapted from Ward (1978).

4.1 STRUCTURAL WORKS

During the nineteenth century, residents of the Red River valley simply abandoned homesteads and fled to high ground in response to flooding. The earliest flood control structures built in the Red River basin were a series of dykes along the Assiniboine River between Portage la Prairie and Winnipeg. Dyking began along the Assiniboine before the 1900s but did not become more widespread until after the floods of 1922 and 1923 (Andrews, 1993). The dykes were generally low and could not contain a major flood.

Prior to the construction of the dykes, flooding was a severe problem. When river-banks were overtopped, many square kilometers of agricultural land were flooded, often without the possibility of the water returning to the rivers during flood recession.

Following the Red River flooding in 1950, federal and provincial agencies began investigation of the nature of the flood problem on the Red and Assiniboine rivers and of possible ways of reducing the hazard. A large-scale structural approach was planned and implemented for protection against future flood damages by the Red and Assiniboine rivers.

4.1.1 Flood Control Works

In 1956, a provincial Royal Commission was appointed to undertake a cost-benefit analysis of alternative protection schemes. In its report of 1958, three structural projects were recommended. These flood control works were constructed between 1962 and 1972. The works, operated by the provincial Department of Natural Resources, consist of:

(1) A floodway, with a design capacity of $1700m^3/s$, diverts water from the Red River south of Winnipeg around the east of the City, discharging it back into the Red at Lockport.

(2) A $700m^3/s$ capacity diversion channel conveys flood waters from the Assiniboine River just upstream from Portage la Prairie northward to Lake Manitoba.

(3) A dam cross the Assiniboine River near Russell impounds waters to create the Shellmouth Reservoir (Mudry et al, 1981) (Figure 4-2).

4.1.1.1 Red River Floodway

The Red River Floodway is Manitoba's largest flood protection structure. As over 80 per cent of the river water that passes through Winnipeg during the spring runoff typically comes from the Red River, control of the latter is the key to Winnipeg's flood protection. Construction of the Red River Floodway was started in 1962 and completed in 1968. The floodway consists of four components: the floodway channel, the inlet control structure, the dykes, and the outlet structure (Water Control and Conservation Branch, 1963; Andrews, 1993).

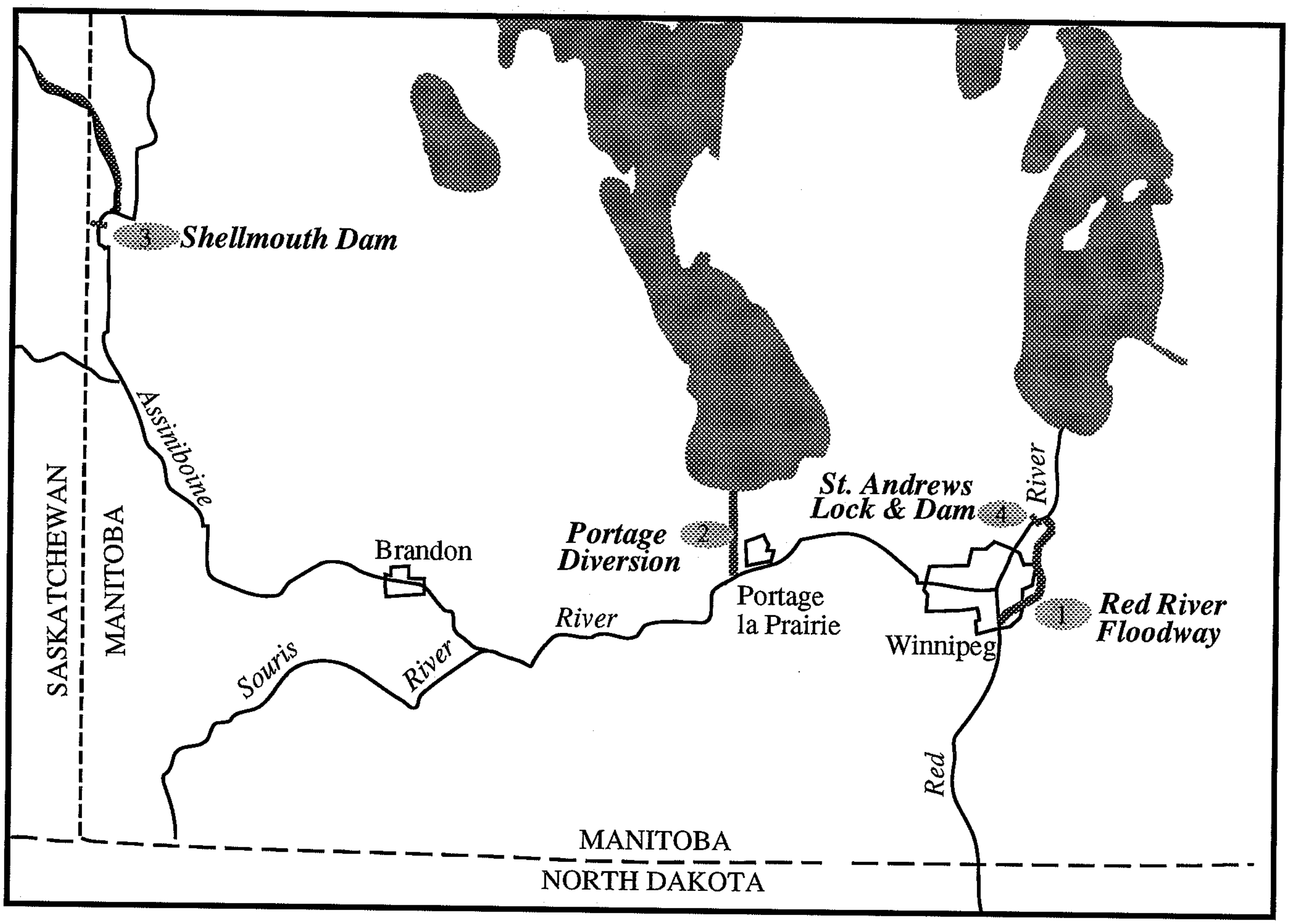


Figure 4-2 Location of the Major Flood Control Works

Source: adapted from Shady (1989).

The floodway channel (Figure 4-3) is approximately 48km (29.4 mi.) long, with a drop of 5.5m (18 ft.) between the inlet and outlet, and it has an average depth of 9m (30 ft.). The top width of the channel varies from 213m to 305m (700-1000 ft.). 76 million m^3 (100,000,000 $yd.^3$) of earth were excavated in order to create the channel. This material was deposited along the sides of the channel thereby forming embankments 6m high (Water Control and Conservation Branch, 1963).

The entrance to the floodway is located in the eastern bank of the Red River near St. Norbert. An earth-fill weir at the entrance ensures that river flows below flood level continue down the Red River. The inlet control structure, with its gates, is located on the Red River just downstream from the floodway inlet. The purpose of this control structure is to regulate the flow between the natural channel of the Red and the floodway channel during the period of high water levels. The gates are normally in the submerged position. In times of floods, the gates are raised and thereby partially block the flow of the river to effect an artificial division of the flood water between the floodway and the river itself.

In order to prevent flood waters inundating riparian land in the City, dykes were constructed adjacent to the inlet structure. On the east side of the river the dyke is incorporated into the floodway embankment and extends from the control structure parallel to the floodway for a distance of

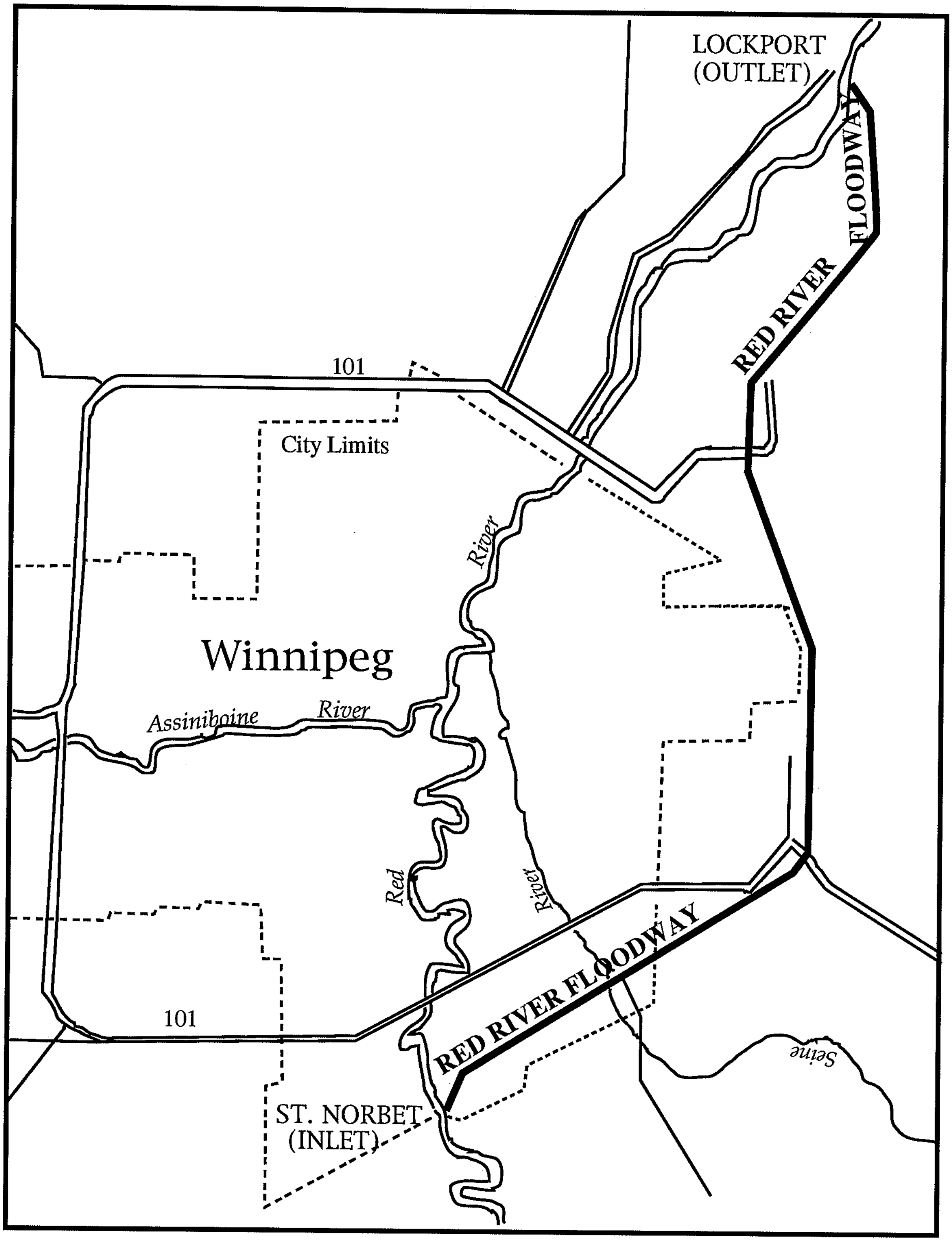


Figure 4-3 The Red River Floodway

Source: Water and Waste Department, City of Winnipeg.

about 10km (6 mi.). On the west side of the Red the dyke extends westward for some 34km (21 mi.) from the inlet structure to a point where the natural ground is above the design flood elevation.

The decline in altitude over the entire length of the floodway is 5.5m, whereas the corresponding water surface drop in elevation of the Red River between the inlet and outlet of the control structure is 9m. Therefore there is a surface difference of 3.5m. To reduce the potential energy in the water at its re-entry point near Lockport, a drop outlet structure was constructed on the floodway, thereby preventing damage and erosion in the river.

The Red River Floodway allows all the water in the Red River to flow through Winnipeg during normal summer, fall and winter months. But in the spring, when the discharge is greater than 850m^3/s (30,000 cfs), the water flow divides between the Red River and the Floodway. The control structure at St. Norbert maintains the Red River's natural level upstream from the floodway, but allows up to 1700m^3/s (60,000 cfs) of flood water to enter the floodway and bypass the City of Winnipeg (Water Resources Division, 1974).

4.1.1.2 Portage Diversion

Flooding of the Assiniboine River between Winnipeg and Portage la Prairie can be severe as the adjacent land is an extensive flat plain, which makes it difficult for water to drain back into the river channel after a flood crest. This drainage is normally slow, by means of ditches and tributary streams. As a consequence of standing water in fields, crop planting may be delayed for several weeks (Water Resources Division, 1974). To alleviate this situation and to reduce flooding within Winnipeg, the Portage Diversion was constructed from Portage la Prairie due north to Lake Manitoba.

The Portage Diversion is second to the Red River Floodway in cost ($10.8 million, compared to $62.7 million of the Floodway) and importance. The 29km (18 mi.) diversion channel is designed to carry a maximum of $700m^3/s$ (25,000 cfs) of flood discharge from the Assiniboine River, just upstream from Portage la Prairie, northward through Delta March to Lake Manitoba. Construction of the project began in 1965 and was completed in 1970 (Water Resources Division, 1974; Rannie, 1980; Andrews, 1993).

A dam was constructed across the Assiniboine River, southwest of Portage la Prairie; this created a reservoir with a storage capacity of 18 million m^3 and a maximum area of 652 hectares. The spillway at the dam allows flow down the river under normal conditions, and it is used to help regulate discharge along the diversion channel. An inlet control structure, with adjustable gates, regulates the flow from the reservoir into the diversion channel.

4.1.1.3 Shellmouth Dam

Another major structure in the flood control system for Winnipeg is the Shellmouth Dam, which is located about 19km northwest of Russell. The dam impounds waters of the upper Assiniboine River and its tributaries. Construction was started in 1964 and completed in 1972. The dam is an earth-fill structure with gravel and rock riprap for slope protection, and possesses a reinforced concrete spillway. The reservoir created by the dam is approximately 56km (35mi.) long, with a gross storage capacity of nearly 500 million m^3. Of this, 58 per cent of storage capacity can be available for flood storage. The protection provided by the reservoir extends along the Assiniboine from the dam site to its confluence with the Red River. Cities benefiting from its flood protection and low flow augmentation include Brandon, Portage la Prairie, and Winnipeg (Water Resources Division, 1974; Rannie, 1980; Andrews, 1993).

4.1.1.4 St. Andrews Lock and Dam

The St. Andrews Lock and Dam is located at Lockport, 32km (20 mi.) below the confluence of the Red and Assiniboine rivers in Winnipeg, and it is operated by the Public Works of Canada. The dam was initially constructed (before 1953) to facilitate navigation between Lake Winnipeg and the City by means of maintaining the Red River several feet above its natural level through the Greater Winnipeg area. From November

1st each year until after the spring runoff, the lock is opened and the river water level is permitted to fall to its natural level, thus allowing flood flow of the river to pass through the City (Red River Basin Investigation, 1953e).

4.1.2 Flood Protection System

In addition to the flood control works established outside the City limit that are designed to reduce the magnitude of flood discharges, another approach to mitigating flood damage in Winnipeg is the urban flood protection system. This flood protection system consists of two main parts. Firstly, there is a dyking system to prevent the rivers from actually flooding low-lying areas within Winnipeg. Secondly, there are flood pumping stations, with sluice gates, to keep the rivers from flooding most of the trunk sewers by gating them and by pumping out the sewage and surface water from these sewers (Jordan, 1980).

4.1.2.1 Dykes in the Greater Winnipeg

Following the spring 1950 Winnipeg flood, the Greater Winnipeg Dyking Board was established in July 1950 by agreement between the Federal and Manitoba governments, to direct the construction of the dyking systems (Water Resource Division, 1974). The permanent dykes were intended to provide a partial degree of flood protection, consequently reducing the flood hazard in Winnipeg. These dykes were built along both sides of the Red River and the Assiniboine River (Figure 4-4). This primary dyking scheme provided a main line of flood defence at a height of about 0.6m (2 ft.) above the 1948 flood level and 1.2m (4 ft.) below the 1950 flood level (Water Resources Branch, 1971; Water Resources Division, 1974).

The primary dykes are typically designated street rights of way, and in most cases they have become paved roadways throughout the City. For example, the primary dyke along part of the east side of the Red River in St. Vital has become River Road (Figure 4-5). Riverine property owners affected by river flooding were encouraged to build and preserve secondary dykes along the river banks in order to increase protection of their lots against flooding and to reduce the disruption to private property caused by sandbagging around buildings. The aggregate length of secondary dykes on private property in Winnipeg is not known.

It is apparent that there remains the need to undertake a survey to determine low elevations and gaps along the primary dykes and to check the slope stability on dykes after many years of operation. It is suggested that the City undertake necessary engineering for conversion of some temporary sandbag dykes into permanent structures.

4.1.2.2 Pumping Stations

Flood pumping stations are used to pump runoff water collected in the sewer system into the Red and Assiniboine

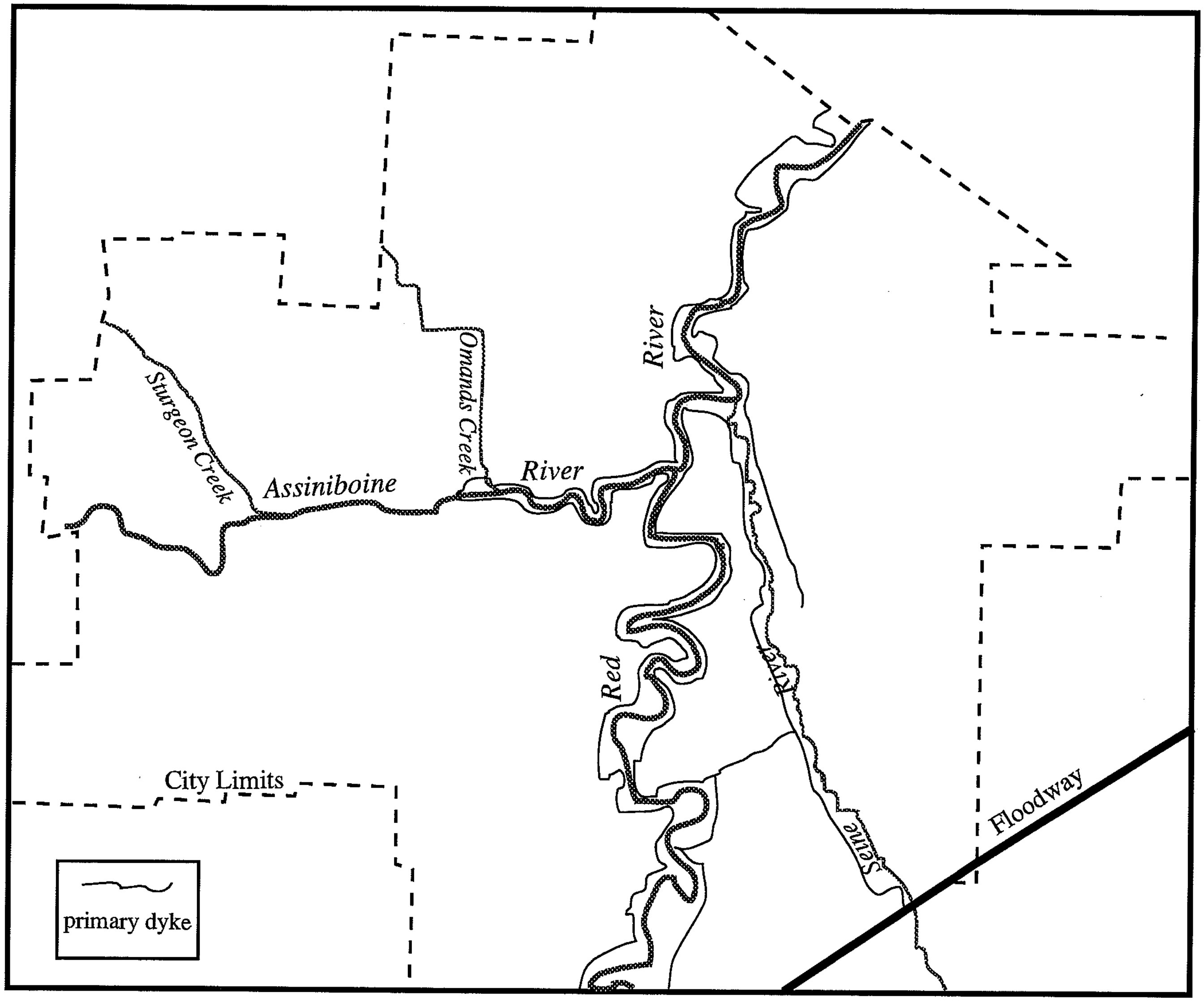


Figure 4-4 Primary Dyking System

Source: Water and Waste Department, City of Winnipeg.

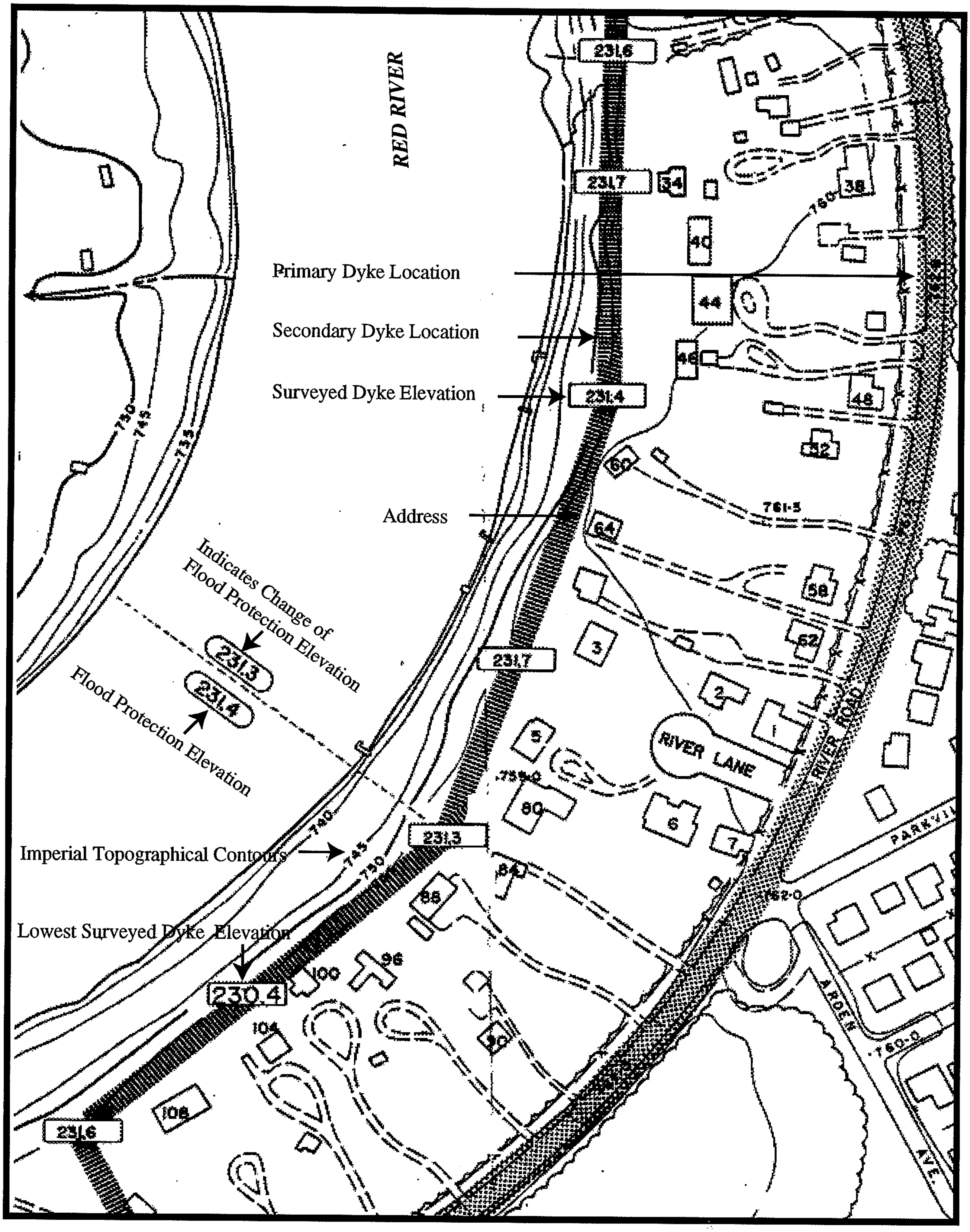


Figure 4-5 Portion of the Winnipeg Dyking System

Source: Water and Waste Department, City of Winnipeg.

rivers. These stations are located on trunk outlet sewers adjacent to the rivers. As the river level rises, the pumping stations are activated sequentially in accordance with the instructions of the *Flood Control Activities Manual* of the Waterworks & Waste Department. These instructions, which are derived from comprehensive studies and analysis, optimize pumping station system capacities.

A total of 34 flood pumping stations and 6 underpass pumping stations has been constructed in the City and can be operated during high river levels (Waterworks, Waste and Disposal Department, 1993).

4.1.3 Summary

A series of flood control measures has been implemented on the Red and Assiniboine rivers so that now the City of Winnipeg is protected. In conjunction with Winnipeg's dyking system, the major flood control structures were believed to protect Winnipeg against a flood with a 165-year recurrence interval and a discharge up to 4,780m^3/s (Mudry et al, 1981; Rannie, 1980; Water Resources Branch, 1971). With emergency dyking and some accepted flooding of low-lying riverbank areas, it was asserted by the Royal Commission (1958) that a discharge of 5,660m^3/s might be accommodated in Winnipeg. By comparison, the largest flood in historically settled times (1826) had an estimated discharge of 6,371m^3/s.

Carlyle (1984) indicated that some experts believed that the statistical bases for deriving the 160-year flood are incorrect, and that its discharge and water level are far higher. Based on Harden's (1996) frequency curve (Figure 3-3) using the updated annual series of peak discharges, the design capacity of Winnipeg flood protection level, up to 4,416m^3/s (156,000cfs, at Redwood Bridge, according to Water Resources Branch, 1981; p.9) is now computed to possess a recurrence interval of about 120 years, whereas the discharge for a 160-year flood is now identified as approximately 4,600m^3/s. In this case, the protective works are not as effective as commonly assumed.

In conclusion, all structural measures endeavour to change the magnitude and frequency of flood events by the control of excess water, hence reducing flood losses. It should be noted that they are quite reliable up to the design standards of the works. However, the Water Resources Branch (1980) stated that structural measures have a number of disadvantages. Firstly, there is always a chance of breaching or collapse during a severe flood. Secondly, following construction of works, there often develops a false sense of security among the general population. Thirdly, structural works are often so expensive that the only economical alternative is to restrict floodplain development in certain areas allowing flooding to occur. Finally, it has been claimed that structural flood protection works are usually paid for by the public at large, yet only benefit a small percentage of the general population. The latter is a false argument, in that all Winnipeg, with two-thirds of Manitoba's population, is the beneficiary of these structural works.

4.2 NON-STRUCTURAL MEASURES

Structural flood control works can be very effective, but they can generate a false sense of security and may encourage, rather than discourage, development in flood prone areas. Furthermore, they cannot protect a flood prone area against all possible floods because there is no upper limit to a flood's magnitude. As a result, structural measures are often only a partial solution to a flood problem. Non-structural measures, such as flood zoning, building codes, flood proofing, flood forecasting and specifically-defined legislation, constitute another important component of total flood hazard reduction. Instead of controlling flood water itself, non-structural measures concentrate on reducing human vulnerability to flooding.

4.2.1 Canada-Manitoba Flood Damage Reduction Program

The Canada-Manitoba Flood Damage Reduction Program (FDRP) is a joint federal-provincial program with a specific goal of reducing flood damages in urban communities most affected by flooding. This FDRP was initiated in December 1976, when three agreements were signed by the federal and Manitoba governments. These agreements recognized that the best way to reduce flood damage potential is to consider all practicable structural and non-structural alternatives, including allowing some flooding to occur. The simplest approach to minimizing future flood damage is to preclude floodplain development.

The Flood Damage Reduction Program, summarized by the Water Resources Branch (1981), originally consisted of the following three agreements:

(1) The General Agreement Respecting Flood Damage Reduction, through which the Manitoba government agreed to implement policies respecting designated flood-prone areas, provides a coordinated framework for a number of implementation agreements.

(2) The Agreement Respecting Flood Risk Mapping, which provides for the risk mapping of 45 places in Manitoba, is intended to determine and designate those urban areas that are prone to river flooding. The Agreement requires the public to be informed about such designated areas.

(3) The Agreement Respecting Studies for Flood Damage Reduction, enables determination of the most suitable measures for reducing or preventing flood damages to existing development in specific problem areas.

In March 1981, the Agreement Respecting Flood Forecasting was introduced. This Agreement was to provide for the development, or improvement, of flood forecasting capabilities for the Red, Assiniboine and Souris rivers in Manitoba. Following this provision, the Ring Dyke Upgrading (now referred to as the Construction of Flood Protection Projects) Agreement was signed in March 1983; this aimed at improving dyking systems of 10 communities in Manitoba except the City of Winnipeg.

The Flood Risk Mapping Agreement and Studies for Flood Damage Reduction Agreement expired in March 1988. However, these agreements became effective again in January 1990, and were in place until March 1996. The Forecasting Agreement expired in September 1989 (Manitoba Natural Resources, 1992). Table 4.1 specifies the duration and years of expiry of the FDRP agreements. The funding provided by governments under the FDRP for each of the five agreements is indicated in the table.

Table 4.1 FDRP Agreements in Manitoba

Agreements	Duration (years)	Total Commitment (dollars)	Expiry Date
General Agreement	22		1999
Flood Risk Mapping Agreement	19	2 850 000	1996
Studies Agreement	19	510 000	1996
Flood Forecasting	8.5	1 000 000	1989
Construction of Flood Protection Projects Agreement	7	6 900 000	1991

Source: Environment Canada, 1992; p.22.

4.2.2 Flood Risk Mapping

Flood risk mapping is the key element of the Flood Damage Reduction Program. The City of Winnipeg was added to the array of communities by federal and provincial Order-in-Council in March 1978. Pursuant to the Flood Risk Mapping Agreement, flood maps were produced by the Land Surveys and Mapping Branch of the Natural Resources Department. For Winnipeg, flood risk areas for the 160-year flood level (as determined from flood frequency analysis by the Water Resources Branch in 1979) were designated and delineated on 1:5,000 scale working maps, under the direction of the Steering Committee. These maps can be used by agencies of governments, companies or individuals to make decisions on specific uses of lands subject to flooding.

The Flood Risk Mapping Agreement had several requirements. Firstly, hydraulic studies were to be undertaken in order to determine the extent and depth of flooding in flood prone areas. Based on this, flood prone areas were to be formally designated. A final requirement consisted of a public information program, involving the distribution of maps and brochures to local governments, financial lending institutions, and relevant provincial and federal government agencies.

In the context of the Flood Damage Reduction Program (FDRP), a flood risk area was defined as the zone that would be flooded by the design flood, which includes the floodway area and the floodway fringe area. The Manitoba Department of Natural Resources (1980) provided a detailed definition of the flood risk area; the latter consists of: (1) the floodway area, that is the portion of the flood risk area where the flood waters are deepest, fastest and most destructive; and

(2) the flood(way) fringe area, which is the outer, remaining portion of the flood risk area adjoining the floodway. In the fringe area, the flood water is shallower and tends to pond, and is less hazardous than in the floodway (Figure 4-6).

In 1980, as part of the Flood Risk Mapping Agreement, the federal environment minister and Manitoba's natural resources minister designated, on an interim basis, flood risk areas along the Red, Assiniboine and Seine Rivers in Winnipeg. The Agreement stipulated that, for most flood-prone communities in Manitoba, the design flood would be the 100-year flood (as computed in 1979). For the City of Winnipeg, the so-called 160-year flood was adopted as the basis for determining the flood risk areas, since permanent flood control works, based on the original design criteria, would provide protection to Winnipeg's urban area up to this flood level.

The criteria for delineation of the flood risk areas in Winnipeg are as follows:

(1) The limit of the floodway area was based on the 160-year flood. To identify the floodway area of the Red River, a height of 0.1 feet above the 160-year flood level was adopted because backwaters have to be considered. For the Assiniboine River, the 160-year flood level was used to determine the floodway area, as there is little or no overbank flow along this river.

(2) Delineation of the flood fringe area was based on the elevation of the 160-year flood plus two feet of

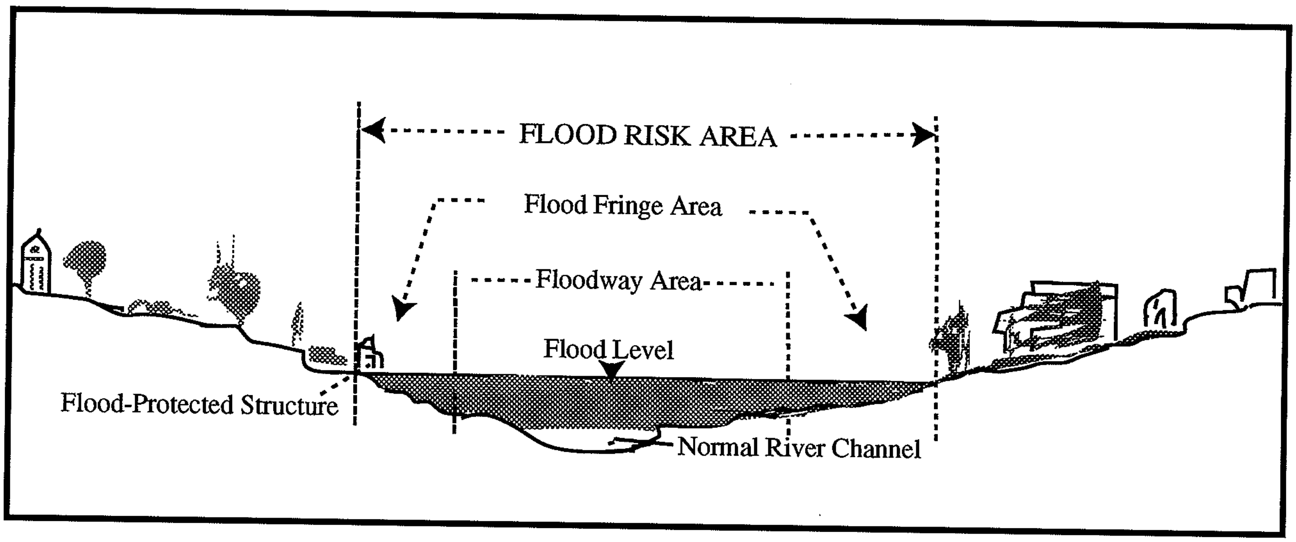


Figure 4-6 Flood Risk Area Designation

Source: Manitoba Natural Resources (1980).

freeboard. On the interim designation maps, this elevation is referred to as the Flood Protection Level (Water Resources Branch, 1981).

In the absence of the flood control works, the flood risk areas would have extended well beyond the limits of the primary dykes in Winnipeg.

Tables 4.2 and 4.3 reveal the flood risk levels at some key locations on the Red and Assiniboine rivers in Winnipeg. Figure 4-7 is a portion of the flood risk map, showing the floodway area, floodway fringe area, and flood protection level in Winnipeg.

Table 4.2 Red River Water Surface Levels Associated with the 160-Year Flood, the Floodway and the Flood Protection Level (in feet)

Location	160-Year Flood	Floodway	Flood Protection Level
Red & La Salle Rivers Confluence	761.6	761.7	763.7
Ducharme Avenue	760.9	760.9	762.9
South Perimeter Bridge	760.0	760.1	762.1
Grierson Avenue	759.0	759.0	761.0
Bishop Grandin Boulevard	757.5	757.6	759.6
Pulberry Street	756.1	756.1	758.1
Elm Park Bridge	755.2	755.2	757.2
Rue Tache	754.4	754.5	756.5
Red & Assiniboine Rivers Confluence	753.9	754.0	756.0
Bannatyne Avenue	753.5	753.5	755.5
Louise Bridge	752.3	752.4	754.4
Redwood Bridge	751.8	751.9	753.9
Jefferson Avenue	751.1	751.1	753.1
Bergen Cut-off	750.4	750.4	752.4
Red River Boulevard	749.7	749.8	751.8
North Perimeter Bridge	740.0	749.0	751.0

Source: Water Resources Branch, 1981.
Note: to keep the accuracy of the original text, the imperial system is adopted here.

Table 4.3 Assiniboine River Water Surface Levels Associated with the 160-Year Flood, the Floodway and the Flood Protection Level (in feet)

Location	160-Year Flood	Floodway	Flood Protection Level
West Perimeter Bridge	764.3	764.3	766.3
Cass Street	763.5	763.5	765.5
Paradise Drive	762.4	762.4	764.4
Carroll Road	761.8	761.8	763.8
Dieppe Road	761.0	761.0	763.0
Sunnyside Boulevard	759.6	759.6	761.6
Princeton Boulevard	758.5	758.5	760.5
Davidson Street	757.9	757.9	759.9
Overdale Street	757.3	757.3	759.3
Edgeland Boulevard	756.1	756.1	758.1
St. James Street South Bound Bridge	755.7	755.7	757.7
Omands Creek	755.5	755.5	757.5
Cambridge Street	755.2	755.2	757.2
Maryland Street Bridge	754.9	754.9	756.9
Wellington Crescent & River Avenue	754.6	754.6	756.6
Osborne Street Bridge	754.4	754.4	756.4
Main Street Bridge	754.1	754.1	756.1
Red & Assiniboine Rivers Confluence	753.9	754.0	756.0

Source: Water Resources Branch, 1981.
Note: to keep the accuracy of the original text, the imperial system is adopted here.

The designation of flood prone areas along the Red and Assiniboine rivers, and along tributaries within the City of Winnipeg, was completed in February 1980. In recent years there has been concerns about the accuracy of the information presented on flood risk maps. Several neighborhoods in Winnipeg have developed since mapping completion. Furthermore, new bridges, such as the new Portage Avenue bridge spanning Sturgeon Creek, have implications in terms of the flood risk along this watercourse (Manitoba Emergency Measures Organization, 1989b). More updating of maps is required in view of the substantial residential and commercial

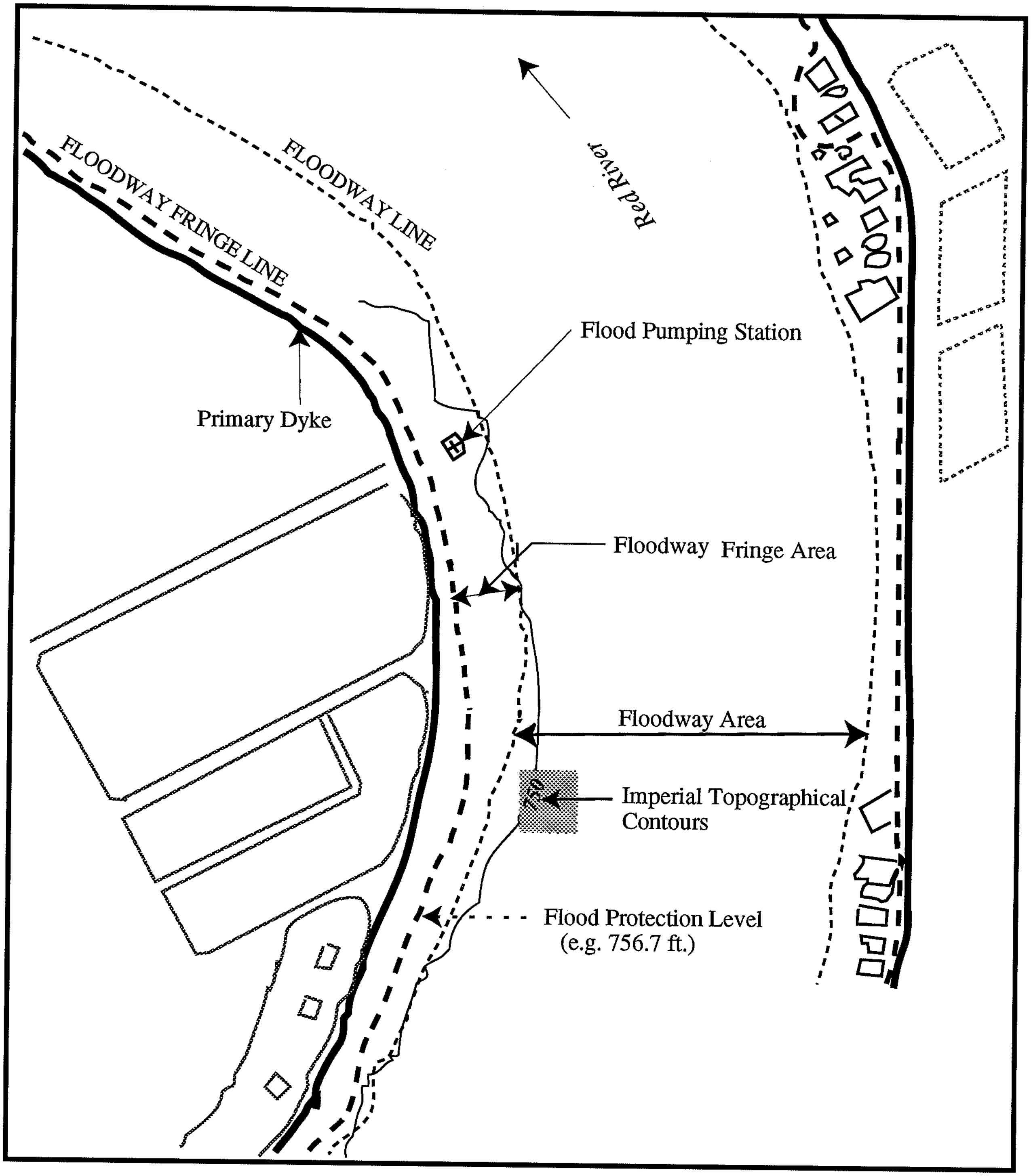


Figure 4-7 Portion of Flood Risk Map

Source: Water and Waste Department, City of Winnipeg.

development in Winnipeg over the past decade.

The public information brochure entitled "*Reducing Flood Damage in Winnipeg*", which summarizes the Flood Damage Reduction Program, was distributed to appropriate departments of the City of Winnipeg, Manitoba Government and Federal Government, and to selected establishments, such as realtors, banks, and construction companies in Winnipeg. In addition, the Winnipeg Interim Flood Risk Map, with a size of 1.25m x 1m at a scale of 1:30,000 was produced for distribution to the public. By comparison, maps for smaller Manitoban communities are at 1:5,000 scale. The Winnipeg flood risk map and its accompanying brochure were not widely distributed to all households in the designated flood risk area of the City.

According to the Water Resources Branch (1980), the objectives of flood risk mapping are fourfold. One goal is to prevent unsuitable land development in flood prone areas, so averting the possibility of flood damage. A second objective is protection of prospective buyers of residential or commercial property from the consequences of locating in flood prone areas. The flood risk map is also intended to guide the purchase of open space for public use. Finally, the map can be valuable to agencies involved in emergency measures.

4.2.3 Flood Zoning

Flood zoning is a legislative device that excludes certain activities from a flood plain. It thereby reduces the risk associated with flood plain occupancy. The 1950 flood damaged many houses in the southern portion of Winnipeg. By 1976, the number of occupied dwellings in this area of the city was 3.4 times that of 1950 and its population had more than doubled. The development was continued in low-lying riverbank areas subject to flooding at levels well below design discharge until 1978, when a general freeze was placed on further building outside the dykes in Winnipeg (Rannie, 1980). Locating structures in flood risk areas is not only hazardous; it also impedes and delays the movement of flood water during severe flooding, and thus causes increased damage upstream.

The Canada-Manitoba Flood Damage Reduction Agreements reached in 1976 were to discourage flood prone development in designated flood risk areas by withdrawing mortgage guarantees and other forms of financial assistance. While these agreements were originally intended to apply to the area outside Winnipeg, the City of Winnipeg was added in 1978 as more stringent controls were needed.

A designated area is a part of a flood risk area, within which the federal and provincial governments have chosen to restrict and discourage further development which is subject to flood damage. In most cases, the natural floodways are designated to discourage any type of new construction. In the floodway fringe area, some development is allowed, provided that structures are adequately flood-proofed.

Through the application of Provincial Land Use Policy No.11, enacted in November 1980 under The Planning Act, Manitoba exercises control over development in designated areas (Manitoba Natural Resources, 1992, 1995).

The City of Winnipeg Act also sets up restrictions on development in the designated flood risk areas. Furthermore, financial assistance could not be obtained from Canada Mortgage and Housing Corporation (CMHC) or the former Federal Department of Regional Economic Expansion (DREE) for building a new home or business in the floodway portion of the flood risk area after February 15, 1980; flood damage assistance in the floodway fringe area was only available for structures which satisfy floodproofing criteria (Water Resources Branch, 1980).

4.2.4 Flood Proofing

Smith and Tobin (1979, p.18) defined flood proofing as consisting of "adjustments to building structures, and the contents of buildings, designed to reduce flood damage". A distinction is often made between permanent flood proofing measures and temporary ones. The most effective measures are permanent ones, which may be structural. Temporary measures are undertaken when there is a flood warning; these may include sandbagging around houses, closing of sewer valves, or removal of furniture to a higher floor. Some major flood proofing measures include:

a) Elevation of the building foundation above the design flood level.

b) Construction of floodwalls, which may be comprised of floodproof masonry or concrete.

c) Allowance of basement flooding, whilst keeping the habitable portion of the structure above the flood line.

d) Sandbag dyking as an emergency floodproofing technique that is especially useful in areas prone to ice jam flooding or flash flooding.

e) Ring dyking, which is used to protect either a household or a community from flooding.

Of the above, a, b and e are permanent flood proofing adjustments.

The Manitoba Government amended the City of Winnipeg Act to require floodproofing of structures in the designated areas. The Designated Floodway Fringe Area Regulation (Regulation 266/91) prescribes the floodproofing criteria for the City of Winnipeg. The Regulation requires that every structure, other than an accessory structure, be constructed on a site raised by fill or be supported by piles. Detailed criteria were set up for the following three situations (see Figure 4-6, schedules A-C): 1) a structure, with a basement or cellar, constructed on a site raised by fill; 2) a structure, without basement or cellar, constructed on a site raised by fill; and 3) a structure supported by piles. However,

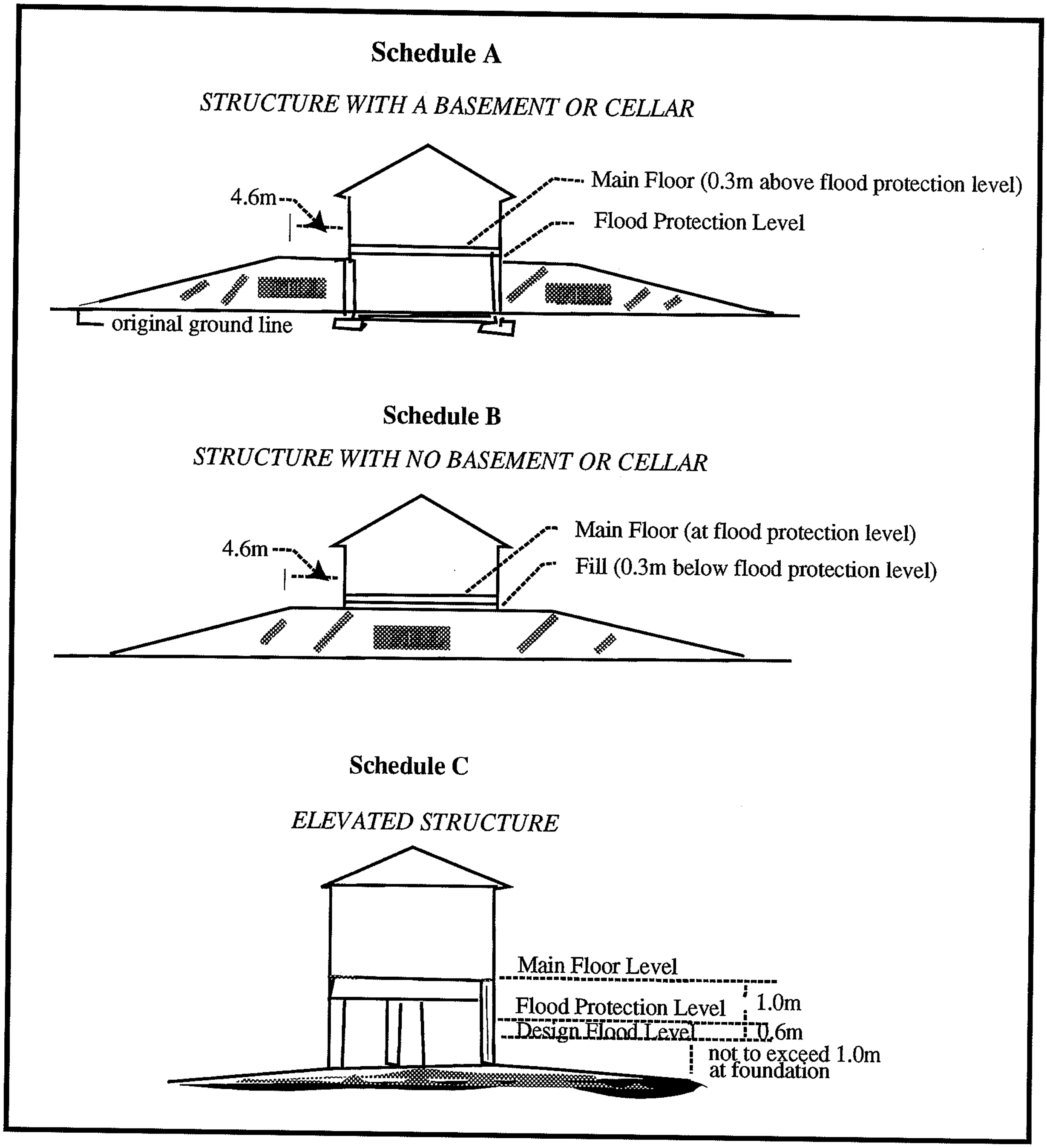


Figure 4-8 Floodproofing Criteria

Source: Manitoba Regulation 266/91

handouts or information materials to inform homeowners of how to construct dykes were not available for distribution.

In 1991, the Manitoba Department of Natural Resources and the Manitoba Disaster Assistance Board of the Department of Government Services initiated a joint program for the Red River Valley to inventory all floodproofing measures constructed after the 1966, 1974 and 1979 floods. The Regional Engineering Operations Branch conducted the surveys, and the Water Resources Branch evaluated the adequacy of the floodproofing measures in relation to the 100 year flood level (Manitoba Natural Resources, 1990 - 1994).

4.2.5 Flood Forecasting

4.2.5.1 Flood forecast organization

Flood forecasting plays an important part in flood damage reduction. To facilitate the efficient operation of flood control works, and to supply as much advance flood warning as possible, the Flood Forecasting Review Committee (FFRC) in Manitoba was established in 1954. This Committee, composed of technically qualified representatives of all three levels of government, scrutinizes and approves all information obtained from contributing agencies in Canada and the United States. On the basis of the data supplied, forecasts of spring runoff potential are prepared for use of the Government of Manitoba. Although the main concern of the Committee is flooding by the Red River, spring peaks are also forecast for the Assiniboine

River. The Committee holds two regular meetings each year, one in February and one in March, and as many more meetings as are deemed necessary, depending on the severity of flood conditions from year to year (Water Resources Branch, 1971).

The Manitoba River Forecast Centre of the Water Resources Branch, Department of Natural Resources, carries out streamflow forecasting for agricultural and urban areas of southern Manitoba. River forecasting is primarily directed toward floods, since the climate, topography and soils make the area highly susceptible to severe spring floods.

The Canada-Manitoba Flood Forecasting Agreement was of great assistance to this Flood Forecast Centre in the improvement of the timeliness and accuracy of flood forecasts through increased use of electronic data acquisition and computer analysis. Under the Agreement significant improvements have been made in electronic information transmission, enabling river stage and precipitation data to be forwarded almost instantaneously to the forecast center using satellites, radar, and computers (Shady, 1989; Water Resources Branch, 1987).

4.2.5.2 Flood forecast method

Flood forecasting was formally initiated in 1954 following completion of the Red River Basin Investigation reports subsequent to the 1950 Red River flood. In this investigation, a graphical procedure was developed to forecast flows on the

Red River at the international boundary near Emerson (Red River Basin Investigation, 1953c). This graphical method was based on four parameters: soil moisture, soil priming index[1], winter and spring precipitation, and melting index[2] of degree days per day. Forecasts for the Red River at Winnipeg were obtained using either a peak stage relationship between Emerson and Winnipeg or a manual streamflow routing procedure. These forecasting procedures were used until 1974, when a statistically based method was introduced (Warkentin, 1986). The multi-linear regression analysis employed in the latter forecasting method was dependent on five parameters: precipitation since November of the previous year, antecedent precipitation index[3], melting index, winter temperature index, and previous spring runoff (Goulter and Hannan, 1984). In 1977 the Manitoba River Forecast Centre became established (Warkentin, 1986), and a forecasting method known as the Manitoba Antecedent Precipitation Index (MANAPI) model was

---

[1] Soil priming index: it is expressed as a ratio of the average streamflow for the period October to January inclusive to the long term mean discharge during these months (Red River Basin Investigation, 1953c).

[2] Melting index: it is the average number of degree-days per day during active snow melt period (Warkentin, 1986:p.9).

[3] Antecedent precipitation index: the total weighted monthly precipitation from the previous May to October, with precipitation in the later months being weighted more heavily (e.g. 0.07, 0.08, 0.12, 0.18, 0.25, 0.30, respectively) (Goulter and Hannan, 1984; Warkentin, 1986).

employed. During the 1980s, a seven-year streamflow simulation study was undertaken (under the terms of the Canada-Manitoba Flood Damage Reduction Agreement Respecting Flood Forecasting) that included testing several models of varying complexity for data requirements, calibration, accuracy and cost effectiveness (Water Resources Branch, 1987; Andrews, 1993).

4.2.5.3 Flood forecast operation

The River Forecast Centre provides multiple services and operates on a year-round basis. Spring flood forecasting is its primary role, and spring is usually the busiest time of year. Flood forecast preparation usually involves two types of runoff forecast each spring: a preliminary one and an operational one (Water Resources Branch, 1971 and 1987; Warkentin, 1986; Andrews, 1993).

Preliminary forecasts, or pre-melt outlooks, are prepared well in advance of spring runoff in order to give an indication of peak flows and water levels that can be expected under various probabilities of future weather conditions. Outlooks are prepared each year during the third week of February, but these forecasts are very general in nature. Each year in the third week of March, the Flood Forecast Centre issues a more detailed forecast of the flood potential. Appendix A provides the updated flood outlook for the spring of 1996 for Manitoba. The forecast calculations are usually done on a Tuesday, based on data observations up to the previous morning. The outlooks are reviewed by the Flood Forecasting Review Committee on that Thursday and then are released to the public on Friday (Warkentin, 1986). However, the errors in preliminary forecasts do not affect the operation of the Red River Floodway since the actual operation of flood control works is based upon operational forecasts.

Operational forecasts are done once spring runoff has begun, and involve prediction of daily as well as peak river levels and dates. A forecast includes the updating of the earlier flow and stage predictions, based on observed melt rates, spring precipitation and runoff. Up to date information is very important at this time. The forecaster must know what is happening in the fields and streams before the forecast can be fine-tuned. To help in quantifying the magnitude of early forecast revision, small watersheds are often monitored to obtain an early indication of runoff coefficients (Warkentin, 1986; Water Resources Branch, 1987).

Operational forecasts for small watersheds and tributaries are updated by adjusting predicted runoff volumes based on field observations. Index areas are a useful aid in quantifying the magnitude of early forecast revisions; these are small basins (75-200 km^2) where snow cover and runoff are intensively monitored. They can provide an early indication of the runoff coefficient, which is then used to adjust the predicted runoff in nearby larger tributaries. Unit hydrographs for various rates of melt are used to convert predicted tributary runoff to daily streamflow. Predictions for larger watersheds are made by flood routing of the predicted daily tributary flows. The Muskingum routing method is generally used, while the one-dimensional hydrodynamic model calibrated by Environment Canada is available for major floods on the Red River (Andrews, 1993).

In practice, the methodologies employed in the preparation of operational flow forecasts vary considerably with the nature of the runoff conditions. When the spring runoff potential is average or below average, i.e. when there is no significant threat of flooding, there may be little or no operational forecasting (Warkentin, 1986). The methodologies used in updating forecasts also depend on the severity of the flood threat. When there is little threat of flooding, qualitative forecast revisions and updates may be made by an experienced forecaster, and flood routings may not be required. When there is a serious flood threat or if flooding is underway, procedures used are as quantitative as possible.

4.2.5.4 Forecast distribution

Preliminary forecasts are prepared by the River Forecast Centre in the third week of February and of March. The Centre presents the forecasts to the Flood Forecasting Review Committee for approval, and the Minister of the Manitoba

Natural Resources is responsible for official release to the Manitoba Legislature by a messenger.

When the outlook forecasts have been released, copies are usually sent by telecopier to the Manitoba Emergency Measures Organization (EMO), Emergency Preparedness Canada (EPC), and the regional water resources managers of the Water Resources Branch. They are also distributed by mail to all municipalities, cities, towns, villages, Indian bands, local government districts, and to pertinent federal and provincial government officials (Warkentin, 1986)

During a spring flood, status reports and operational forecasts are issued daily before noon. These reports are submitted to flood fighting organizations and concerned government officials. Major changes and periodic updates are announced through news releases. Three-day forecasts for the Red River in Winnipeg are usually prepared daily by the River Forecast Centre during spring runoff at the request of the City of Winnipeg (Andrews, 1993; Manitoba Natural Resources, 1995) (see Appendix B).

4.2.5.5 Evaluation of flood forecasts

The accurate prediction of magnitude and timing of flood passage is needed for the implementation of flood damage mitigation measures. Goulter and Hannan (1984) investigated two recent flood events on the Red River, and found that there were differences between the actual floods and the predicted ones (Table 4.4). Furthermore, the accuracy of forecasting does not have a direct relationship with the aversion of flood damage. Forecasting is merely a device that induces timely flood fighting activity.

Table 4.4 Comparison of Actual and Predicted Floods for 1974 and 1979 at Winnipeg

Contents	1974	1979
March Forecast: Actual height above flood stage (m) Predicted height above flood stage (m) Difference (m)	 1.37 2.13 -0.76	 1.67 -0.61 2.28
Forecast 10 Days before Peak: Actual height above flood stage (m) Predicted height above flood stage (m) Difference (m)	 1.37 0.61 0.76	 1.67 2.74 -0.07
Actual date of peak Predicted date of peak	April 22 April 24	May 8 May 6

Source: Goulter and Hannan, 1984.

4.2.6 Flood Insurance

Flood insurance programs were initiated in the United States and New Zealand, but neither the Canadian government nor any of the provinces have yet widely implemented this flood hazard adjustment (Mitchell et al, 1979). In Canada, the property and casualty insurance coverage is most available for intensive natural hazard events such as tornadoes, windstorms, hailstorms, earthquakes, and heavy rainstorms that cause flash flooding or major sewer backups. However, insurance is not offered for regional flood and tsunami hazards in general (The Joint Committee of the Royal Society of Canada and the Canadian Academy of Engineering, 1990; CNC-

IDNDR, 1994).

According to the Royal Commission on Flood Cost-Benefit (Royal Commission, 1958), a flood insurance scheme is not practicable in Manitoba due to a number of difficulties. It asserted (incorrectly) that, because the settled area of the province is small, the weather conditions that produce flooding in one area might well apply throughout the whole insured area; hence, claim payments would be very numerous in particular years. This would make the insurance industry's financial resources insufficient to meet the high-risk flood losses throughout a region, thus causing its bankruptcy. Secondly, most large river floods in Manitoba are of the slow-rising type; these can be predicted well in advance. It is therefore possible to reduce potential flood damage either by moving property out of the flood zone or by building temporary dykes to protect the areas subject to flooding. It was argued that if potential flood losses were covered by insurance, the steps taken to move or protect property might be considerably less prompt and vigorous. Thirdly, because floods in Manitoba are prolonged, with slow recession, assessing flood damages and making claim payments would also be more difficult. The effects of protracted flooding may only be fully apparent many months after the flood has passed. This is particularly true of structural damage to buildings and of the loss of income from crops. In the light of the above considerations the Royal Commission (1958) concluded that it would not be advisable for the Province of Manitoba to enter into any general flood insurance program.

In Winnipeg, insurance companies do not assume flood insurance against riverine flooding, but they do provide partial insurance against basement flooding due to sewer backup damage. For instance, the 1993 basement flooding damage claims were about $160 million in the Winnipeg area. Since then, insurance companies have changed basement flooding coverage. Insurance may no longer cover this kind of loss, especially for those people living in flood-prone older residential areas or having past water damage claims (Water and Waste Department, 1995).

The Manitoba Crop Insurance Corporation has an "All Risk Crop Insurance Program", which recognizes flood as one of the insurable causes of the "designation perils" loss in the Province. However, the causes of loss that are within the insured producer's control are not covered in this program, which implies that the crops in the designated flood risk areas are not insurable. The arable land within the City of Winnipeg is very limited, and flood crop loss rarely occurs as there is a good land drainage system, and the farmland is generally away from the rivers (Manitoba Crop Insurance Corporation, 1994).

Some other avenues of compensation, such as government subsidization, are available for major flood damages. The joint federal-provincial National Flood Damage Reduction

Program, which has been in existence for nearly 20 years, provides funds. The Disaster Financial Assistance Agreement (described in Chapter 6) also gives effective support. These programs that get local levels of government to agree not to build on flood plains are strongly endorsed by the insurance industry and the Insurance Bureau of Canada. They provide funds to flood victims (Mann, 1994).

However, the growing flood damage potential in Canada requires a joint government and insurance industry response in order to ensure public financial protection while reducing the financial exposure of governments to the risk of flood damages. It is highly desirable that an insurance program, involving public funds and the private insurance industry, be established in order to provide financial assistance to property owners affected by flooding in flood-prone areas of Winnipeg because of the increased flood damage potential, particularly in the south of the City where residential development has been large during the past four decades.

4.2.7 Legislation and Legal Framework

Within the array of flood hazard mitigation measures, the role of legislation is vital because it has a significant influence on flood plain management and flood damage reduction activities. Some major legislation is discussed in this section under three categories, corresponding to the three levels of governments (Table 4.5).

Table 4.5 Flood Hazard Adjustment Related Legislation

<u>Federal</u> 1) Canada Water Conservation Assistance Act (1953) 2) Canada Water Act (1970) 3) National Flood Damage Reduction Program (FDRP) (1976) 4) National Housing Act
<u>Provincial</u> 1) Water Resources Administration Act (led to establishment of Water Resources Branch of Manitoba Department of Natural Resources) (1959) 2) Dyking Authority Act (1950) 3) Planning Act of Manitoba (1975)
<u>Municipal</u> 1) City of Winnipeg Act

4.2.7.1 Federal Level

(1) Canada Water Conservation Assistance Act

The Canada Water Conservation Assistance Act, promulgated in 1953, was the first federal legislation directly concerned with water resources management. The Act enabled the federal government to provide financial assistance for provincial water storage projects. The intention of the Act was to provide assistance for projects that normally would exceed the financial means of the province and municipalities. Under the Act, the federal government contributed up to 37.5% of the cost of project works, provided that its contribution did not exceed that of the province. Another 37.5% would be borne by the province involved and the remainder by local government in the area affected (Foster, 1981; Andrews, 1993).

Only a few small flood control works qualified for funding under the Act. The rigid cost-sharing requirements prevented the automatic application of the Act to the construction of the Red River Floodway. For the latter, a special agreement outside the Act was reached between the Manitoba and Federal Governments (Booth and Quinn, 1995). According to Rannie (1980), the federal government shared 37.0%, 9.3%, and 10.8% respectively in the construction of the Red River Floodway, Portage Diversion, and Shellmouth Dam, which provide flood protection to Winnipeg.

(2) Canada Water Act

The Canada Water Act, passed in 1970, superseded the Canada Water Conservation Assistance Act as the primary instrument for joint federal-provincial management of Canada's water resources. The new act supports research, planning, and implementation of measures relating to the conservation, development and utilization of water resources.

Andrews (1993) described the Canada Water Act as encompassing the following ideas:

a) Planning should proceed on a very comprehensive basis, by including all water uses and their economic, social and environmental importance (Sections 2 & 4).
b) The views of the people likely to be affected should be taken into account (Section 4).
c) Non-structural alternatives to traditional structural measures should be considered (Section 5).
d) Financial and technical support of the programs should be

shared by the federal and provincial governments (Section 7).

Under the auspices of the Canada Water Act, a federal-provincial Consultative Committee was established for each province. Periodic meetings of these consultative committees provide a forum whereby problems, policies and projects can be discussed among officials of the two governments. At the time of passage of the Act, flooding was a major problem in many parts of the country; it demanded fresh adjustments beyond the traditional ones of structural works and financial assistance to victims and institutions. Based on the discussions and recommendations of consultative committees, a national Flood Damage Reduction Program was established in 1975.

Under the Canada Water Act, the joint Canada-Manitoba Flood Damage Reduction Program, which included policies, mapping and research studies, and flood forecasting was funded. The Manitoba Dykes Upgrading Agreement was also financially supported during the period 1983-1989, with the aim of upgrading the level of ring dykes protection in several communities in the Red River Valley (Booth and Quinn, 1995).

(3) National Flood Damage Reduction Program

The federal government actively pursued the signing of accords with each province to reduce potential flood damages in Canada. Until the passage of the Canada Water Act in 1970, the principal federal measures employed to deal with flood hazard were limited to the construction of flood control works and the provision of disaster assistance. The National Flood Damage Reduction Program (FDRP) was introduced in April 1975 by Environment Canada specifically to address flood related problems and mitigation measures. The FDRP created an effective, long-range solution to flood damages. The prime reason for the FDRP program was the escalation in flood disaster payments by the federal government in the early 1970s.

All the provinces except Prince Edward Island and Yukon Territory participated in the FDRP. According to Andrews (1993: 98), the two levels of government agreed to the following polices:

a) They will not build, approve or finance flood prone development in the designated flood risk areas.

b) They will not provide flood disaster assistance for any development built after an area becomes designated (except for floodproofed development in the flood fringe area).

c) The province will encourage local authorities to zone on the basis of flood risk.

According to Environment Canada (1993), as most of the FDRP programs approached completion, a comprehensive policy review of the National FDRP mission was undertaken. Watt (1995) examined the National FDRP and made an overall evaluation. He concluded that "the FDR Program has been extremely successful in identifying urban flood risk areas across Canada and in redirecting flood-prone development away from flood-risk areas" (p.247) under the joint efforts of federal, provincial and local governments. This Program will be continued to the maintenance phase by 1996, which needs updating existing maps and public information as necessary, and continuing the polices of the program.

(4) National Housing Act

The Canada Mortgage and Housing Corporation (CMHC) administers the National Housing Act (Government of Canada, 1970). Under the Act, the amount and type of future development on flood plains are restricted. Mortgage loans can only be insurable on conditions of guarantee of protection of buildings from flooding, either through location in a non-flood prone area, or through protective measures within an area that is recognized as a flood plain.

The following sections of the Act (Government of Canada, 1970; McKerness, 1976) are of particular importance in the management of flood plains:

- Section 6 describes the conditions under which a mortgage loan is insurable. Sub sections (j) and (h) state that the terms, conditions, and regulations governing the issuance of mortgage loans are to be agreed upon between the approved lender and the Corporation. Presumably CMHC could require that these terms, conditions and regulations include a guarantee of protection of the building from flooding.

- Sections 13 and 16 provide a further safeguard of CMHC insurance funds by requiring CMHC approval of the house site location and that building construction be done in accordance with CMHC-approved standards. This presents another opportunity for CMHC to limit unprotected development on flood plains.
- Section 45 permits CMHC to enter into an agreement with the federal or any provincial government to undertake a project for the planning of new communities. CMHC could help insure that no new communities are located on flood plains.

4.2.7.2 Provincial Level

(1) Water Resources Administration Act

The Manitoba Water Resources Administration Act, passed in 1959, established the authorities responsible for the construction, operation and jurisdiction over all Provincial water control works, including flood control structures such as dams and storage reservoirs. This Act led to the establishment of the Water Resources Branch of the Manitoba Department of Natural Resources.

The Act provides for the delimitation of an area subject to flooding from natural causes to be a designated flood area. Development within such area is restricted, and only permitted if the resulting buildings are adequately floodproofed. Construction of any structure within such an area requires a permit issued by the Natural Resources Minister (Shady, 1989).

After the 1979 flood, the flood risk areas in the entire Red River valley from Emerson to Winnipeg were designated under the Water Resources Administration Act. Under this Act and Manitoba Regulation 266/90, any person wishing to build in the designated area must first obtain a permit from the Water Resources Branch (Manitoba Natural Resources, 1992). The permit requires that any structure to be erected shall be floodproofed to prevent damages up to the 1% probability flood level.

(2) Dyking Authority Act

The Dyking Authority Act, passed in 1952, provides for the maintenance of dykes and pumping stations in Greater Winnipeg. The Water Resources Branch administers this Act, which calls for a Dyking Commissioner appointed by it. The Commissioner is required to make an annual report to the Minister of Natural Resources on the administration and implementation of the provisions of this Act. However, full authority for the construction, operation and maintenance of dykes and pumping stations is invested with the City of Winnipeg under the terms of the Act. For Winnipeg protection, the City may increase the height of the dykes, subject to the prior approval of the Commissioner.

(3) Planning Act

The Planning Act of Manitoba was passed in 1975. Under this Act, the Minister of Rural Development Department may recommend to the Executive Council the establishment of special planning areas. Particularly, Part V of the Act contains special provisions on land use control. Section 41(3) prohibits the erection of any building or structure within a specified distance of any natural or artificial river, watercourse or body of water, and on land that is subject to flooding.

Through the application of Provincial Land Use Policy No.11, enacted in 1980 under the Planning Act, the Province of Manitoba exercises control over development in areas subject to flooding, erosion, river bank instability, landslides and subsidence (Manitoba Natural Resources, 1992).

4.2.7.3 Municipal Level

The City of Winnipeg Act defines the building standards and sets out regulations on development restrictions in Winnipeg's designated flood risk areas (Part 15, S.M. 1989-90).

The construction in a designated floodway area is limited as follows:

> No person shall construct, erect or bring any building, structure or erection within or on a designated floodway area except public services including water control works, electrical, gas, water, sewage, communications, or transportation services, or publicly owned open air structures for

recreational uses (section 485).

And in a designated floodway fringe area, no person shall

> (a) construct, erect or bring any building, structure or erection other than a fence within or on a designated floodway fringe area; or
>
> (b) make any addition to, or reconstruct, any building, structure or erection, other than a fence, within a designated floodway fringe area;
>
> except in accordance with the floodproofing criteria and in accordance with a building permit, or where such permit is not required, in accordance with a floodproofing permit issued by the supervisor of building inspections (section 486).

After the designation of the Red River Valley as a designated flood area, the City of Winnipeg Act was amended to restrict development in floodway areas, and to establish floodproofing criteria in floodway fringe areas with regards to the Red and Assiniboine Rivers within the Perimeter Highway. Under the Act, individuals are generally not permitted to build in a designated floodway area, and must comply with floodproofing criteria in any floodway fringe zone. Under Section 493(1) of the Act, the Minister of Natural Resources may make an order to vary the floodproofing criteria established by Manitoba Regulation 439/88R. On January 1, 1992, amendments to the City of Winnipeg Act were proclaimed empowering the City of Winnipeg to administer the *Designated Floodway Fringe Area Regulation* (Manitoba Urban Affairs, 1990; Manitoba Natural Resources, 1992).

The provisions of Section 490 in the Act also state that individuals who either build in the designated floodway area, or fail to comply with the floodproofing criteria in floodway fringe areas, are not entitled to receive flood protection or damage assistance from either the Manitoba or municipal governments. Moreover, the supervisor of building inspections may make an order requesting that any building, structure or erection which is built in the designated floodway area, or which does not comply with the floodproofing criteria within a designated floodway fringe area, should be removed or evacuated (Sections 485 & 489).

4.3 EFFECTIVENESS OF THE FLOOD MITIGATION MEASURES

4.3.1 Flood Control Works Operation

The implementation of the flood control measures on the Red and Assiniboine rivers has successfully protected the City of Winnipeg and most of its immediately surrounding areas. Since their completion, the flood control works on these rivers have been extensively used, and have provided the most obvious benefits by protecting Winnipeg from damaging floods in 1969, 1970, 1974, 1979, 1987, 1993 and 1996.

The first critical test of the control works came in 1974, when an unusual combination of high discharges on the Red and a record flow on the Assiniboine produced flood levels of potentially disastrous proportions within Winnipeg. At the flood peak, nearly 1,133m^3/s (40,000 cfs) were routed around Winnipeg via the Floodway, 510m^3/s (18,000 cfs) were diverted from the Assiniboine River to Lake Manitoba, and the detention of runoff by the Shellmouth Dam reduced peak flow on the Assiniboine River below the dam by another 170m^3/s (6,000cfs) (Rannie, 1980). Without the control works, the estimated water level in 1974 which could have occurred within Winnipeg would have been only 0.09m (0.3 ft.) lower than the 1950 flood level. Undoubtedly, the damage and disruption would have been great if the total discharge had passed through the City.

In the spring of 1979, conditions produced the most severe flood threat in the Red River valley since 1950; at places south of Winnipeg, the 1979 peak discharges were comparable with those of 1950. More than 7,000 people were evacuated from the Manitoban flooded zone south of Winnipeg. Within Winnipeg, property damage was negligible, and normal city activity was scarcely affected by the major flood that occurred to the south of St. Norbert (Rannie, 1980). With the operation of the flood control works, the controlled peak stage in the City was 3.3m below the computed natural stage. The damages in Winnipeg could have totalled $750 million if the flood control works had not been built (Wild, 1996c). Yet, the total flood damages reached only $27 million (Jarolim, 1986).

The cost of the Red River Floodway, Portage Diversion and Shellmouth Dam totalled $94 million when constructed, or about $378 million in 1991 dollars. At the time of construction of these works, the estimated respective benefit-cost ratios were 2.89:1, 7.21:1, 6.18:1 (Royal Commission, 1958). Based on the estimates of Andrews (1993), the potential flood damages prevented during the 1969-1991 period are in excess of $1 billion (in 1991 dollars) in Winnipeg. In light of the significant damages prevented by the flood control works, it is clear that the latter are extremely cost effective.

The 1993 flooding in Winnipeg was caused by three extreme rainstorm events in the locality in July and August. Many low-lying areas along the Red, the lower Assiniboine, and such streams as Sturgeon Creek were flooded. According to Winnipeg Waterworks, Waste and Disposal Department (1993), due to the heavy rainfall on Saturday, August 14, 32 streets were temporarily closed, including 12 regional streets and 3 underpasses. In order to combat flooding, 22 of the 40 pumping stations were operated to pump runoff water from the sewer system into the rivers. The St. Andrews Dam was opened to allow maximum flow of the Red River through Winnipeg.

4.3.2 Flood Forecasts versus Flood Damage

It is widely assumed that flood damage potential can be reduced by using good flood forecasting techniques. Having investigated the floods of 1974 and 1979 in the Red River valley, Goulter and Hannan (1984) found that, when flood magnitudes were badly underestimated, the ratios of flood fighting costs to restoration costs (i.e. damage values) were low, indicating that the Manitoba flood fighting activities were rather inefficient. However, on the other hand, for the cases of overestimation of flood peaks, the flood fighting activities were again ineffective, because the flood fighting costs might be in excess of that justified by the actual flood levels and flood damages sustained might be less. They concluded that there is no apparent relationship between the accuracy of a flood forecast and the effectiveness of flood fighting actions on the Red River during that respective event. This conclusion is in contrast to previous studies (e.g. Day and Lee, 1976; Penning-Rowsell, Chatterton, and Parker, 1978), which showed the flood damage reduction potential of well designed flood forecasting/warning systems. Goulter and Hannan (1984) attributed this disparity to the difference in nature of the floods in the Red River valley and that of the floods reviewed in other studies.

4.3.3 Flood Alleviation Benefits

Undoubtedly, the City of Winnipeg is the major beneficiary of the current Manitoban flood control measures. In essence, the implementation of this series of measures was a human response to Winnipeg's flood problem. The great flood damages averted in Winnipeg are a combined result of effective flood control works and efficient non-structural measures.

The benefits of flood alleviation are often regarded as the losses which are avoided by the scheme when compared to the 'do nothing' option. While complete flood damage data are not available from responsible agencies, the information adapted from Andrews (1993) is used here for a simple comparison. As can be seen in Table 4-6, very substantial flood damage has been prevented with the flood control works operational; their benefits are highly apparent in the severe flood events of 1970, 1987, (and especially) 1974 and 1979.

Table 4-6 Winnipeg Flood Damages in Selected Years (in 1987 million dollars)

	1969	1970	1974	1975	1976	1978	1979	1986	1987
Actual	0.67	1.31	2.61	1.30	0.58	0.64	4.52	0.34	1.00
Poten -tial	36.73	65.3	292.4	1.96	2.34	1.74	629.9	1.44	60.9

Source: Andrews, 1993.

5. FLOOD DISASTER PREPAREDNESS

In the Manitoba Emergency Measures Act, emergency preparedness is defined as "a readiness for emergencies and disasters, and includes the planning, training, exercises and education necessary or designed to achieve a state of readiness for emergencies." (p.1).

Implementing preparedness activity is predicated on the assumption that extreme hazard events of various types will occur, but that their negative consequences can be reduced. Preparedness action can lead to either a reduction, or to the quick alleviation, of disaster impact consequences.

There are many ways to prepare for disasters, such as through planning, education, and provision of warning systems. Manitoba's Emergency Measures Organization (EMO) has the Emergency Preparedness Program that provides the following four activities:

- development and maintenance of emergency plans
- establishment and enhancement of emergency resources
- emergency training and education
- emergency response exercise.

5.1 PLANNING

For disaster preparedness, in the first instance a comprehensive hazard analysis must be conducted. The latter usually involves the identification of the likely hazards that face the community, and the assessment of the level of risk that they present. After analyzing the risks and recognizing what constitutes an emergency, it is necessary that a community develop an emergency plan. In Manitoba, it is now required by law, through the Manitoba Emergency Measures Act, that any community prepare an emergency preparedness plan. The plan should prescribe the emergency procedures and responsibilities, and it should aid in the coordination of an all-hazards emergency response (Bennett, 1988).

A community is, for the most part, the place where emergency management activities must be implemented. The initial responsibility to respond to disasters/emergencies often lies with the individual or municipality directly affected. Therefore, the motivation, and sometimes the initiatives, must come from communities. In this regard, municipal emergency plans provide the most effective response tool. The Manitoba EMO usually assists communities with the development of these plans. In conjunction with the Manitoba Disaster Assistance Board, the Manitoba EMO conducted presentations throughout Manitoba on the Manitoba Emergency Plan and the Disaster Financial Assistance Policy. The Manitoba EMO established the Manitoba Emergency Plan in 1984.

The City of Winnipeg Emergency Plan was presented in 1992.

5.2 TRAINING

A training program is mainly targeted at informing the individuals, groups, and organizations involved in emergency response of their responsibilities and the ways of executing them.

The Federal Government, through its agency Emergency Preparedness Canada (EPC), trains officials, from provincial and municipal governments, in aspects of emergency planning and response at the Canadian Emergency Preparedness College in Arnprior, Ontario. The Alberta Public Safety Services Training School is also a valuable resource facility for anyone involved with disaster preparedness and response. Each year Manitoba EMO arranges for representatives from Manitoba to attend courses and seminars at these two training institutions.

Manitoba's training program is directed primarily at small communities, where training is needed by their planners or response people. As part of its Training /Education program, Manitoba EMO has given numerous lecture presentations to municipal councils on a variety of emergency preparedness subjects, including flood management. Flood emergency seminars have been given in different places, including Winnipeg. These seminars were usually joint provincial/municipal initiatives for the purpose of defining roles and responsibilities in the event of flooding (Manitoba Government Services, 1982 - 1995).

Figure 5-1 shows a dynamic increase from 1991/92 to 1994/95 in the number of Manitobans trained in emergency management. The number of trainees in emergency preparedness has grown without allocation of more resource. The students that were trained came from municipalities, provincial departments, and non-government organizations.

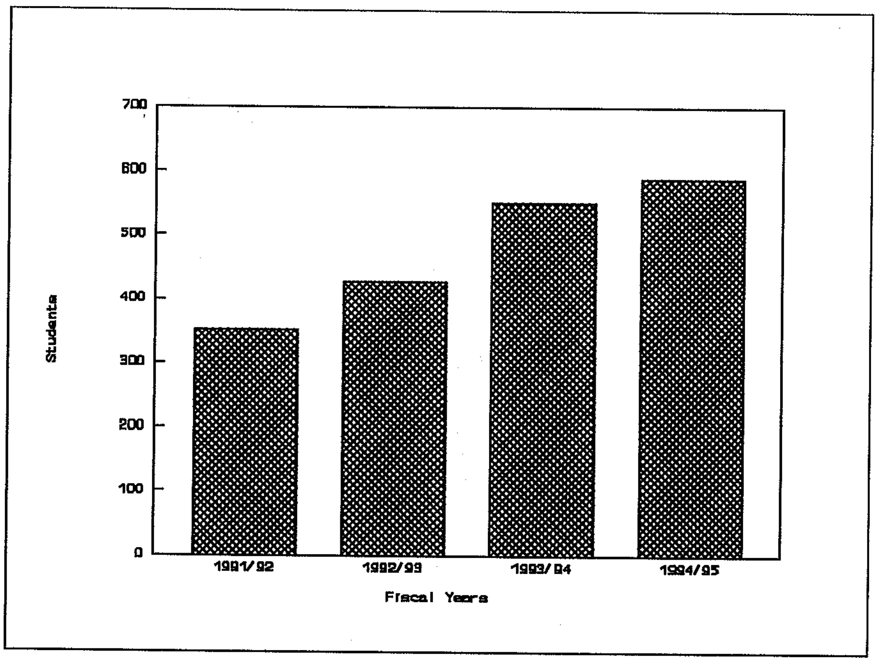


Figure 5-1 Manitoba EMO Training Program

Source: Manitoba Government Services, 1995

With the assistance of the Manitoba EMO, the City of Winnipeg sponsored a one-week training course on Plans and Operations in June 1994, which was the first time a municipality had sponsored a federally-recognized provincially-run course (anon. 1993b). Those in attendance at the course represented fire, police, ambulance, public works and utilities personnel and purchasing departments, as well as the Red Cross.

The training programs, in general, are not available to the public; they are intended for professionals engaged in emergency preparedness and management. Provision of training for the general public is desirable, but this cannot be accomplished through reliance on traditional classroom delivery. Alternative delivery methods, including the electronic media - notably videos, Internet and television - enable a wider portion of the public to receive basic instruction on emergency preparedness.

5.3 EDUCATION

In any successful operation of an emergency plan, designed to reduce the disaster potential, good educational programs must be provided to the general public in order to increase its awareness of disasters and of emergency measures. Although all three levels of government work to reduce the disaster impact of floods, the first line of disaster defence is the individual. Each resident has a responsibility to protect his or her home and family to the greatest extent possible. By planning ahead and taking sensible precautions flood damage can be minimized.

In all cases, local government authorities try to keep residents of flood-prone areas informed of developments. As part of their duties, authorities recommend actions that people should take to limit or prevent disaster. Detailed instructions can be given, as the need arises, by the municipal or provincial authorities.

Public information, awareness and education are important aspects of disaster prevention. The Manitoba EMO, Emergency Preparedness Canada and other responsible agencies have produced emergency preparedness literature and have provided the media with public service material. These agencies have developed public awareness programs by providing emergency preparedness information, in French and English, utilizing brochures and tapes, and have incorporated braille materials for the visually impaired. Additionally, radio and television public service announcements were devised, and television segments are now close-captioned. Promotional campaigns on flooding are often conducted during the spring season of each year.

As parts of the public education program, the following brochures and booklets (Figure 5-2) have been published:

- Are You Prepared in Case of Disaster?, produced by Health and Welfare Canada, recommends that individuals and families stock essential items, such as water, food, clothing and first aid supplies, in the event of a major emergency.
- Family Emergency Handbook, produced by Manitoba EMO, is

designed for the International Year of the Family - 1994, and includes sections on individual responses to flood warnings and on evacuation during flooding.

- Your Family Emergency Plan and Emergency Preparedness Checklist, produced by Manitoba EMO, are both designed for family emergency preparedness. They assist families by providing a list of points addressing emergency preparedness activities in the unit of a family.
- Seniors Emergency Preparedness, prepared by Manitoba Seniors Directorate, describes the flood emergency measures designed to reduce potential harmful effects to family and property.
- Emergency Measures for Floods, by the Manitoba EMO, provides advice on flooding precautions, flood warning action, flooded homes, evacuation of inhabitants and their return after the flood event.
- Floods, a self-help advice brochure, produced by EPC, suggests some emergency activities before and after a flood in terms of electricity, heating equipment, water contamination, food, general precautions, and evacuation.
- After Flooding: Procedures for Returning to Your Home, prepared by Manitoba EMO, provides important information to help residents clean up and restore property after flooding.

These education materials have not been widely distributed to the general public. Specific publications were

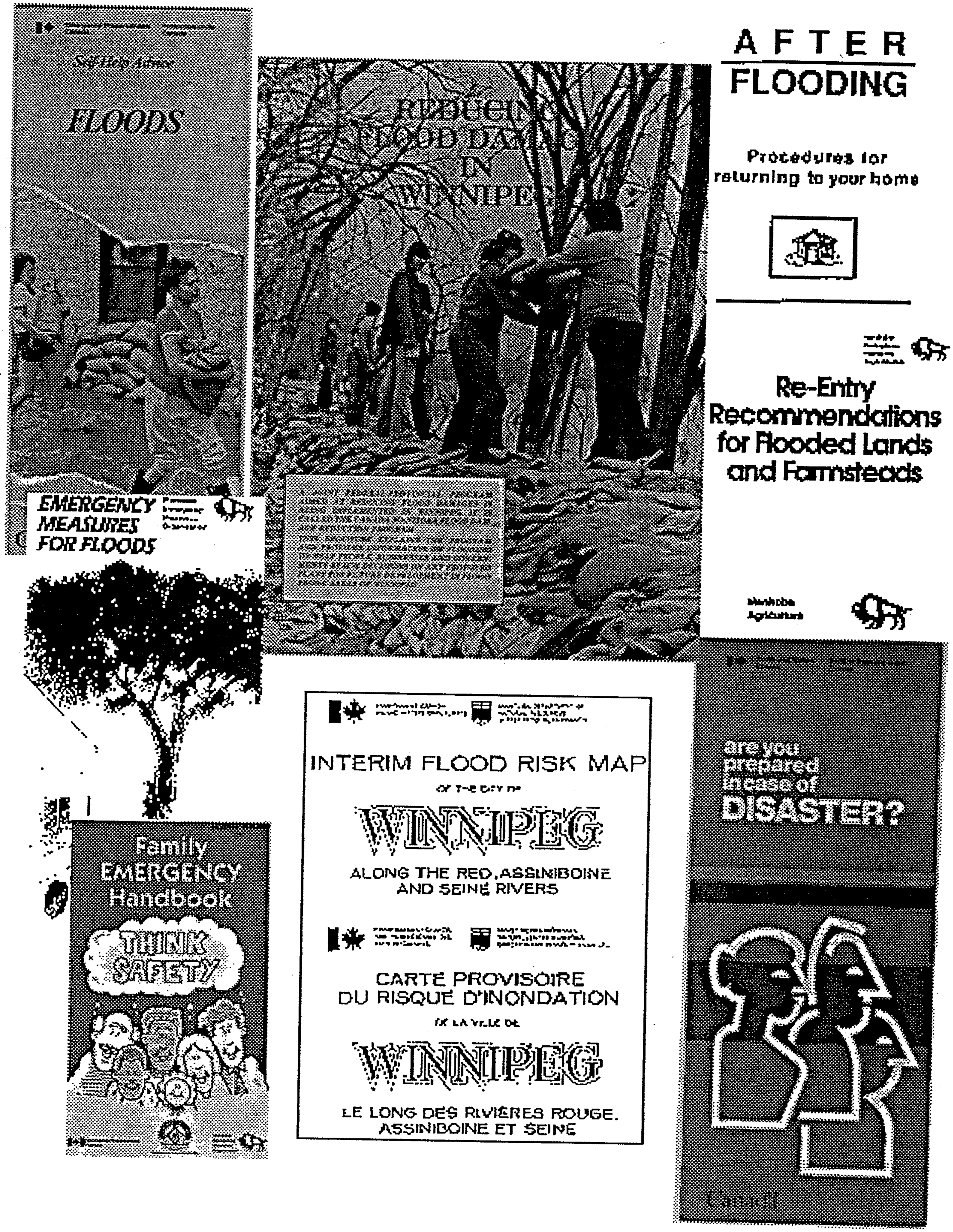


Figure 5-2 Public Education Program

only available upon request. Not surprisingly, public flood disaster awareness is still very low, and many Winnipeggers do not know the major agencies responsible for flood hazard reduction and emergency response. In general, residents are ignorant of the legislation and regulations pertinent to flood hazard reduction. There is a great need to educate the public with respect to specific measures that should be implemented by Winnipeg's residents immediately prior, during and shortly after a flood event in the City. Particularly important is the education of the general public with respect to precautionary measures in dwellings, such as the installation of sewer back-up valves, sump pumps, and waterproofing of basement walls. It is recognized that informing public will be more valuable, not only in preparedness but also in response.

In light of the fact that it is impracticable to distribute education materials to all individuals and households in Winnipeg, it is advisable that short articles on flood emergency measures be presented in newspapers. Radio and television programs on the flood threat and preparedness should be broadcast in the spring time. The increase in the number of non-English and non-French-speaking people in Canada means many inhabitants are unable to fully understand the awareness and warning packages available only in Canada's two official languages. These information packages need to be developed in other languages and must be available for print impaired individuals.

In 1994 the Manitoba EMO launched its first Emergency Preparedness Week under the theme "Family Emergency Preparedness" (anon., 1994). This particular week of May 15-21, 1994 was chosen to coincide with the May 17 to May 19 anniversary of the cresting of the Red River in the 1950 flood.

In conjunction with the Manitoba Department of Education, the Manitoba EMO developed a general guideline for emergency preparedness in schools, and in 1994 introduced an emergency preparedness program for students in Grades 7, 8, and 9 in 1994 (anon., 1995).

In preparation for possible flooding, the City of Winnipeg has provided special public information sessions. For example, in St. Norbert a public meeting was held on April 10, 1996 to provide its residents with information about potential flooding and possible mitigation activities. An accompanying "hands-on" demonstration of the construction of sandbag dykes was held on April 13, 1996 (Bennett, 1996a).

5.4 EXERCISE

A disaster exercise consists of the performance of duties, tasks, or operations very similar to the way they would be undertaken in a real mass emergency or disaster. To be effective, emergency plans and response procedures must be tested and updated, hence the need for disaster exercises. There are several types of exercises which can be used to evaluate community disaster preparedness procedures. They are orientation seminars, tabletop seminars, field exercises, computer simulations, and recovery exercises (Britton, 1991).

The Manitoba EMO assisted the City of Winnipeg in developing and conducting simulated emergency response exercises. These exercises allowed for an evaluation and subsequent enhancement of the community's response capability. In April 1990, the Manitoba EMO coordinated preparation for a provincial response to flooding in the Red River Valley.

In February 1989 a one-day Flood Emergency Workshop was conducted in Winnipeg, and a document of syndicate responses was compiled. Participants included representatives from all sectors of the Winnipeg Emergency Response Organizations, Manitoba Natural Resources, and the Manitoba EMO. This workshop was a type of indoor tabletop exercise, which dealt with various scenarios of flood emergency and presented adaptable response activities. The appropriate sectors participating in this exercise were public safety (e.g. fire, police, ambulance), public aid (e.g. social services, health, hospitals), public utilities (e.g. water & waste, hydro, gas, MTS), public information section (media), and public works (e.g. operations, street & transportation, transit) (Manitoba Emergency Measures Organization, 1989a).

5.5 JOINT EMERGENCY PREPAREDNESS PROGRAM (JEPP)

In October 1980, the Government of Canada initiated the

Joint Emergency Preparedness Program (JEPP), through which the Federal Government, in consultation and co-operation with the provincial and territorial governments, undertakes or contributes to projects that enhance the national emergency response capability. The JEPP is financed at an annual rate of approximately $6 million, about one-third of EPC's annual budget (EPC, 1989b).

JEPP projects are normally submitted by a province or territory to EPC, and evaluated by EPC's regional directors and senior managers according to established criteria. Projects favoured for funding are the development and evaluation of emergency plans, training programs, and the purchase of communications and emergency response equipment.

The Manitoba EMO participates in the ongoing JEPP, and from its inception, Manitoba has received over $5.7 million funds (as of March 1995) (Manitoba Government Services, 1995). However, flood-related projects have never been sponsored by this program for the City of Winnipeg.

5.6 WARNING SYSTEM

Flood warning systems play a key role in flood disaster reduction, and therefore they are often regarded as a component of preparedness activity. Early warning may save life, property and economic facilities. Almost all damage can be reduced if people have more time to save their belongings and take proper precautions. Emmenegger, Spreafico and

Lateltin (1994) stated that in the case of flood hazard, a comprehensive flood warning system includes sub-systems such as data collection and transmission, the calculation of forecasts, the evaluation of this information for decision-making and action, the warning dissemination, and the execution of emergency response measures (Figure 5-3).

As the ultimate purpose of flood forecasting is to provide flood warnings, the dissemination of information is an integral part of the Manitoba Flood Forecast Centre's duties. Generally, information on flood situations, forecasts and warnings is disseminated, through press release to the news media, by the Minister of the Natural Resources Department. Detailed information relating to a particular problem area is communicated directly to municipal officials by Water Resources Personnel, some of whom are on location and provide engineering advice as required (Water Resources Branch, 1971).

With regards to flood event communications, Andrews (1993) and CNC-IDNDR (1994) have provided similar description. There are several forms and levels of flood warnings given to the public and emergency agencies to prepare for flooding. The warning system is usually initiated with a statement of flood forecast or flood alert early in the spring season. The alert often gives a general indication of the potential threat based on various weather scenarios. During the course of the spring melt the Flood Forecast Centre will issue a flood warning when a flood event is foreseen. The warning is delivered to the

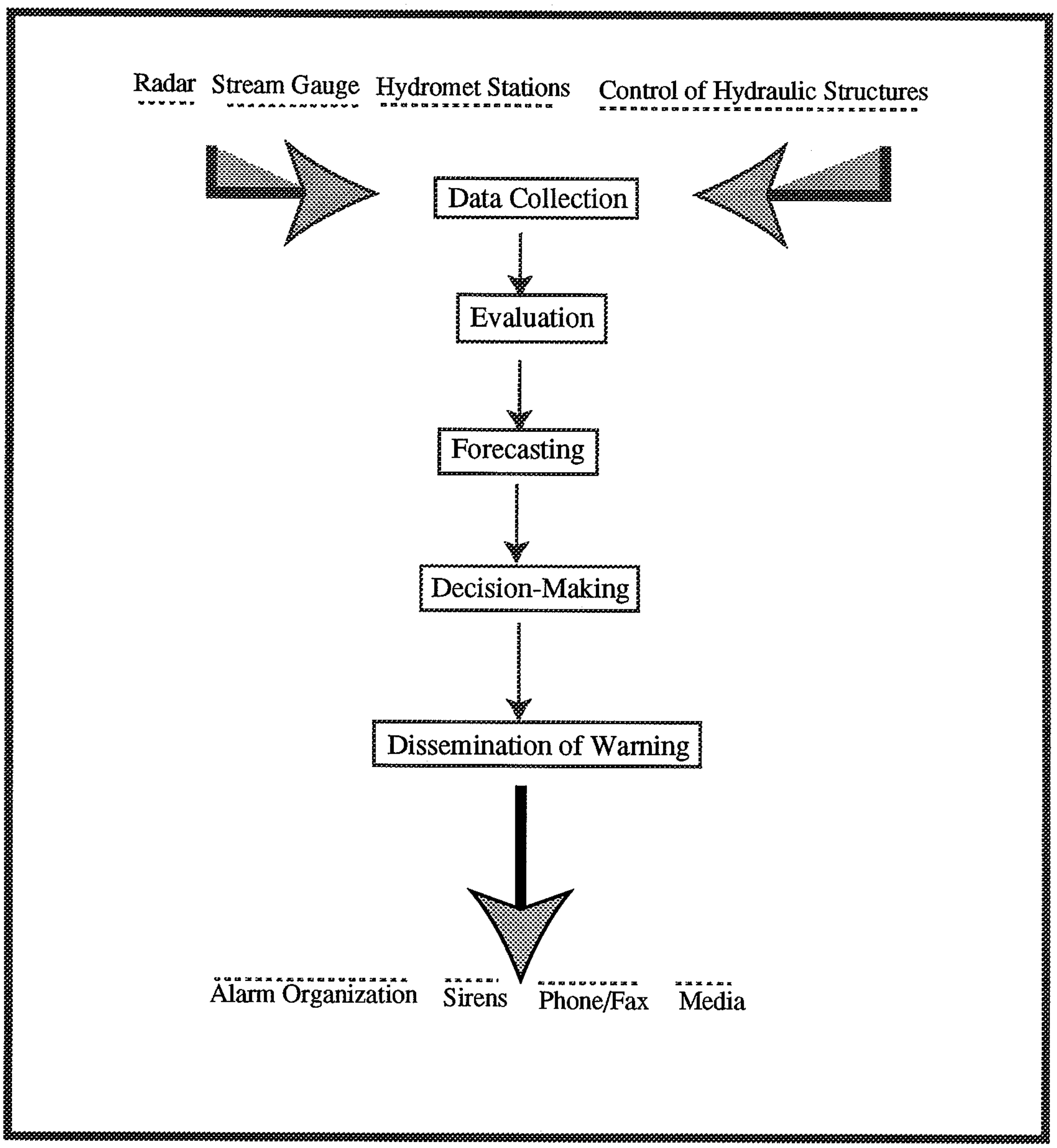


Figure 5-3 Flood Warning System

Source: Emmenegger et al (1994).

Flood Forecasting Review Committee, which releases the information to the Manitoba Legislature and the press (Andrews, 1993). The warning triggers Manitoba Flood Fighting Plans to be put into effect by the collective response of police, fire, public works, emergency measures, and other departments. These agencies assist in the evacuation, sheltering, feeding and clothing of the flood-threatened population. These warnings also give the public from several hours to a couple of days to prepare themselves by moving valuables to higher ground, possibly sealing the home to some extent, and volunteering to aid in the flood fighting.

To effectively organize the response to an impending or actual (flood) disaster, arrangements for the dissemination of a warning are established in the City of Winnipeg Emergency Plan (as shown in Figure 5-4). This Plan prescribes that if the nature and magnitude of the imminent disaster require warning of the general public, this warning will be broadcast over all Winnipeg TV and radio stations. In addition, it may be necessary to use loud speaker-equipped vehicles to warn the general public.

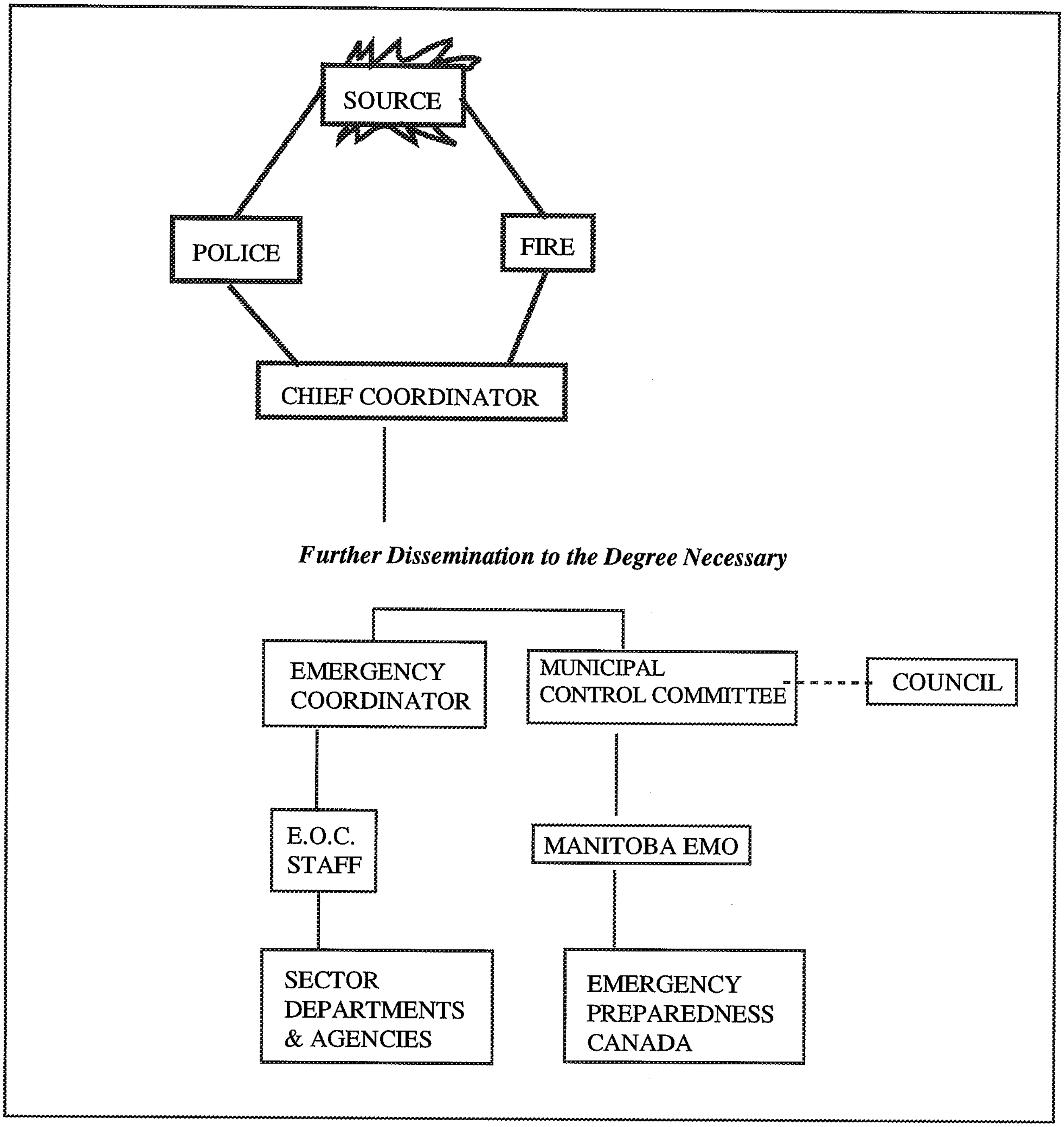


Figure 5-4 Warning Arrangements

Source: Emergency Program Office, the City of Winnipeg Emergency Plan (1992).

6. FLOOD DISASTER MANAGEMENT

Flood disaster management is a broad activity, providing a rational response to the threats of flood hazards. The process of flood disaster management can be represented as a chain of action, which includes four sequential phases - mitigation, preparedness, response, and recovery. In this chapter the emphasis will be on the aspects of institutional management, legislative support, and disaster response organization.

6.1 DISASTER MANAGEMENT AGENCIES

A number of institutions, either government agencies or non-government organizations, are involved in emergency /disaster management. Following is a brief introduction to the principal government agencies (Table 6.1), whose mandates are related to flood disaster management practice.

Table 6.1 Government Agencies for Managing Flood Disaster

Federal	
1)	Emergency Preparedness Canada (EPC)
2)	Environment Canada - Inland Water Directorate (IWD)
3)	Department of National Defence
4)	Agriculture Canada
5)	Canadian National Committee (CNC) for the IDNDR
Provincial	
1)	Manitoba EMO
2)	Department of Natural Resources - Water Resources Branch
3)	Manitoba Disaster Assistance Board (MDAB)
City of Winnipeg	
1)	Emergency Program Office
2)	Water and Waste Department
3)	Streets and Transportation Department
4)	Social Services Department

6.1.1 Federal Government

(1) Emergency Preparedness Canada (EPC)

EPC is the federal agency responsible for co-ordinating a national response to peacetime emergencies, including both natural and human-made disasters. EPC's role and mandate are defined in the Emergency Preparedness Act, 1988. An EPC Regional Director and an Assistant in each provincial capital are in constant touch with provincial emergency organizations and officials in order to ensure a country-wide network of preparedness (Emergency Preparedness Canada, 1987).

EPC maintains close liaison with the Manitoba EMO. EPC provides assistance and guidance to the Manitoba Government and to municipalities concerning preparation of civil emergency measures in matters that are not the responsibility of any department agency or Crown Corporation of the Federal

Government. EPC and the Manitoba EMO are active components in flood compensation boards. To help the Manitoba Government with the financial burden of flood relief measures, EPC administers, on behalf of the Federal Government, the Disaster Financial Assistance Agreements.

In Manitoba, EPC is actively involved in flood problems. The extent of EPC involvement is greatest during the spring, when floods are imminent or have occurred. In fact, in April and May, most of the regional staff time and resources are spent in flood related activities. EPC also sponsors civil emergency planning and training for all levels of government and private sectors.

(2) Environment Canada (EC)

Within Environment Canada, the Inland Water Directorate (IWD) is the national water agency. Through federal-provincial agreements, the IWD provides basic data on the flows and levels of rivers and lakes, which are used for frequency analyses of flood discharges and stages, and for the design of dams, channels, and other river and lake structures. The IWD's goals include formulation and co-ordination of integrated national water policies and programs and reduction of the undesirable effects of water resource development, such as flooding. Particularly, the IWD is responsible for the National Flood Damage Reduction Program. Additionally, it administers the Canada Water Act (CNC-IDNDR, 1994).

(3) Department of National Defence (DND)

In many disaster situations the Department of National Defence (DND) may be called on to assist in a variety of circumstances in order to provide a number of services: the latter include sandbag wall construction in flood control, helicopter and other rescue operations, and erection of temporary structures. The involvement of military expertise in engineering, medical and logistical activities in natural disaster emergencies is particularly significant (The Joint Committee RSC/CAE, 1990).

(4) Agriculture Canada

In addition to its major responsibility for emergency management of Canadian food and agriculture, Agriculture Canada is involved in crop insurance, including protection against losses due to flooding. This program, funded in part by this federal department, is designed to provide coverage to farmers who suffer periodic losses as a result of flooding. However, it is not available for lands which have been designated as flood-prone areas.

(5) Canadian National Committee (CNC) for the IDNDR

In order to promote activities and initiatives related to the IDNDR, the CNC for the INDR was established in 1993 by the Government of Canada, under the auspices of the Royal Society of Canada and the Canadian Academy of Engineering. The CNC has representation from government, science and engineering, and the private sector.

The major responsibilities of the CNC are both within Canada and abroad. Of course, the river flood hazard is a major focus of natural disaster reduction.

6.1.2 Provincial Government

(1) Manitoba Emergency Measures Organization (EMO)

The Manitoba EMO, through the authority of The Emergency Measures Act, is responsible for coordinating the activities of federal, provincial and municipal governments, crown corporations and agencies to mitigate the effects of an emergency. The Manitoba EMO grew out of the 1950 flood event, and was transferred from the Municipal Affairs Department to Government Services in 1980. The director of EMO reports to the Deputy Minister of the Department of Government Services.

The Manitoba EMO's main functions involve the planning of protective action and preparedness for disasters and emergencies, and the provision of assistance during actual disaster conditions. In addition to its operational activities, the Manitoba EMO also provides training programs for municipal officials. These courses are designed to meet the training requirements in such activities as communications, public information and community health planning (Manitoba Government Services, 1993).

The Manitoba EMO's role is similar to that of EPC in that it is directed towards the prevention of damage and the provision of assistance to a community once a disaster is imminent or has occurred. Their role is vital in minimizing property damage and loss of life in Manitoba due to all peacetime disasters, including floods. However their role is not conducive to a reduction of possible future damages, other than by emergency measures. Normally the Manitoba EMO is informed by the Water Resources Branch of potential flooding, and then the Manitoba EMO contacts the affected communities by facsimile and letter. This is followed up by the Manitoba EMO District Manager's visiting communities to advise and assist in preparing for the flooding (Manitoba Government Services, 1993).

(2) Department of Natural Resources

The Manitoba Department of Natural Resources is responsible for the management, protection and enhancement of the province's air, water and land resources. The Department's Water Resources Branch is the major agency that provides flood forecasting services and manages water control structures. As of 1992, within the Water Resources Branch, there were five functional divisions: Administration, Water Licensing and Approvals, Water Management, Hydrotechnical Services, and Regional Management (Manitoba Natural Resources, 1992). The Administration Section administers the Dyking Authority Act, the Rivers and Streams Act, the Water Resources

Administration Act, and the Water Rights Act that are pertinent to the flood hazard. The Water Licensing and Approvals Section has the responsibilities for administering the Water Use Regulation and Water Diversion Works Regulation, both under the aegis of the Water Rights Act of Manitoba.

The Water Management Section's activities include administering legislation and policies pertaining to flood damage reduction. The Section also undertakes investigation of both structural and non-structural means of reducing existing levels of agricultural, industrial and property damage from flooding. This unit is responsible for the implementation of the Canada-Manitoba Flood Damage Reduction Program.

With reference to the flood hazard, the Hydrotechnical Services Section provides flood and runoff forecasting, and also produces an inventory of ground and surface waters.

The Regional Management Section provides engineering services and is capable of responding to flood emergencies. Some of its duties are the operation and maintenance of flood control facilities, coordination of all flood fighting activities, and assistance to the Manitoba Disaster Assistance Board with restoration works and claims from the public.

(3) Manitoba Disaster Assistance Board (MDAB)

The MDAB has been an independent body of the Department of Government Services since 1982. It was established in law under the Emergency Measures Act in July 1987. The Board is responsible for communicating and administering government policy on disaster assistance in accordance with the Emergency Measures Act and the Disaster Financial Assistance Policy. The Board can provide compensation and financial assistance both during and after the occurrence of a disaster.

As outlined in the Manitoba Government Services Annual Report (1993), the activities of the MDAB include public disaster assistance awareness program, investigation of claims, and implementation of disaster assistance programs.

The MDAB has completed many disaster assistance programs including flood assistance programs for the City of Winnipeg and other communities. This Board has compensated homeowners and farmers for losses and damage to their homes and personal items, as well as providing compensation to the City of Winnipeg for its damages (Manitoba Government Services, 1995). For example, the Board paid almost $14 million to Winnipeg as compensation for flooding in 1993. Approximately $10.8 million of this total was paid to individual property owners in a private sector program, whereas $3.1 million was paid to the City of Winnipeg government. For the 1996 spring flood, the City of Winnipeg will get about $1 million from the MDAB, mainly to reimburse it for its flood fighting expenditure (Bennett, 1996b).

6.1.3 The City of Winnipeg

(1) Emergency Program Office

In 1990 the City of Winnipeg established an Emergency Program Office and hired, as its director, an Emergency Program Coordinator whose essential functions were to establish, enhance, and maintain emergency preparedness activities in Winnipeg (The Board of Commissioners, City of Winnipeg, 1993). The Emergency Program Coordinator is responsible for writing and developing the local emergency response plan, and works with all response agencies such as police, fire and ambulance, in order to ensure a coordinated planning effort. With the assistance of the Manitoba EMO, the Coordinator produced the City of Winnipeg Emergency Plan in 1992.

In addition to managing and coordinating any emergency response for Winnipeg, the coordinator is required to keep City Council and the Mayor informed of developments as they occur, and to ensure that all their directions are carried out. The Emergency Operations Centre (EOC), located in the Emergency Program Office in City Hall, is the key to emergency/disaster response. The EOC serves as the master coordination and control point for all counter-disaster efforts. The Centre contains the necessary personnel, physical facilities and communications for the central coordination of the City's emergency response.

(2) Water and Waste Department

The City of Winnipeg's Water and Waste Department provides regional services for drinking water, wastewater, land drainage and solid waste to the residents and businesses of Winnipeg.

The Department's responsibilities include maintenance of the flood protection facilities and the City's system of stormwater retention basins. The operation of the urban sewage collection system and pumping and treatment facilities is also a major part of the Department's function. Through its services, the Department manages to protect property and public health against river flooding and snowmelt and rainstorm runoff.

In 1996 Winnipeg flood, the Department staff monitored water levels very closely to assess the possibility of flooding and the staff consulted daily with provincial representatives to determine the need for operation of the Red River Floodway. The staff also manned flood pumping stations on a 24-hour basis to ensure that they were all operational (Taylor and Turner, 1996).

(3) Streets and Transportation Department

The Streets and Transportation Department's major areas of responsibility include transportation planning, construction of regional streets, construction and maintenance of bridges, and installation/application and maintenance of all traffic control devices. With regard to flooding, the Department's Equipment & Material Services Division is in charge of sandbag production and filling that enable secondary dyke construction and raising in the City.

In the 1996 flood, the Department filled 375,000 sandbags; 325,000 of these were delivered to homeowners for the construction of necessary secondary dykes along the Red River. This helped protect over 100 residences in the St. Norbert, St. Germain and Scotia Street localities from the danger of river flooding. In addition, Department staff monitored bridges and other river crossing structures for possible hazards (Taylor and Turner, 1996).

(4) Social Services Department

The Social Services Department is charged with the responsibility for providing financial aid and rehabilitative services to destitute people in Winnipeg. Germane to damaging flood events, the Department provides emergency food, clothing, shelter, registration/inquiry, and other personal services to victims of disasters and emergencies. In the flood emergency of 1996, the Department placed two families at the University of Manitoba and provided food for two additional families.

6.1.4 Summary

When faced with a serious situation, such as river flooding, there is an increased need for mutual support and cooperation between government agencies. To avoid working at cross-purposes or in ignorance of the other's objectives, federal, provincial and municipal departments concerned with flood emergencies should augment inter-agency communication and co-ordination.

6.2 EMERGENCY LEGISLATION AND GUIDELINES

Emergency legislation and flood fighting arrangements have established the responsibilities of appropriate departments, and set out the procedures in responding to flood disasters. These jurisdictions ensure that flood disaster/emergency responses can be effectively organized. The following relevant legislation is investigated in order to identify its impact on flood disaster management practice (Table 6.2).

Table 6.2 Emergency Legislation

General legislation	
1)	Emergencies Act (1988)
2)	Emergency Preparedness Act (1988)
3)	Manitoba Emergency Measures Act (1987)
4)	Manitoba Emergency Plan (1984)
5)	City of Winnipeg Emergency Plan (1992)
6)	Disaster Financial Assistance Arrangements
Flood-Specific legislation	
1)	Community Emergency Management Guidelines - Floods
2)	Emergency Action Guidelines - Flood Incident
3)	Flood Fighting Plan

6.2.1 General Legislation

(1) Emergencies Act

In June 1987, the Government of Canada introduced in Parliament new comprehensive federal emergency legislation to replace the *War Measures Act*; the resulting Emergencies Act was given Royal Assent in July 1988 (Emergency Preparedness Canada, 1989a).

The Emergencies Act is a multi-part statute, which includes fully safeguarded and appropriately limited exceptional powers to deal with four types of national emergency. The Act includes provisions for major emergencies in Canada, such as armed conflict against the nation and internal large-scale public disorder beyond the capacity of a province to handle. Of special importance to a flood disaster in Winnipeg, the Emergencies Act covers public welfare emergencies, such as severe natural events that creates major and immediate adversity beyond the ability of a province to cope with.

This legislation also contains procedures to ensure that individuals who suffer loss or injury as a result of the application of the Act will be fairly compensated.

(2) Emergency Preparedness Act

The Emergency Preparedness Act, legislated in 1988, provides a statutory basis for the planning and preparedness programs which are necessary for dealing effectively with emergencies of all kinds. The Act led to the establishment of Emergency Preparedness Canada (EPC), an independent agency of the federal government. The Act (Government of Canada, 1988) set out the specific functions of EPC with respect to both the development and implementation of civil emergency plans, established the emergency planning responsibilities of federal ministers generally, and explicitly recognized the interests of the provinces in relation to federal assistance provided during a provincial emergency (EPC, 1989a).

(3) Manitoba Emergency Measures Act

The Manitoba Emergency Measures Act was assented to in July 1987. The Manitoba EMO administers this Act. In this Act, Part II establishes the responsibilities and powers of the Minister of Government Services and the local authorities in respect of emergency preparedness.

Part III details the implementation of emergency plans, declaration of a state of emergency, emergency powers, and compensation for loss. Section 6 specifically requests the establishment, modification, and approval of emergency preparedness plans and programs. Sections 11(1) and 11(2) permit the declaration of a state of local emergency by the local authority. Such declaration can be crucial in enabling local authorities to take actions necessary to provide maximum protection to people, property and the environment.

Part IV provides for the establishment of the Manitoba

Disaster Assistance Board and its duties relating to the implementation of disaster assistance policy.

(4) Manitoba Emergency Plan

The aim of the Manitoba Emergency Plan is to provide a mechanism for ensuring prompt and coordinated response by the Manitoba Government to emergencies and disasters. The Plan is comprised of two major parts.

Part I outlines the basic emergency plan for dealing with emergencies and disasters. It delineates the respective responsibilities of local authorities and the Manitoba Government and its departments. Furthermore, it describes the essential response structure and response concept which form the basis for emergency action for all emergencies and disasters.

Part II provides emergency action guidelines for emergencies which may require provincial action or coordination. Most important is the *Community Emergency Management Guidelines* for various disasters/emergencies, including floods.

(5) City of Winnipeg Emergency Plan

The aim of the City of Winnipeg Emergency Plan is to provide a prompt and coordinated response by the City to major peacetime emergencies and disasters. The Plan generally sets out the basic arrangements applicable to any peacetime emergency, and it describes in detail the emergency response structure and emergency response procedures. In addition, the Plan outlines the responsibilities of the City's departments in emergency or disaster operations. Detailed emergency response plans outlining operating procedures for combatting particular emergency situations, such as river flooding, are maintained by the sector coordinators under the general direction of the Chief Coordinator (Emergency Program Office, 1992).

(6) Disaster Financial Assistance Arrangements

EPC manages, on behalf of the Government of Canada, the Disaster Financial Assistance Arrangements. These Arrangements are intended to monetarily assist a provincial government where the damage costs from a disaster are greater than the respective province could reasonably bear. Under these arrangements, the Federal Government provides, at the request of a province, financial assistance in accordance with a formula based on population. Generally, payments are made to restore public works to their pre-disaster condition, and to facilitate the restoration of essential property of private citizens, farmsteads and small businesses (Emergency Preparedness Canada, 1989b).

Under the formula, no federal assistance is provided unless provincial expenditure exceeds an amount equal to $1 per capita of the provincial population. When a province's expenditures exceed this level, the amount of federal financial assistance payable to a province is determined as specified in Table 6.3.

Table 6.3 Federal Post-Disaster Financial Assistance

Provincial Eligible Expenditures	Federal Share
First $1 per capita	0
Second $2 per capita	50%
Next $2 per capita	75%
Remainder	90%

Source: EPC, 1989b.

When cost-sharing is arranged with a province, the EPC's Regional Director plays a key role in co-ordinating the facilitation of financial assistance eligible under the Arrangements.

The formula used by the Manitoba Government to aid the City of Winnipeg is the same as that which the federal government uses with respect to provinces (Table 6.3). Therefore, the aid threshold for Winnipeg would be about $615,000. The formula the Province uses for determining cost sharing levels is as follows (Table 6.4):

Table 6.4 Manitoba-Winnipeg Disaster Cost-Sharing

Per Capita Eligible Cost	Government of Manitoba Share	City of Winnipeg Share
$0.00 to $1.00	0%	100%
$1.01 to $3.00	50%	50%
$3.01 to $5.00	75%	25%
$5.01 plus	90%	10%

Source: Bennett, 1996b.

6.2.2 **Flood-Specific Legislation**

(1) Community Emergency Management Guidelines - Floods

The second part of the Manitoba Emergency Plan is the Community Emergency Management Guidelines concerning various emergency situations. In order to assist a community in preparing for, and responding to, a flood, the Guidelines specify possible major effects of a flood and resources that may be used in an emergency.

With respect to flood emergencies, the Guidelines stipulate that the community emergency coordinator is clearly assigned duties at the three sequential stages: pre-emergency, emergency, and post-emergency (see Appendix C). The role of an emergency coordinator is emphasized; this person may delegate many of the tasks defined in the Guidelines. As there is no exclusive flood emergency action plan existing in the City of Winnipeg, these Guidelines are very useful.

(2) Emergency Action Guidelines - Flood Incident

The Manitoba EMO's Emergency Planning Guideline provides a guide for communities in designing their emergency plans. As part of the general planning guidelines, a sub-guideline, called *Emergency Action Guidelines - Flood Incident*, is also included. The latter describes the provincial and municipal responsibilities pertaining to a flood event. It also specifies the flood emergency response procedures at five stages: pre-emergency, preparatory, limited flood emergency, flood emergency, and post emergency (see Appendix D).

As an expansion of the above Flood Incident Guideline, the *Red River Flood Incident Emergency Action Guidelines* (see Appendix E) specifically for flooding of the Red River Valley communities are presented. This Guideline explicitly describes the procedures of flood response organization, and sets out the responsibilities of pertinent departments and agencies for coping with flood emergency.

As these two flood emergency guidelines were designed by the Manitoba EMO with the focus on the whole province, much of the document discussed is about the responsibilities of provincial responding departments, rather than the specific situation of the City of Winnipeg.

(3) Flood Fighting Plan

The objective of the Flood Fighting Plan is to establish standing operating procedures to meet a flood emergency. The first-documented plan, called Manitoba Flood Fighting Plan, was produced in 1966 under the authority of the *Civil Defence Act*. It has been replaced by the *Manitoba Department of Natural Resources Emergency Response Plan*, in which flood emergency response organization is simply described as part of the general plan. The Department of Natural Resources is directly responsible for responding to flood emergencies. Its responsibilities are as follows: the Water Resources Branch provides flood forecasting services; the Operations Division directs flood control operations, it also provides technical advice and assistance to municipalities concerning flood protection measures and flood damage assessment (Manitoba Natural Resources, 1993).

In Winnipeg, the major responsible agency is the Water and Waste Department. The Department does not have a formal written flood response plan; nevertheless, its flood emergency operation is normally based on its "Flood Activity Manual", which was produced in 1980. This Manual needs to be revised periodically as necessary to reflect any changes in operation of the sewer systems and pumping stations. As the pumping stations are operated by the Water and Waste Department, they are activated in sequence as the river level rises, according to the instructions in this Manual and in the comprehensive "Instruction Manual of Operations for Flood Pumping Stations".

6.3 FLOOD DISASTER MANAGEMENT ORGANIZATION

Unlike weather disaster mitigation, flood damage reduction in Canada is primarily a responsibility of provincial and municipal governments. Flooding is a regional concern, and many of the measures which could be implemented to reduce flood damages are under the jurisdiction of the provincial and municipal governments. To ensure successful flood damage reduction in Winnipeg, the Federal and the Manitoba Governments should work in close co-operation with the City of Winnipeg.

6.3.1 Emergency/Disaster Response Concept

Generally, responsibility for responding to emergencies or disasters starts with those persons or organizations closest to the extreme event. As the magnitude of the event surpasses the response capability of a particular individual, organization, or local level of government, the next logical agency level will be involved. However, involvement of this next level of response does not eliminate the responsibility or authority of those levels closer to the emergency/disaster (Dimitrijevic, 1995) (Figure 6-1).

6.3.2 Winnipeg Emergency Response Organization

The City of Winnipeg Emergency Plan outlines the all-emergency response approach procedures (Emergency Program Office, 1992; P.3).

> When an emergency/disaster occurs or threatens, the initial response will be made by the established City emergency services (i.e. police, fire and ambulance). If an emergency situation threatens to exceed the capability of the regular City emergency services, the City of Winnipeg Emergency Response Organization will be alerted and activated if necessary.
>
> Responsibility for the control and conduct of the emergency operation rests with the City of Winnipeg. The Manitoba EMO acts only as a support group, providing advice and assistance in areas either not available within the City's normal organization functions or where an expansion of activity is required beyond the City's own resource capacity (Figure 6-2).
>
> To avoid disruption or change, as much as possible, when it becomes necessary to adopt an emergency posture, departments responsible for a specific function will also be responsible for that function in an emergency.

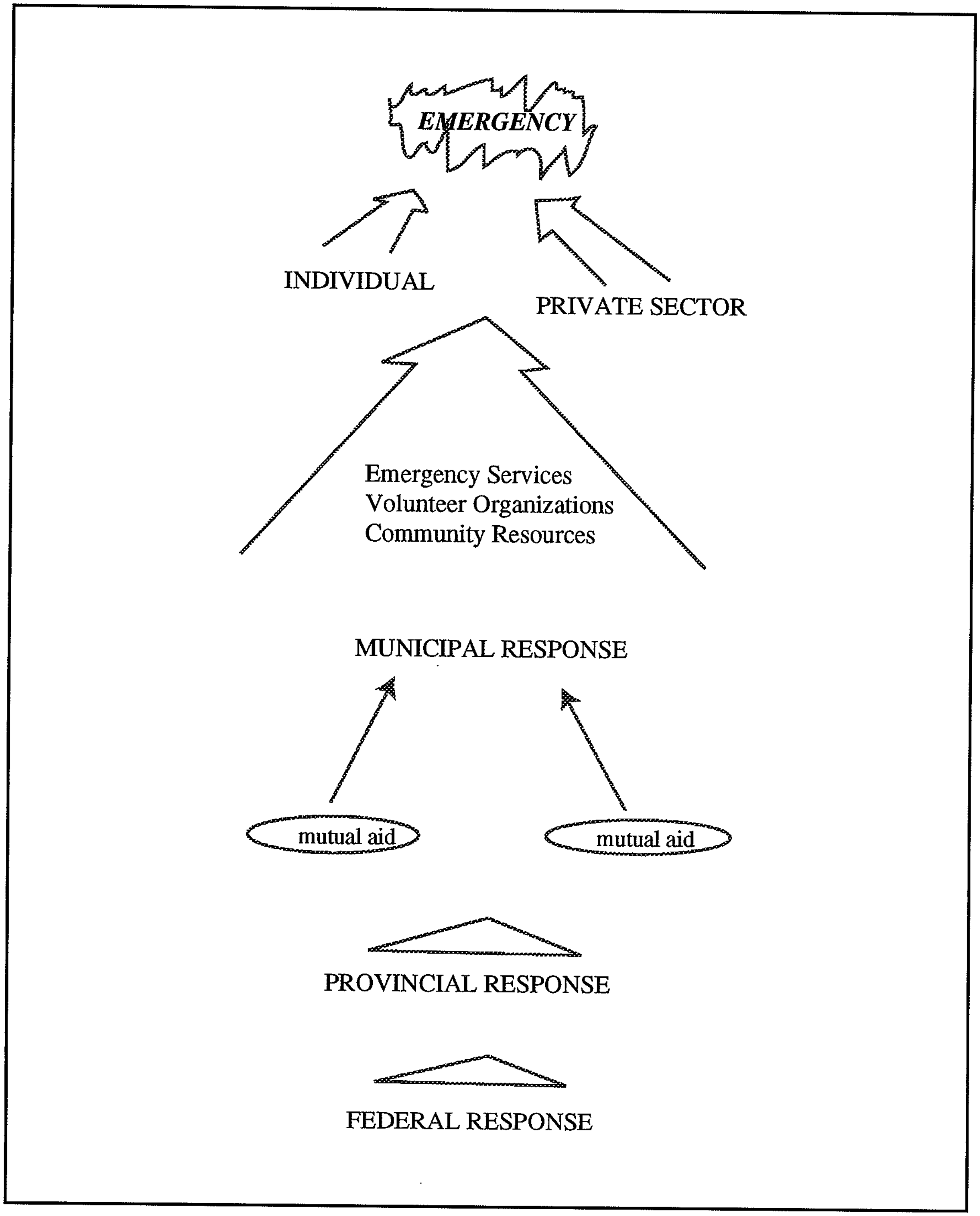


Figure 6-1 Emergency/Disaster Response System

Source: Dimitrijevic (1995).

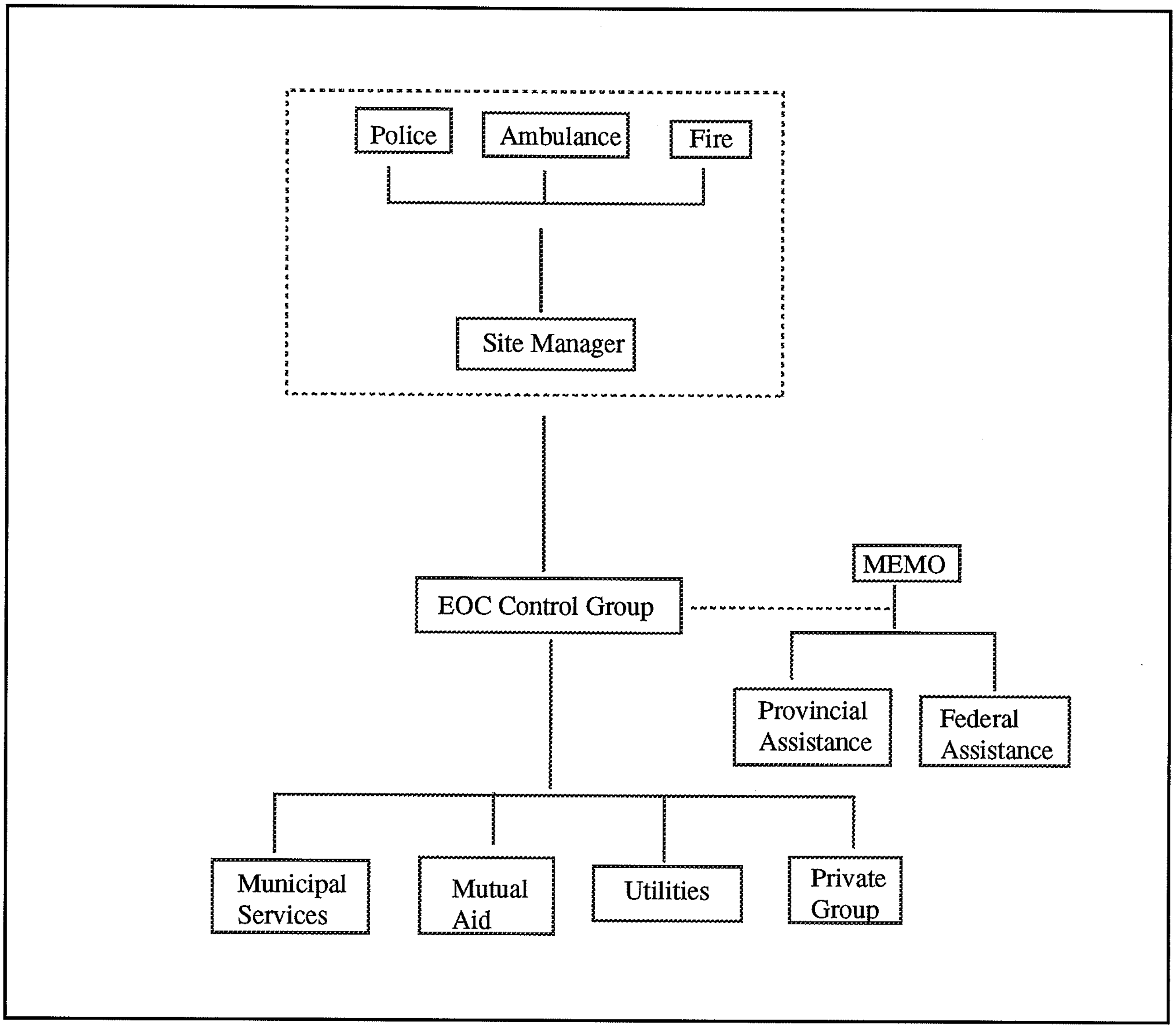


Figure 6-2 Community Emergency/Disaster Response Organization

Source: adapted from Dimitrijevic (1995).

6.3.3 Winnipeg Flood Disaster Management Organization

Winnipeg suffered the most serious spring flood since 1826 in May 1950, which triggered the largest emergency operation in the history of Winnipeg. In many ways, the management of the 1950 flood was an exemplary demonstration of societal response to a natural disaster. In dealing with the flood emergency, a special committee consisting of the chief coordinators from several Winnipeg's departments was set up. In retrospect, W.D. Hurst (1950), the chairman of the Committee, stressed the important role of the Committee in coordinating and cooperating emergency response activities. He reported that "this Committee ... was given more power than any other committee has ever been given in the history of the City of Winnipeg.", and "all in all this was a wise move." (Hurst, 1950a, p185; and 1950b, p.18).

The lessons from the 1950 flood catastrophe made the City of Winnipeg Council keep this committee functioning by vesting it with adequate authority and providing it with the necessary funds. It was once suggested by F.J. Fleury (1950) that a "Disaster Organization" should be established and a disaster plan to deal with emergencies should be existing at any time. Consequently, the Manitoba Emergency Measures Organization grew out of the 1950 disaster, and provincial and municipal emergency plans have been developed.

Accordingly, the City of Winnipeg has established an emergency response organization, which consists of the

Emergency Control Committee (ECC), the Emergency Preparedness and Coordination Committee (EPCC), and the Emergency Operations Centre (EOC). The City Emergency Program Office is a permanent agency for managing and coordinating emergency responses, in which the EOC is located. The EOC contains the necessary personnel, physical facilities and communications for the central coordination of the emergency response. All of these put a guarantee in operating emergency/disaster response.

Figure 6-3 illustrates the general framework of the flood disaster organization management system in the City of Winnipeg. As disaster response in Canada is generally the responsibility of elected officials at municipal level, the City of Winnipeg plays a central part in flood disaster response action. The two major lead agencies are the City's Water and Waste Department and the Streets and Transportation Department. In the meantime, provincial and federal involvements are also necessary, particularly in respect of flood forecasting and external resources support. In flood fighting, the Water Resources Branch and the Operations Division of the Manitoba Natural Resources are in charge of flood forecasting and operating flood control works. Under no circumstances are the Manitoba EMO and the Winnipeg Emergency Program Office major players in any emergency response, but they can render assistance through coordinationg other departments' activities, such as public aid, public works,

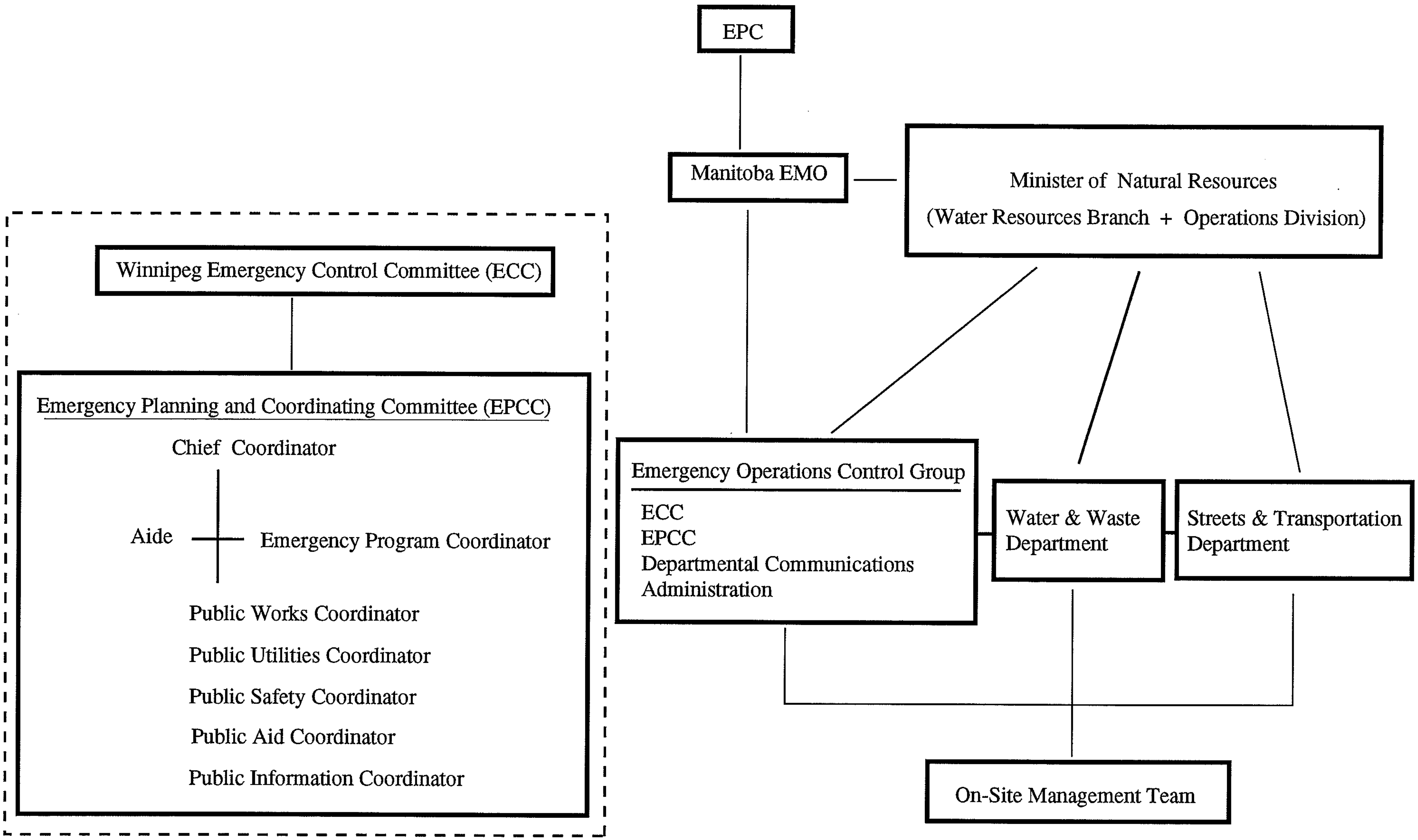


Figure 6-3 Winnipeg Flood Disaster Management System

public safety sectors.

At the municipal level, the ECC's role is to determine overall policies, and to provide direction of all phases of a comprehensive disaster management. The EPCC is responsible for creating and maintaining the City's emergency response plan and for coordinating response to a major emergency or disaster. At the stage of emergency, the ECC and EPCC make up part of the Emergency Operations Control Group (EOCG), which fulfils a response role and exists only then. The Site Management Team, under the direction of the appointed Site Manager, works for the EOCG. The EOCG is to support the response efforts of the site management, and to funnel the resources provided by external agencies to the site. The site management is to return life to 'normal' as soon as possible.

In organizing an efficient flood emergency response, the key is teamwork. Both inter-department and inter-governmental coordinations should be strengthened. Departmental roles and responsibilities need to be well established. The joint efforts of the government agencies in the effective planning, preparation and implementation of flood protection activities are particularly important in this aspect.

Additionally, a network of volunteers should be created for flood fighting. In most cases, property owners have access to volunteers only through friends, neighbours, and local communities. This situation can be improved. The City of Winnipeg provides sandbags for building dykes and has some expertise on sandbagging and dyking. However, the City is unable to provide a labour source for the construction of emergency dykes. It is apparent that an operational system be developed that provides volunteers to those residents who need them during a flood. It is hoped that the Canada Employment Centres of the federal department, Human Resources Development Canada, will become involved in helping accomplish this task by developing inventories of volunteer labour.

7. CONCLUSIONS

7.1 SUMMARY

There are many ways to combat flood hazards. These usually involve four overlapping functional phases: mitigation, preparedness, response, and post-disaster recovery. In this thesis the themes discussed are: flood hazard analysis, mitigation measures, disaster preparedness, and emergency response organization. There is no consideration of the recovery phase.

The flood hazard analysis undertaken in this thesis included a survey of the causes of flooding and the historical floods in Winnipeg. Based on the historical data, flood frequency analysis and risk analysis were conducted in order to identify the recurrence of flooding. By comparing the results of three different methods of analysis and the work of the Water Resources Branch, it is apparent that the accuracy of flood frequency estimation is largely dependent upon the length of the data record and on the selection of frequency distributions.

To cope with the Red River flood hazard, mitigation measures have been adopted. Since the 1950s, these consisted of reduction of either the probability of flood occurrence, or of the magnitude of damaging flood impacts in Winnipeg. The construction of four major flood control works, specifically the Red River Floodway, Portage Diversion, Shellmouth Dam, and St. Andrews Lock and Dam, and the Winnipeg flood protection system, with its dyking and pumping components, has prevented major flood damages in Winnipeg. All these structural works are highly cost effective. In particular, the operation of the Winnipeg Red River Floodway has consistently provided a safeguard for Winnipeg in spring time. Based on the analysis of the flood data at Redwood Bridge, it has been found that the actual 160-year flood has a higher discharge than the capacity of the flood protection system. The City of Winnipeg, therefore, may not handle a 160-year flood as designed.

In Winnipeg many non-structural measures have been employed to reduce potential losses from flooding. Under the Canada-Manitoba Flood Damage Reduction Program, Winnipeg flood risk areas were designated along the Red, Assiniboine and Seine Rivers in 1980, based on the apparent 160-year flood level. The resulting Winnipeg Interim Flood Risk Map and its accompanying brochure were not as widely distributed to home owners in the flood risk areas as required by the Flood Risk Mapping Agreement. Flood forecasting has been critically important in the provision of discharge information for operating flood control works and for organizing flood response activities. Moreover, the implementation of government legislation and legal arrangements has had an important impact on Winnipeg flood hazard reduction efforts, through exercising control over urban development in areas subject to flooding. Although a formal flood insurance program was not recommended by the Royal Commission in the 1950s, it is highly desirable that an insurance program, involving public funds and the private insurance industry, be established in order to provide financial assistance to property owners affected by flooding in flood-prone areas of Winnipeg because of the increased flood damage potential, particularly in the south of the City where residential development has been large during the past four decades.

Flood disaster preparedness entails activities designed to increase the effectiveness of emergency response prior to and during a flood disaster. In this preparedness phase, disaster planning, warning system establishment, and the Joint Emergency Preparedness Program (JEPP) were implemented by the responsible federal, provincial and municipal government departments. Disaster preparedness training in Winnipeg was mainly designed for government officials and personnel in non-government organizations; it was not available to the general public. With respect to the public education program, a variety of materials, especially literature, was produced. Unfortunately, these were not widely distributed to the public. Public flood disaster awareness is still very low. Many Winnipeggers do not know the major agencies responsible for flood reduction and emergency response. In general, residents are unaware of the legislation and regulations pertinent to flood hazard reduction.

To effectively reduce Canadian flood damages, much legislation has been enacted and many institutional arrangements have been established by federal, provincial and municipal governments. Accordingly, some government agencies are committed to flood disaster management. Inter-agency communication and coordination should be augmented in order to increase the efficiency of the latter. In organizing disaster response, the Manitoba EMO has developed excellent guidelines, which explicitly prescribe the responsibilities and the response procedures of different government departments. In flood fighting in Winnipeg, the major lead departments are the Manitoba Natural Resources Department and the City of Winnipeg's Water and Waste Department. The Manitoba EMO and the Winnipeg Emergency Program Office provide assistance through coordinating the flood response activities of other departments. In responding to a flood emergency, there must be efficient teamwork. A volunteer network system, involving the City of Winnipeg and the Human Resources Development Canada, should be developed.

The full range of aspects of Winnipeg's flood hazard management discussed in this thesis is summarized diagrammatically in Figure 7-1.

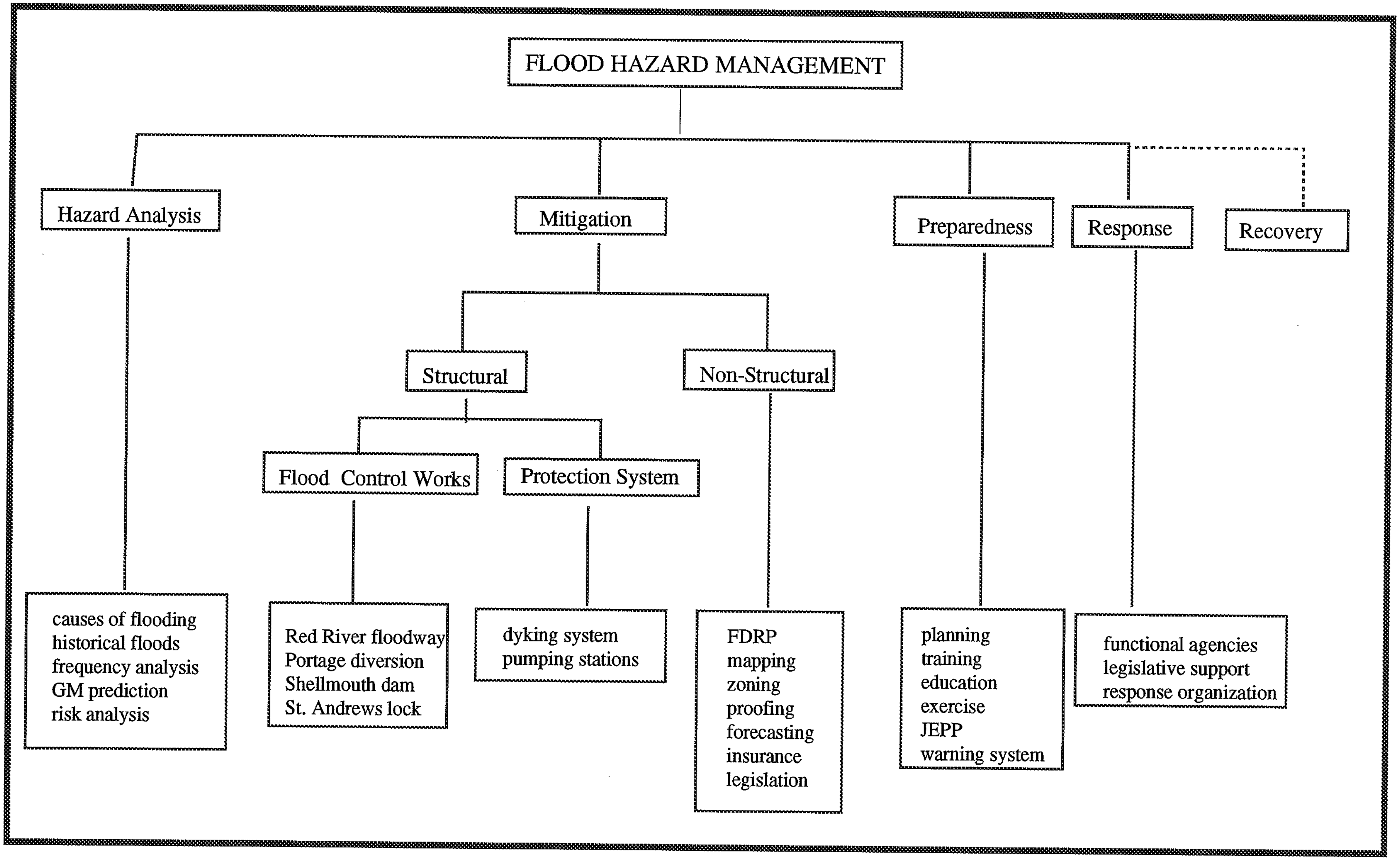


Figure 7-1 Winnipeg Flood Hazard Management

7.2 RECOMMENDATIONS FOR IMPROVEMENT OF WINNIPEG'S FLOOD HAZARD MANAGEMENT

In managing Winnipeg's flood hazard, the following issues will need to be improved:

1) Frequency analysis

When undertaking flood frequency analysis, scientists concentrate on statistical methodology and lengthening the historical flood data record. However, many scientists disregard the impact of historical climatic changes on the hydrological regime. The Water Resources Branch should conduct in-depth research on Winnipeg's flood frequencies in terms of the impact of climatic change in the Red River basin during the past 120 years.

2) Primary and secondary dykes

The dyking system was constructed in the 1950s. It is necessary to raise the primary dykes, where their crests are low, to the designed protection level. Large quantities of sandbags are used to raise or construct secondary emergency dykes around private properties in each spring flooding, especially in south Winnipeg. It is recommended that some these temporary sandbag dykes be converted into permanent structures.

3) Flood risk map

The Winnipeg Interim Flood Risk Map was produced in 1979. As several neighbourhoods in Winnipeg have developed since mapping completion, updating of this map is required. The map should reflect the updated flood frequencies completed by the Water Resources Branch.

4) Public education

Improvement in public education is necessary. Most of the educational publications on flooding and emergency response were only available upon request. As it is impracticable to distribute such materials to all individual households in Winnipeg, it is recommended that short articles on flood emergency measures be presented in newspapers. Radio and television programs on the flood threat and on flood preparedness should be broadcast in the spring time in order to increase the public's flood disaster awareness and to enhance citizens' collective response ability. An alternative to training and education is the use of electronic media, such as video and the Internet, to disseminate information to the public.

5) Flood manuals and guidelines

The Flood Activity Manual, produced by the City of Winnipeg's Water and Waste Department, needs to be revised periodically in order to reflect any change in operation because of the increasing flood damage potential and the restructuring of City departments involved in flood response.

6) Teamwork

When faced with a serious flooding situation, there is an increased need for teamwork. Both inter-departmental and inter-governmental coordinations should be strengthened.

Departmental roles and responsibilities need to be clarified. The joint efforts of government agencies in the effective planning, preparation and implementation of flood protection activities are particularly important.

7) Volunteer management

Whenever there has been spring flooding in Winnipeg, some citizens have volunteered to help residents protect their properties. In most cases, the volunteers were either contacted directly by flood-threatened homeowners or by the local community organizations. To efficiently organize the volunteer resources necessary to combat flooding, the City of Winnipeg should establish an inventory of persons volunteering their services. This network of volunteers can be created with the involvement of the federal department, Human Resources Development Canada.

7.3 RECOMMENDATIONS FOR FURTHER RESEARCH

Flood hazard management is a broad topic, and not every aspect was covered in this thesis. To better understand Winnipeg's flood situation, two major issues need to be thoroughly researched; these are public unawareness and anticipated flood damage losses.

7.3.1 Public Awareness Assessment

The Canada-Manitoba Flood Damage Reduction Program has existed for over two decades, and a series of flood mitigation and preparedness activities have been implemented widely. Actually, coping with the flood hazard is not only the routine work of some government agencies, but is a task for the whole society. Therefore, the general public should be actively involved in flood hazard reduction activity.

It is necessary to examine public awareness of the flood reduction and preparedness programs implemented for Winnipeg. In 1976, following the introduction of the national FDRP program, Hannigan and Kueneman (1978) conducted a sociological survey that revealed general public unawareness of the major flood control works, flood response agencies and flood emergency measures pertinent to Winnipeg. Twenty years later, it is reasonable to assume that public awareness may have increased. A new study needs to be undertaken in Winnipeg to reassess the level of flood-related knowledge, the public attitudes toward flood legislation, and the property owners' likely emergency response to a flood event affecting them.

7.3.2 Vulnerability Analysis

A vulnerability analysis should be undertaken in order to estimate the degree of loss or damage that would result from the occurrence of future flood hazard events of given severity in Winnipeg. This work should include existing developed locations and also those localities with the greatest residential and commercial development potential in flood-prone areas.

A major aspect of the vulnerability analysis for Winnipeg is mapping the likely effects of future floods; this work can be accomplished by using GIS technology. Two specific topics of research are vital. Firstly, flood boundary maps for flooding of different magnitudes, such as 20-, 50-, 100- and 150-year floods, should be generated for Winnipeg. Secondly, the potential damage impacts of flooding on residential property, critical infrastructures, and industrial and commercial facilities, should be scientifically analyzed in order to provide a complete assessment of Winnipeg's flood vulnerability.

BIBLIOGRAPHY

Agyare, Kwame A. 1992. Development of a Decision Support System for Flood Control Management. MSc Thesis. Department of Civil Engineering, University of Manitoba.

Anderson, David. 1873. Notes of the Flood at the Red River in 1852. London: Hatchards.

Andrews, Jeanne (ed.). 1993. Flooding: Canada Water Book. Ottawa: Environment Canada.

anon. 1993a. "Manitoba Experienced in Emergencies", Emergency Preparedness Digest 20(4): 2-4.

anon. 1993b. "Manitoba Municipality Sponsors Training", Emergency Preparedness Digest 20(4): 33.

anon. 1994. "Manitoba Launches Emergency Preparedness Week", Emergency Preparedness Digest 21(3): 33.

anon. 1995. "Manitoba Students Planning to Make the Grade", Emergency Preparedness Digest 22(1): 35.

anon. 1996. "He Watches the Rising Waters". Winnipeg Free Press, April 14, 1996.

Arnell, N.W. 1984. "Flood Hazard Management in the United States and the National Flood Insurance Program", Geoforum 15(4): 525-542.

Artibise, Alan F.J. 1975. Winnipeg: A Social History of Urban Growth 1874-1914. Montreal; London: McGill-Queen's University Press.

Artibise, Alan F.J. 1988. "Winnipeg", in The Canadian Encyclopedia (2nd edition), edited by James H. Marsh. Edmonton: Hurting Publishers. pp.2316-2319.

Atwood, C.H. 1923. Report on the Assiniboine River Floods. Winnipeg: [s.n.].

Babcock, M. and B. Mitchell. 1979. "Impact of Flood Hazard on Residential Property Values in Galt (Cambridge), Ontario", Water Resources Bulletin 16(3): 532-537.

Baker, Victor R. 1994. "Geomorphological Understanding of

Floods", Geomorphology 10(1-4): 139-156.

Baracos, A. 1954. Effect of the 1950 Winnipeg Flood on House Foundations. Ottawa: National Research Council, Division of Building Research.

Baumann, D.D. and J.H. Sims. 1978. "Flood Insurance: Some Determinants of Adoption", Economic Geography 54: 189-196.

Bell, F.C., G.S. Dolman, and J.F. Khu. 1989. "Frequency Estimation of Natural Hazards and Extremes", Australian Geographical Studies 27(1): 67-86.

Bell, G.L. 1963. The Red River Valley of North Dakota.

Bennett, Mark. 1988. "Community Emergency Planning", in Proceedings of the 40th Annual Convention of Western Canada Water and Wastewater Association. pp.85-89.

Bennett, Mark. 1996a. Analysis of Floodwatch'96 Questionnaires Distributed by Councillor John Angus.

Bennett, Mark. 1996b. Federal-Provincial Cost Sharing-Disaster Compensation.

Blaikie, Piers, Terry Cannon, Ian Davis, and Ben Wisner. 1994. At Risk: Natural Hazards, People's Vulnerability, and Disasters. London; New York: Routledge.

Booth, Larry and Frank Quinn. 1995. "Twenty-Five Years of the Canada Water Act", Canadian Water Resources Journal 20(2): 65-90.

Booy, C. and Morgan, D.R. 1985. "The Effect of Clustering of Flood Peaks on a Flood Risk Analysis for the Red River", Canadian Journal of Civil Engineering 12(1): 150-165.

Britton, Neil. 1991. Mass Emergency and Disaster Planning (III). Armidale: University of New England.

Bumsted, J.M. 1982. Winnipeg Floods through the Years (sound recording): a talk delivered 28 April 1982 in the University of Manitoba Libraries Department of Archives and Special Collection Discovery Hour Series.

Bumsted, J.M. 1987. "Developing a Canadian Disaster Relief Policy: The 1950 Manitoba Flood", Canadian Historical Review 68(3): 347-373.

Bumsted, J.M. 1988. "Red River Colony", in The Canadian Encyclopedia, edited by James H. Marsh. Edmonton: Hurting Publishers. pp.1836-1837.

Bumsted, J.M. 1993. The Manitoba Flood of 1950: An Illustrated History. Winnipeg: Watson & Dwyer Publishers.

Burby, R.J. and S.P. French. 1981. "Coping with Floods: The Land Use Management Paradox", Journal of American Planning Association 47(3): 289-300.

Bureau of Travel and Publicity, Department of Industry and Commerce. 1957. City of the Rivers. Winnipeg: Manitoba Department of Industry & Commerce.

Burton, I. 1965. "Flood Damage Reduction in Canada", Geographical Bulletin 7(3-4): 161-185.

Canada Geological Survey. 1964. Geotechnical Investigation, Red River Floodway. Winnipeg, Manitoba.

Canadian National Committee for IDNDR (CNC-IDNDR). 1994. National Report of Canada.

Canada-Manitoba Flood Damage Reduction Program. 1985. Manitoba River Forecast Development. Environment Canada and Manitoba Natural Resources 1985-88.

Carlyle, W.J. 1983. "Agricultural Drainage in Manitoba: the search for administration boundaries", in River Basin Management: Canadian Experiences, edited by B. Mitchell and J.S. Gardner. Waterloo: University of Waterloo, Department of Geography. pp.279-295.

Carlyle, William J. 1984. "Water in the Red River Valley of the North", The Geographical Review 74(3): 331-358.

City of Winnipeg. 1991. Designated Floodway Fringe Area Regulation.

City of Winnipeg. 1995. Municipal Manual: City of Winnipeg.

Clark, R.H. 1950. Notes on Red River Floods, with particular reference to the flood of 1950. Manitoba Department of Mines and Natural Resources. Printed by R.S. Evans, Queen's Printer for Manitoba.

Courage, William. 1950. Local Disaster Organization. Montreal, Quebec: The Federation.

Crocus, Heritage Resource Planning. 1989. Time and the River: A conceptual interpretive plan for the Core area riverbanks of Winnipeg.

Cunnane, C. 1975. "Flood Estimation by Statistical Methods", in Proceedings of Flood Studies Conference, London, 7-8 May

1975. pp.43-46.

Cutter, Susan L. (ed.). 1994. Environmental Risks and Hazards. New Jersey: Prentice-Hall, Inc.

Darwent, Thelma J. (ed.). 1975. Flood Studies Conference: papers and discussion on the flood studies report and discussion on reservoir flood standards. The Institute of Civil Engineers, London, 7-8 May 1975.

Day, H.T. and K.K. Lee. 1976. "Flood Damage Reduction Potential of River Forecasts", Journal of Water Resources Planning and Management 102(1): 77-87.

Deng, Julong. 1987. Principles of Grey System. Wuhan, China: Central China University of Science and Technology Press.

Deng, Julong (ed.). 1988a. Grey System. Beijing, China: China Ocean Press.

Deng, Julong. 1988b. "Grey Forecasting Model", in Grey System, edited by Julong Deng. Beijing: China Ocean Press. pp.54-69.

Deng, Qi, Qiang Zhou, Bingren Wang, and Shouling Ran. 1989. Water Resources Grey System Forecasting and Decision-Making. Beijing, China: China Surveying and Mapping Press.

Department of City Planning, University of Manitoba. 1971. Environmental Capacity of the Red River Floodway for Human Activities. Winnipeg: [s.n.].

Department of City Planning, University of Manitoba. 1990. The Red River Action Plan: A program for sustaining the river's use, development and enhancement into the 21st century. Winnipeg, Manitoba.

Department of Environmental Planning (Winnipeg). 1979. Historic Flood Profile, City of Winnipeg.

Department of Resources and Development Canada. 1952. Floods of 1950 in the Red River of the North and the Winnipeg Basin.

Deyman, I.H. 1966. "Manitoba Flood 1966", EMO National Digest 6(3): 1-7.

Dimitrijevic, Andre. 1995. Lecture on Emergency Management in Manitoba. Disaster Research Institute, University of Manitoba. January 1995.

Eastman, J. Ronald. 1993. "Uncertainty and Risk", in Idrisi User's Guide (Version 4.1). Graduate School of Geography, Clark University. pp.50-54.

Ebert, Charles H.V. 1988. Disasters: Violence of Nature and Threats by Man. Iowa: Kendall/Hunt Publishing Company.

Emergency Planning Canada. 1974. Report on the 1974 Spring Floods. Federal-Provincial Arrangements Branch, Emergency Planning Canada.

Emergency Planning Canada. 1985. Symposium 1985: Training and Education for Emergency Preparedness in Canada Today and Tomorrow.

Emergency Preparedness Canada (EPC). 1987. Emergency Preparedness in Canada (Pamphlet).

Emergency Preparedness Canada (EPC). 1988. Floods: self-help advice (brochure). Minister of Supply and Services Canada.

Emergency Preparedness Canada (EPC). 1989a. Fact Sheet. April 1989.

Emergency Preparedness Canada EPC). 1989b. Fact Sheet. August 1989.

Emergency Preparedness Canada (EPC). 1993. Report to Parliament on the Operation of the Emergency Preparedness Act (April 1, 1992 - March 31, 1993). Minister of Supply and Services.

Emergency Preparedness Canada (EPC). 1996. Natural Hazards - National Atlas of Canada.

Emergency Program Office, City of Winnipeg. 1992. The City of Winnipeg Emergency Plan.

Emmenegger, C., M. Spreafico, and O. Lateltin. 1994. "Flood and Landslide Warning Systems", in United Nations World Conference on Natural Disaster Reduction, Technical Committee F - Warning Systems, 26 May 1994. pp.59-74.

Environment Canada. 1982. A Study of the Impact of Flood Plain Designation on Local Real Estate Prices. Water Planning and Management Branch, Inland Waters Directorate, Ottawa.

Environment Canada. 1985a. Canada-Manitoba Red River Valley Ring Dyke Upgrading Agreement: annual report for the period - 1984-85. Regina: Environment Canada, Inland Waters Directorate, Western and Northern Region.

Environment Canada. 1985b. Federal Guidelines for the National Flood Damage Reduction Program. Water Planning and Management Branch, Inland Waters Directorate, Ottawa.

Environment Canada. 1991. Canada-Manitoba Flood Protection Projects Agreement: annual report for the period - 1986-1991. Regina: Environment Canada, Inland Waters Directorate, Western and Northern Region.

Environment Canada. 1992. The Canada Water Act Annual Report 1991-1992.

Environment Canada. 1993. The Canada Water Act Annual Report 1992-1993.

Environment Canada, and Manitoba Natural Resources. 1985. Manitoba River Forecast Development, Phase I: planning and design. Canada-Manitoba Flood Damage Reduction Program Agreement Respecting Flood Forecasting.

Environment Canada, and Manitoba Natural Resources. 1988. Manitoba River Forecast Development, Phase II: application and evaluation. Canada-Manitoba Flood Damage Reduction Program Agreement Respecting Flood Forecasting.

Epstein, Donald. 1986. Urban Rivers - Expanding Our Vision: the 1985 Winnipeg rivers conference summary. Institute of Urban Studies, University of Winnipeg.

Ericksen, Neil J. 1975. Scenario Methodology in Natural Hazards Research. Institute of Behavioral Science, University of Colorado.

Falconer, Susan. 1993. "Flooding and River Management", Geography Review 7(2): 38-41.

Fleury, F.J. 1950. "Lessons to Be Learned from the Manitoba Floods", in Local Disaster Organization. Canadian Federation of Mayors and Municipalities. pp.1-13.

Foster, Harold D. 1981. "Reducing Disaster Losses: the management of environmental hazards", in Canadian Resource Polices: Problems and Prospects, edited by Bruce Mitchell and W.R. Derrick Sewell. Toronto: Methuen. pp.209-232.

Freshwater, David and l.M. Arthur. 1985. Towards an Assessment of the Economic Impacts of the Canada-Manitoba and Canada-Saskatchewan Flood Reduction Programs. Department of Agricultural Economics and Farm Management, University of Manitoba. Occasional Series No. 15, March 1985.

Gardner, James S. 1976. "Natural Hazards of Climatic Origin in Canada", in Canada's Natural Environment: Essays in Applied Geography, edited by G.R. McBoyle and E. Sommerville. Toronto: Methuen. pp.46-68.

Gardner, J. and B. Mitchell. 1980. "Floodplain Regulation in Ontario: an analysis of existing and proposed policy in the Grand and Credit River watersheds", Journal of Environmental Management 11(2): 119-132.

Goulter, I.C. and T.C. Hannan. 1984. "Flood Warnings and Flood Responses for the Red River of the North", Water Resources Bulletin 20(4): 599-610.

Government of Canada Prairie Command. 1950. Report on the Manitoba Flood of 1950: Operation "Redramp". Winnipeg: [s.n.].

Government of Canada. 1970. The National Housing Act.

Government of Canada. 1988. The Emergency Preparedness Act.

Government of Manitoba. 1987. The Emergency Measures Act.

Government of Canada. 1988. The Emergencies Act.

Graham, Robert Michael W. 1984. The Surface Waters of Winnipeg: rivers, streams, ponds and wetlands (1874-1984): the cyclical history of urban land drainage. MLA Practicum, Department of Landscape Architecture, University of Manitoba.

Green, C.H., S.M. Tunstall, and M.H. Fordham. 1990. "The Risks from Flooding: which risks and whose perception?", Disasters 15(3): 227-236.

Green, Karen K. 1995. "The Historical Water Highways of Manitoba", Your Life Style Winnipeg, June 11, 1995. pp.20-23.

Halket, Ian H. 1977. A Geomorphologic Approach for Determining Flood Frequency in the Southern Yukon. MA thesis. Department of Geography, University of Manitoba.

Handmer, J. 1980. "Flood Hazard Maps as Public Information: An assessment within the context of the Canadian Flood Damage Reduction Program", Canadian Water Resources Journal 5(4): 82-110.

Hannan, Timothy Charles. 1986. Rural Land Use Allocation for Flood Damage Mitigation through Dynamic Programming Considering Multiple Annual Floods and Time Dependent Flood Damage Susceptibility. MSc Thesis. Department of Civil Engineering, University of Manitoba.

Hannigan, John A. and Rodney M. Kueneman. 1978. "Anticipating Flood Emergencies: a case study of a Canadian disaster subculture", in Disasters: Theory and Research, edited by E.L. Quarantelli. London: Sage Publications, pp.129-146.

Health and Welfare Canada. undated. Are You Prepared in Case of Disaster?

Henri, Christopher. 1991. "The Insurance Industry Response to Flood", in Natural and Technological Hazards: Implications for the Insurance Industry, edited by Neil R. Britton and John Oliver. Sterling Offices (Australia) Limited. pp.167-174.

Henry, R.F. 1984. Flood Hazard Delineation at Tuktoyaktuk (microform). Sidney, B.C.: Institute of Ocean Science, Department of Fisheries and Oceans.

Hewitt, K. and I. Burton. 1971. The Hazardousness of a Place: A Regional Ecology of Damaging Events. University of Toronto, Department of Geography Research Paper No. 6.

Hurst, W.D. 1949. The Red River Valley Flood Problem. Winnipeg Branch of the Engineering Institute of Canada.

Hurst, W.D. 1950a. Organizing Winnipeg to Meet the Flood Emergency in 1950. The Institute of Public Administration of Canada, September 16, 1950.

Hurst, W.D. 1950b. "Winnipeg Flood Emergency Organization", in Local Disaster Organization, Canadian Federation of Mayors and Municipalities, August 23, 1950. pp.14-27.

Hurst, W.D. 1957. The Red River Flood of 1950. Papers read before the Historical and Scientific Society of Manitoba.

International Coalition for Land and Water Stewardship. 1990. Red River Basin Land and Water Guide. Moorhead, Minnesota.

James F. MacLaren Ltd. 1979. Winnipeg Development Plan Review: water supply study. Winnipeg.

Jarolim, Ladislav. 1986. The Impact of Flood Plain Ordinances on Residential Real Estate Values in the City of Winnipeg. MSc Thesis. Agricultural Economics and Farm Management, University of Manitoba.

Jobin, F.L. 1957. "The Story of Winnipeg", in City of the Rivers, published by Bureau of Travel and Publicity, Department of Industry and Commerce. p.2.

Jones, David. 1993. "Environmental Hazards: the challenge of change", Geography 78(2): 161-165.

Jordan, O.N. 1980. Instruction of Operation for Flood Pumping Stations & Waterworks, Waste and Disposal Facilities.

Kirkland, Alison. 1995. "Living in Winnipeg", Where Winnipeg.

May/June 1995. pp.18-19.

Kite, G.W. 1988. Frequency and Risk Analysis in Hydrology. Water Resources Publications.

Krenz, G. and J. Leitch. 1993. A River Runs North: managing an international river. Red River Water Resources Council.

Kreutzwiser, R. 1988. "Municipal Land Use Regulation and the Great Lakes Shoreline Hazard in Ontario", Journal of Great Lakes Research 14(2).

Kuz, Tony J (ed.). 1974. Winnipeg 1874-1974: Progress and Prospects. Winnipeg: Manitoba Department of Industry & Commerce.

Langford, Jock R. 1985. The Effects of Flood Hazard Risks and the Canada-Manitoba Flood Damage Reduction Agreement on Residential Real Estate Values - An application of the Hedonic Model Technique. Department of Agricultural Economics, University of Manitoba.

Lind, Robert Clarence. 1966. The Nature of Flood Control Benefits and the Economics of Flood Protection. Stanford, Calif.: Institute in Engineering Economic Systems, Stanford University.

Long, J.A. 1970. Red River Floods: with particular reference to years 1956, 1966 and 1969. Winnipeg: Department of Energy, Mines and Resources, Inland Waters Branch, Water Survey of Canada.

Lye, Leonard M. Fung Piau. 1988. Uncertainty in Flood Risk Analysis. PhD Thesis, Department of Civil Engineering, University of Manitoba.

Lye, L.M., S.K. Sinha, and C. Booy. 1988. "Bayesian Analysis of the T-Year Events for Flood Data Fitted by a Three-Parameter Lognormal Distribution", Civil Engineering System 5: 81-86.

MacDonald, Jake. 1994. "The Red River Valley", Canadian Geographic 114(1): 42-51.

MacKenzie, John Nairn. 1978. Optimal Operation of a Flood Control System. MSc Thesis. Department of Civil Engineering, University of Manitoba.

Manitoba Clean Environment Commission. 1980. Proposed Classification of Manitoba's Surface Water: Red River principal watershed division. Environmental Management Division, Department of Consumer & Corporate Affairs &

Environment.

Manitoba Clean Environment Commission. 1992. Report on Public Hearings: application of water quality objectives for the watershed classification of the Red and Assiniboine rivers and tributaries within and downstream of the City of Winnipeg. Environmental Management Division, Department of Consumer & Corporate Affairs & Environment.

Manitoba Crop Insurance Corporation. 1994. Annual Report 1993-94.

Manitoba Department of Natural Resources. 1980. Canada-Manitoba Flood Damage Reduction Program Annual Report 1979-1980.

Manitoba Division, Canadian Red Cross Society. 1950. "Call 320": a documentary record of the 1950 Manitoba flood and Red Cross activities in the disaster. Winnipeg: Manitoba Division, Canadian Red Cross Society.

Manitoba Emergency Measures Organization. 1966. Manitoba Flood Fighting Plan.

Manitoba Emergency Measures Organization. 1969. 1969 Flood Report.

Manitoba Emergency Measures Organization. 1989a. City of Winnipeg Flood Emergency Workshop: Compilation of Syndicate Response. February 23, 1989.

Manitoba Emergency Measures Organization. 1989b. City of Winnipeg Flood Emergency Workshop: Concerns. March 28, 1989.

Manitoba Emergency Measures Organization. 1993. After Flooding: Procedures for returning to your home.

Manitoba Emergency Measures Organization. 1994. Family Emergency Handbook: think safety.

Manitoba Emergency Measures Organization. undated. Community Emergency Management Guidelines.

Manitoba Emergency Measures Organization. undated. Emergency Measures for Floods.

Manitoba Emergency Measures Organization. undated. Emergency Planning Guideline.

Manitoba Emergency Measures Organization. undated. Emergency Preparedness Checklist.

Manitoba Emergency Measures Organization. undated. Manitoba Emergency Plan.

Manitoba Flood Disaster Assistance Board. 1981. Flooding in Manitoba 1971.

Manitoba Government Services. 1980. Annual Report 1979/80.

Manitoba Government Services. 1988. Annual Report 1987/88.

Manitoba Government Services. 1993. Annual Report 1992/93.

Manitoba Government Services. 1995. Annual Report 1994/95.

Manitoba Health. 1992. Manitoba Population Report (June 1, 1992).

Manitoba Natural Resources. 1980. Reducing Flood Damage in Winnipeg.

Manitoba Natural Resources. 1991. Annual Report 1990/91.

Manitoba Natural Resources. 1992. Annual Report 1991/92.

Manitoba Natural Resources. 1993. Department of Natural Resources Emergency Response Plan.

Manitoba Regulation 170/81. 1981. The Manitoba Gazette, 110(33): 647-649.

Manitoba Seniors Directorate. undated. Seniors Emergency Preparedness.

Manitoba Urban Affairs. 1990. Rural Residential Development in the Winnipeg Region.

Manitoba Water Commission. 1977a. A Review of Flood Fighting Activities, 1976.

Manitoba Water Commission. 1977b. A Review of Agricultural Drainage in Manitoba. Winnipeg, Manitoba.

Manitoba Water Commission. 1980. Review of the Red River Floodway, Potage Diversion and Shellmouth Reservoir.

Mann, Brett W. 1994. "Changing Odds in the Insurance Industry", Emergency Preparedness Digest 21(2): 11-15.

Marsh, James (ed.). 1988a. The Canadian Encyclopedia (2nd edition). Edmonton: Hurting Publishers. p.1836.

Marsh, J. 1988b. "Assiniboine River", in The Canadian

Encyclopedia, edited by James H. Marsh. Edmonton: Hurting Publishers. p.136.

Mathur, Brijesh and Mary Ann Beavis (eds.). 1990 Towards Stewardship of Winnipeg's River Corridors: conference proceedings. Institute of Urban Studies, University of Winnipeg.

Mayer-Oakes, William J. (ed.). 1967. Life, Land and Water. Winnipeg, Canada: University of Manitoba Press.

McKerness, Lorna. 1976. The Legal and Institutional Framework Governing Flood Plain Management: a case study of the flood plain of River Park, South of Estevan, Saskatchewan. MNRM Thesis. Natural Resource Institute, University of Manitoba.

Miller, J.E. and D.L. Frank. 1984. Changes in Flood Response of the Red River of the North Basin, North Dakota-Minnesota.

Millerd, Frank W., Christian M. Dufournaud, and Karl A. Schaefer. 1994. "Canada-Ontario Flood Damage Reduction Program-Case Studies", Canadian Water Resources Journal 19(1): 17-26.

Mitchell, B., J. Gardner, R. Cook, and B. Veale. 1978. Physical Adjustments and Institutional Arrangements for the Urban Flood Hazard: Grand River watershed. Waterloo, Ontario: University of Waterloo, Department of Geography, Publication Series 13.

Morgan, John P. 1989. A Natural History Survey of Riverbanks: Winnipeg Core Area. Volume 3 of: Time and the River: a conceptual interpretive plan for the riverbanks of Winnipeg's core area.

Morton, W.L. 1957. Manitoba: A History. University of Toronto Press.

Muckleston, Keith W. 1983. "The Impact of Flood Plain Regulations on Residential Land Values in Oregon", Water Resources Bulletin 19(1): 1-7.

Mudry, N. 1980. Canada-Manitoba Flood Damage Reduction Program Annual Report for 1979-1980.

Mudry, N., G.H. MacKay, and V.M. Austford. 1981. "Flood Control and Flow Regulation Problems on the Assiniboine River", Canadian Water Resources Journal 6(4): 157-173.

National Research Council. 1989. Hydrology of Floods in Canada: a guide to planning and design. Associate Committee on Hydrology, Ottawa.

Nemec, J., J.M. Nigg, and F. Siccardi (eds). 1993. Prediction and Perception of Natural Hazards. London: Kluwer Academic Publishers.

Newson, Malcolm D. 1976. Flooding and Flood Hazard in the United Kingdom. Oxford University Press.

Newson, Malcolm. 1994. Hydrology and the River Environment. Oxford: Clarendon Press.

Ontario Ministries of Natural Resources and Municipal Affairs. 1988. Policy Statement - Flood Plain Planning.

Page, G.A. 1980. "The Canadian Flood Damage Reduction Program", Disasters 4(4): 411-421.

Parker, Dennis J. and Edmund C. Penning-Rowsell. 1983. "Flood Hazard Research in Britain", Progress in Human Geography 7: 182-202.

Parks & Recreation Department. 1982. Muddy Waters: an interpretive guide to Winnipeg's rivers. City of Winnipeg.

Penning-Rowsell, E.C., J.B. Chatterton, and D.J. Parker. 1978. The Effect of Flood Warning on Flood Damage Reduction. Central Water Planning Unit, Reading, England.

Penning-Rowsell, E.C. and J.W. Handmer. 1988. "Flood Hazard Management in Britain: a changing scene", Geography Journal 154(2): 209-220.

Petak, William J. and Arthur A. Atkisson. 1982. Natural Hazard Risk Assessment and Public Policy. New York: Spring-Verlag.

Plate, Erich J. and Wolfgang Kron. 1994. "The International Decade for Natural Disaster Reduction (IDNDR): a challenge to science", Soil Dynamics and Earthquake Engineering 13: 45-48.

Quinn, F.J. 1976. "Canada's Surface Water Resources: inventory and management", in Canada's Natural Environment: Essays in Applied Geography, edited by G.R. McBoyle and E. Sommerville. Toronto: Methuen. pp.72-107.

Raghavan, K.V. and Thyagarajan, G. undated. Hazard and Risk Analysis. Unpublished paper.

Rannie, W.F. 1980. "The Red River Flood Control System and Recent Flood Events", Water Resources Bulletin 16(2): 207-214.

Rasky, Frank. 1961. Great Canadian Disasters. Toronto: Longmans Green.

Red River Basin Investigation, Water Resources Division. 1953. Report on Investigation into Measures for the Reduction of the Flood Hazard in the Greater Winnipeg Area. Ottawa, Ontario: Canada Department of Resources and Development (October 1953).

Red River Basin Investigation, Water Resources Division. 1953a. Report on Investigation into Measures for the Reduction of the Flood Hazard in the Greater Winnipeg Area. Appendix A: Geography and Development (March 1953).

Red River Basin Investigation, Water Resources Division. 1953b. Report on Investigation into Measures for the Reduction of the Flood Hazard in the Greater Winnipeg Area. Appendix B: History of Floods on the Red River (March 1953).

Red River Basin Investigation, Water Resources Division. 1953c. Report on Investigation into Measures for the Reduction of the Flood Hazard in the Greater Winnipeg Area. Appendix C: Flood Runoff Analysis (March 1953).

Red River Basin Investigation, Water Resources Division. 1953d. Report on Investigation into Measures for the Reduction of the Flood Hazard in the Greater Winnipeg Area. Appendix D: Flood Magnitudes and Frequencies (March 1953).

Red River Basin Investigation, Water Resources Division. 1953e. Report on Investigation into Measures for the Reduction of the Flood Hazard in the Greater Winnipeg Area. Appendix E: Channel Improvements and Dyking (March 1953).

Red River Valley Board. 1951. Red River Valley Board Report to the Hon. Douglas L. Campbell. Winnipeg: [s.n.].

Redekop, Bill. 1996. "Itching to Get on Fields - farmers begin to worry as planting time slips by", Winnipeg Free Press, May 19, 1996. p.A5.

Rich, S.G. 1974. "Floodway Prevents 1974 Winnipeg Flood", Canadian Geographical Journal 88(6): 20-29.

Ross, Alexander. 1972. The Red River Settlement: its rise, progress and present state. Edmonton: Hurting Publishers.

Royal Commission. 1958. Report of the Royal Commission on Flood Cost-Benefit. Winnipeg, Manitoba.

Rutherford, D.H. and A. Baracos. 1951. Preliminary Draft Copy of Report on House Damage in the Winnipeg Flood 1950. Ottawa, Ontario: National Research Council, Division of Building Research.

Rutherford, D.H. and A. Baracos. 1953. Damage to Houses; Red

River Valley Flood 1950. Technical Report No.9. Ottawa: National Research Council, Division of Building Research.

Santin, Aldo. 1996. "A Lake to Dry Up the Flood". Winnipeg Free Press, April 8, 1996, p.A1 & A3.

Sauer, Vernon B. 1986. "Flood-Frequency Analysis with Historical Data in China", in Hydrologic Frequency Modelling, edited by Vijay P. Singh. D. Reidel Publishing Company. pp.173-182.

Senjem, N. and D. Freshwater. 1981. The Capitalization of Flood Hazard into Land Prices in Manitoba's Red River Valley. Department of Agricultural Economics and Farm Management, University of Manitoba. Research Bulletin No. 81-2, December 1981.

Sewell, W.R.D. 1965. Water Management and Floods in the Fraser River Basin. University of Chicago, Department of Geography Research Paper 100.

Shady, Aly M. (ed.). 1989. Irrigation Drainage and Flood Control in Canada. Canadian International Development Agency.

Sharp, J.J. and P. Sawden. 1984. Basic Hydrology. London: Butterworths.

Shaw, Elizabeth M. 1983. Hydrology in Practice. Van Nostrand Reinhold (UK) Co. Ltd.

Shrubsole, D., R. Kreutzwiser, B. Mitchell, T. Dickinson, and D. Joy. 1993. "The History of Flood Damage in Ontario", Canadian Water Resources Journal 18: 133-143.

Singh, Vijay P. (ed.). 1986. Hydrologic Frequency Modelling. D. Reidel Publishing Company.

Smith, Keith. 1971. Water in Britain: A Study in Applied Hydrology and Resource Geography. Macmillan.

Smith, Keith. 1992. Environmental Hazards: Assessing Risk and Reducing Disaster. London: Routledge.

Smith, Keith. 1993. "Riverine Flood Hazard", Geography 78(2): 182-185.

Smith, K. and G.A. Tobin. 1979. Human Adjustment to the Flood Hazard. London; New York: Longman.

Stoner, Jeffrey D., David L. Lorenz, Gregg J. Wiche, and Robert M. Goldstein. 1993. "Red River of the North Basin, Minnesota, North Dakota, and South Dakota", Water Resources

Bulletin 29(4): 575-616.

Taylor, Kathy and Yvette C. Turner. 1996. "Operation Dry Feet", Civic Pulse. pp.19-20. September 1996.

Thampapillai, D.J. and W.F. Musgrave.1985. "Flood Mitigation: a review of structural and non-structural measures and alternative decision frameworks", Water Resources Research 21(4): 411-424.

The Board of Commissioners, City of Winnipeg. 1993. The City of Winnipeg Civic Profile 1993.

The Joint Committee of the Royal Society of Canada and the Canadian Academy of Engineering. 1990. Toward a Canadian Program for the International Decade for Natural Disaster Reduction.

Ubertini, L. 1993. "Some Remarks on Scientific Activity of Flood Prediction in Italy", in Prediction and Perception of Natural Hazards, edited by J. Nemec, J.M. Nigg, and F.Sccardi. London: Kluwer Academic Publishers. pp.85-92.

United States General Accounting Office. 1994. Flood Insurance.

United States Geological Survey. 1950. Floods of 1950 in the Red River of the North and Winnipeg River Basins. Water Resources Division, US G.S. Water Supply Paper 1137B.

Viessman, Warren, Gary L. Lewis, and John W. Knapp. 1989. Introduction to Hydrology (3rd Edition). New York: Intext Educational Publishers.

Ward, R. 1978. Floods: A Geographical Perspective. Macmillan.

Wardrop, W.L. 1950. The City of Winnipeg Water Works System and the Manitoba Flood of 1950. Winnipeg: City of Planning, Engineering Department, Water Works & Sewerage.

Warkentin, A.A. 1986. River Flow Forecasting Procedures Employed by the Manitoba Flood Forecast Center for the Period from 1974 to 1986. Water Resources Branch, Department of Natural Resources.

Water Control and Conservation Branch, Manitoba Highways. 1963. The Red River Floodway: the story of one of Canada's biggest excavation projects.

Water Resources Branch, Department of Mines, Resources, and Environmental Management. 1971. Flood Control on the Red River in Manitoba.

Water Resources Branch, Manitoba Natural Resources. 1981. Canada-Manitoba Flood Damage Reduction Program, City of Winnipeg and Additional Zone Interim Flood Risk Mapping Study.

Water Resources Branch, Manitoba Natural Resources. 1987. Flood Forecasting in Manitoba (brochure).

Water Resources Branch, Manitoba Natural Resources. 1991. Manitoba Flood Protection Projects Agreement 1990-1991 Annual Report.

Water Resources Division, Manitoba Department of Mines, Resources and Environmental Management. undated. The Canada-Manitoba Flood Damage Reduction Program: A Summary.

Water Resources Division, Manitoba Department of Mines, Resources and Environmental Management. 1974. Flood Control. Winnipeg, Manitoba.

Water and Waste Department. 1995. Keeping Your Basement Dry during Wet Weather (brochure). Basement Flooding Protection Program. City of Winnipeg.

Waterworks, Waste and Disposal Department. 1993. Inter-Office Memorandum, August 15, 1993.

Waterworks, Waste and Disposal Department. 1980. Instruction Manual of Operations for Flood Pumping Stations. City of Winnipeg.

Watt, W. Edgar. 1995. "The National Flood Damage Reduction Program: 1976-1995", Canadian Water Resources Journal 20(4): 237-248.

Weber, T.E. 1967. The Red River Floodway and Related Control Works, in international Conference on Water for Peace. Washington, D.C.: United States Government Printing Office.

Weir, T.R. 1974. "Winnipeg: a city in the making", in Winnipeg 1874-1974: Progress and Prospect, edited by Tony J. Kuz. University of Winnipeg. pp.43-53.

White, Gilbert F. 1975. Flood Hazard in the United States: A Research Assessment. University of Colorado: Progress on Technology, Environment & Man Monograph.

Whitney, Larry J. undated. The Evolution of Drainage Policy in Manitoba. Water Resources Branch, Department of Natural Resources.

Wild, Stevens. 1996a. "A Fair Fight Against the Red". Winnipeg Free Press, April 23, 1996, p.A5.

Wild, Stevens. 1996b. "Weary and Wet, Winnipeggers Won the War". Winnipeg Free Press, April 23, 1996, p. A5.

Wild, Stevens. 1996c. "Red Reaches High Tide". Winnipeg Free Press, May 2, 1996. p.A5.

Works and Operations Division. 1991a. Waterworks, Waste and Disposal Department. Maintaining a Quality Water Supply for Winnipeg. July 1991.

Works and Operations Division. 1991b. Waterworks, Waste and Disposal Department. Water Quality and Uses for Winnipeg's Rivers. October 1991.

Xia, Jun. 1993. "A Grey System Approach Applied to Prediction of Extreme Hydrological Events: floods and droughts", in Extreme Hydrological Events: Precipitation, Floods and Droughts, edited by Z.W. Kundzewicz, D. Rosbjerg, S.P. Simonovic and K. Takeuchi. IAHS Publication No. 213. pp.447-454.

Zelinsky, Wilbur and Leszek A. Kosinski. 1991. The Emergency Evacuation of Cities: A Cross-National Historical and Geographical Study. Savage, Maryland: Rowman & Littlefield Publishers, Inc.

Zhang, Qinwen, Xuemeng Wang, and Hongsheng Nie. 1989. Grey Systems Analysis of Rural Economy. Beijing: Academic Publishing Company.

Appendix A

UPDATED FLOOD OUTLOOK FOR MANITOBA SPRING OF 1996
(March 18, 1996)

Manitoba's Water Resources Branch has updated its spring flood outlook based on new information on snowcover and soil conditions.

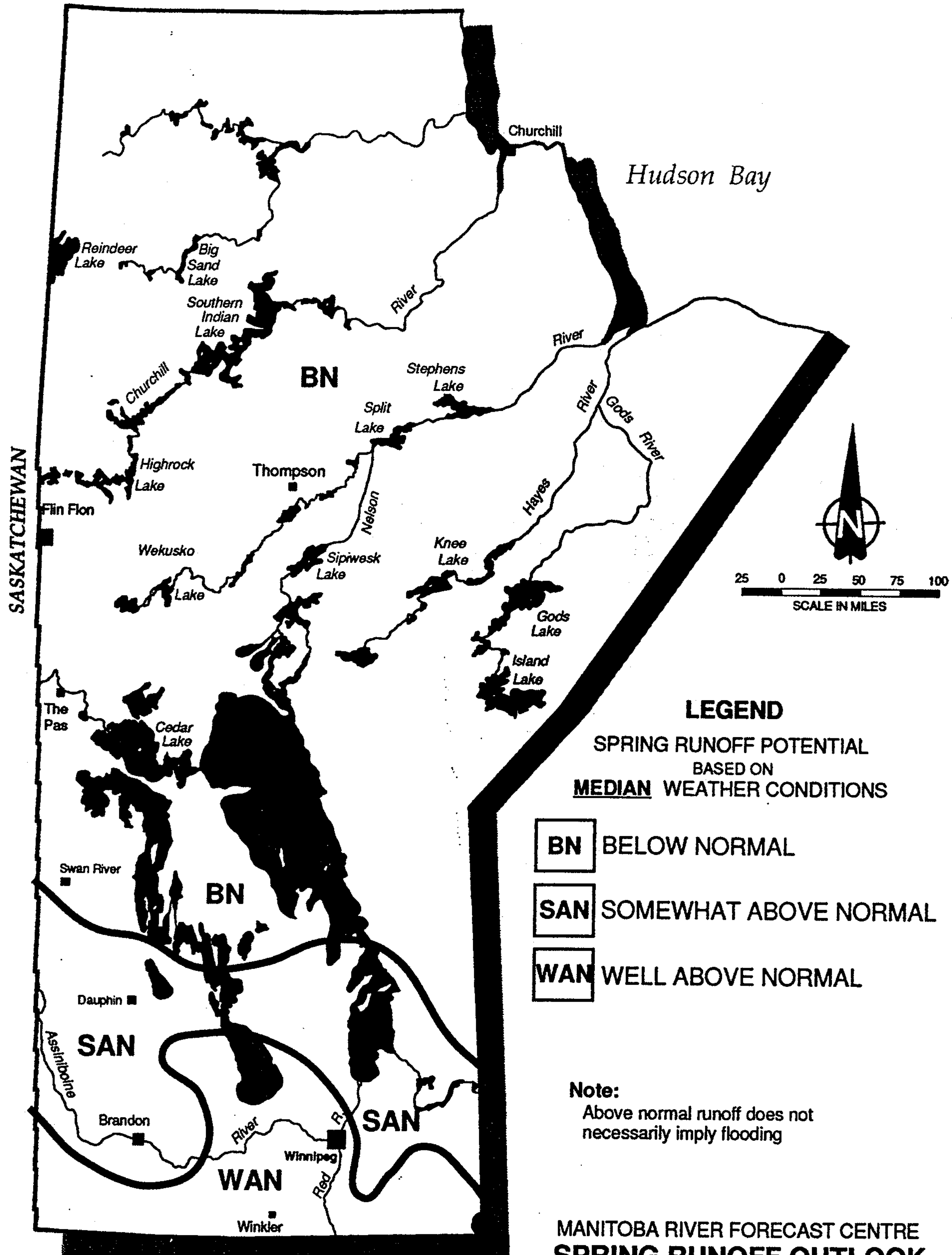
The spring flooding potential remains high in most areas south of the Trans-Canada Highway. However, below average precipitation during the past month or so has resulted in some reduction in predicted peak flows and stages for most streams.

The occurrence or severity of flooding will depend on greatly on spring weather conditions. A gradual melt with little additional snow or rain would allow the flood potential to dissipate. However, a rapid melt and/or additional heavy snow or untimely spring rain could produce serious flooding.

The flood potential decreased to moderate in the Interlake, Westlake and Swan River regions and to low in northern Manitoba.

The Branch's River Forecast Centre will monitor the flood potential closely, and will provide daily updates on conditions and forecasts by means of flood sheets once runoff is well underway.

Source: Alf A. Warkentin, Water Resources Branch, Manitoba Natural Resources.



MANITOBA RIVER FORECAST CENTRE

SPRING RUNOFF OUTLOOK

FORECAST DATE: **MAR.18, 1996**

PREPARED BY A.A.W.

Manitoba
Natural Resources
Water Resources

Manitoba Water Resources Branch
Daily Water Levels and Forecasts
CITY of WINNIPEG, 1996

Date: May 3, 1996, 10:00am

LOCATION	Today's Conditions			Three Day Forecast of Stage or Flow			Predicted Peak Flow or Level		Previous Peak Stages & Flows			
									1979		1995	
	Flow (cfs)	Stage (ft.)	Change from May 2	May 4	May 5	May 6	Q or WL	Date	Flow (cfs)	Stage (ft.)	Flow (cfs)	Stage (ft.)
Red River												
Above Floodway	78,000	764.42	-0.12	764.3	764.1	763.8	764.59	Apr 30	90,000	764.99	55,500	757.41
Below Floodway	41,400	751.44	+0.13	751.4	751.4	751.3	753.5	Apr 19	44,800	752.92	42,900	751.92
S. Perimeter												
Bishop Grandin	44,300	21.0	+0.1	21.0	20.9	20.8	22.1	Apr 19	47,500		43,000	21.40
Elm Park Bridge												
James Avenue	52,500	18.2	0.0	18.2	18.2	18.2	19.6	Apr 28	55,200	19.17	51,500	17.90
Kildonan Bridge	52,700	15.4	+0.1	15.4	15.4	15.4	16.8	Apr 28	55,200		51,500	15.30
Assiniboine River												
Headingley	5,800	762.60	-0.18	762.4	763.0	763.8	767.07	Apr 25	9,500	765.91	12,000	766.00
W. Perimeter												
St. James Bridge												
Sturgeon @ Ness	1,400		-300	1200	1000	800	2250	Apr 29	2,230		1700	
Omands @ Dublin	150		-50	120	100	80	450	Apr 21	600		350	
La Salle-Hwy 75	3,500		-400	3000	2500	2000	5200	Apr 29	5,800		3,500	

Source: Alf A. Warkentin, Water Resources Branch, Manitoba Natural Rsources.

COMMUNITY EMERGENCY MANAGEMENT GUIDELINES - FLOODS

Possible Major Effects --
Resources --

PRE-EMERGENCY

MAYOR/REEVE AND COUNCIL

EMERGENCY COORDINATOR

NOTE: it is well advised for the Emergency Coordinator to delegate many of the tasks found in this guidelines.

[ ] Complete/update flood hazard analysis.
[ ] List and check resources (equipment) required for flood fighting. Deficiencies in equipment should be noted and if possible purchase or rental arrangements should be made.
[ ] Establish/confirm mutual aid arrangements.
[ ] Check water ways, drainage ditches for obstructions.
[ ] Keep fuel tanks full in all vehicles and check mechanical/electrical equipment.
[ ] Develop public information and emergency communications plans.
[ ] Prepare and release public information announcements on the risk/threat of flooding and preventive measures that can be taken.
[ ] Move personal property from flood prone areas to safer areas.
[ ] Remove hazardous chemical from basements and warehouses.
[ ] Assess local nuisance grounds for possibility of flooding.
[ ] Anchor bulk fuel or other structures that may move from the rising water levels.
[ ] Consult with Manitoba Agriculture on the movement of grain, feed and livestock from flood prone area.
[ ] Review Emergency Transportation Guidelines.
[ ] Review Evacuation and Re-Entry Guidelines.
[ ] Seek further advice on flood mitigation procedures from Natural Resources.
[ ] Development flood watch program - train staff in alerting and reporting procedures.
[ ] Conduct public works program, i.e., dyking and drainage ditch construction or clearing.
[ ] Pre-position equipment and supplies (not in the flood prone areas).
[ ] Review Emergency Communications procedures (primary and secondary systems checks; e.g. radio, telephone).
[ ] Update and exercise telephone fan-out of personnel.
[ ] If possible, conduct test exercise of the Emergency Operations Centre (EOC) and correct deficiencies.

EMERGENCY

MAYOR/REEVE AND COUNCIL

- [ ] Notify MEMO and Natural Resources if there is need for provincial resources or assistance.
- [ ] Implement Emergency Plan, in whole or in part.
- [ ] Is Declaration of State of Local Emergency required? i.e., will there be a need to exercise emergency powers over those currently granted to a municipality?
- [ ] Mayor or Reeve should announce to the public the reason(s) for Declaring a State of Local Emergency.

EMERGENCY COORDINATOR

- [ ] Have Emergency Response Control Group report to EOC. Establish EOC.
- [ ] Establish communications between Emergency Site(s) and EOC.
- [ ] Identify extent of impact of the flood. This can be done by consulting with Natural Resources, MEMO and Environment. Commit resources as they are required.
- [ ] Decide with mayor and council on a Site Manager.
- [ ] Assign flood watch crews to their positions.
- [ ] Conduct dyking operations.
- [ ] Turn off power to flood prone buildings.
- [ ] Implement Emergency Communications Plan.
- [ ] Implement Evacuation Guidelines.
- [ ] Establish security perimeter around evacuated area.
- [ ] Implement Emergency Transportation Plan for stranded citizens.
- [ ] Provide security to evacuated areas.
- [ ] Implement and direct mutual aid personnel and equipment to required areas.
- [ ] Shut down or repair utilities to reduce public dangers.
- [ ] Implement Animal Care and Control Program.

POST EMERGENCY

- [ ] Terminate State of Local Emergency. Notify MEMO of Termination.
- [ ] Arrange for Manitoba Disaster Assistance Board to assess damages to community.

- [ ] Consult with Natural Resources that water levels have fallen to allow re-entry.
- [ ] Consult with Highways and Transportation that roads, highways and bridges are safe to use.
- [ ] Determine priorities for flood cleanup, i.e., clear main streets and clear unsafe structures.
- [ ] Restore utilities (phone, gas hydro, sewer).
- [ ] Contact Manitoba Disaster Assistance Board for possible compensation.
- [ ] Test drinking water for safety, assess sewer systems for service ability, assess roads and bridges for safety.
- [ ] Initiate re-entry procedures.

Source: Manitoba EMO, Manitoba Emergency Plan (1993).

Appendix D

EMERGENCY ACTION GUIDELINES -- FLOOD INCIDENT

LEAD RESPONSE DEPARTMENT - Natural Resources

1. OVERALL RESPONSIBILITY GUIDELINES

Province is responsible for

a. flood forecasting and flood information;
b. advising and assisting local authorities in alerting and informing citizens and communities about the flood emergency;
c. supporting municipal flood operation s as required;
d. performing specific flood control tasks when requested and authorized by local authority;
e. the operation of flood control works as provided for in the Water Resources Administration Act and Regulations;
f. advising and assisting local authorities in the evacuation of citizens from and re-entry to their communities;
g. the overall coordination of the provincial and municipal emergency response when necessary or appropriate;
h. providing or arranging for the provision of flood stores and equipment;
i. maintaining emergency communications with local authorities of flooded areas;
j. arranging for support from federal, other provincial and U.S.A. authorities; and
k. flood damage estimation of provincial structures.

Municipal, local authorities are responsible for

a. directing and controlling all flood operations in the municipality;
b. arranging for the performance of specific flood control tasks by provincial departments or agencies;
c. arranging the necessary administrative support for provincial, departmental, agency or other personnel who are supporting the municipal operation;
e. assisting provincial authorities with damage estimation and advising citizens about disaster assistance; and
f. warning and alerting the municipality of flood danger.

2. DEVELOPMENT OF A FLOOD INCIDENT

The progressive stages in the development of a flood incident are as follows:

Normal Spring Runoff - Conditions will be monitored by Natural Resources personnel and the progress of the flooding runoff will be reported.

Limited Flooding - Limited flooding will produce local problems which will be handled by municipal authorities with the technical advice and assistance of provincial departments.

Advanced Flooding - When the required emergency response to flooding exceeds the municipal capability, the municipality may formally request the responsible provincial departments to act as the municipality's agent to fight the flood. The municipality continues to be responsible for all costs including equipment rental, sandbags, sandbagging, etc.

Flood Emergency - When the flooding involves large areas if contiguous local flooding and is beyond the response capability of the several municipalities involved, the provincial government may declare a flood emergency and authorize and coordinate the required provincial support response.

3. FLOOD EMERGENCY RESPONSE PHASES

Phase I - Pre-Emergency

Beginning in February of each year, the Flood Forecasting Committee evaluates the possibility of spring flooding. Preliminary flood forecasts are made before the melt period begins. Key departments are alerted and the Central Task Team begins its meeting to monitor the flood threat. emergency Measures District Managers increase their visits to municipalities in the flood prone areas. Grain stocks are moved from flood prone areas.

Phase II - Preparatory Stage

An increased state of readiness will result from the growing threat of flooding indicated in flood forecasts. Municipalities in the threatened areas and provincial departments will prepare for flood emergency operations. Preparations include the review and updating of flood emergency plans and procedures, the checking of stores, equipment and manpower resources. where appropriate, fodder and equipment should be moved to safe areas and livestock evacuated. Emergency Measures District Managers and departmental office and/or field staff will advise and assist local authorities. Elements of the provincial emergency response structure are altered and response personnel briefed.

Phase III - Limited Flood Emergency

Limited flood emergency operations may be conducted simultaneously in several areas of the province by the involved local authorities. Provincial advice and assistance will be provided within the capabilities of responding departments. Coordination of the provincial response will, where necessary, be provided by the Manitoba Emergency Measures Organization.

Phase IV - Flood Emergency

When it is clear that a substantial and sustained provincial response will be required to deal with the flood emergency, elements of the provincial emergency response structure will be activated. Provincial departments and municipalities will respond in accordance with their emergency plans. The Manitoba Emergency Coordination Centre will be activated and will provide the necessary coordination of departmental and provincial/municipal emergency responses. Provincial on-site response teams will be dispatched to advise and assistant local authorities in the conduct of flood fighting operations and, when necessary, the evacuation of citizens.

Phase V - Post Emergency
Post emergency operations will involve extensive provincial assistance to municipalities in such activities as re-entry operations, clean-up, the restoration of utilities, flood damage estimation, claims for compensation and the resolution of flood operations costs.

Source: Manitoba EMO, Emergency Planning Guideline, Section 8.

Appendix E

RED RIVER FLOOD INCIDENT

EMERGENCY ACTION GUIDELINES

Serial	Action	Responsibility
Phase I	**Pre-Emergency**	
1	Preliminary flood forecasting liaison with U.S. authorities on flood prediction	Water Resources - Natural Resources
2	News releases on flood forecast issued	Minister of Natural Resources/ MEMO Coordinator/ Director of Communications Services
3	Central Task Team meets to consider threat	MEMO Coordinator/Departments
4	Key provincial departments are alerted	MEMO Coordinator
5	District Managers increase liaison visits to municipalities of flood prone areas	MEMO
6	Contact and advise local authorities on movement of grain stocks from flood prone areas	Agriculture
Phase II	**Preparatory Stage**	
1	Flood forecasting continues	Water Resource - Natural Resources/ MEMO Coordinator/ Director of Communications Services
2	Spring runoff outlook issued	Water Resources - Natural Resources/ MEMO Coordinator/ Director of Communications Services
3	Update flood plans/procedures	Departments/Municipalities
4	Check resources of stores, equipment and manpower. Take replenishment and/or purchasing action	Departments/Municipalities
5	Meet with local authorities to consider flood control measures, emergency dyking	Regional Operations - Natural Resources
6	Meet with local authorities to review emergency response/evacuation plans and procedures	MEMO/ EHS/ESS

7	Meet with local authorities to advise and assist movement of fodder and livestock	Agriculture
8	Central Task Team continues to meet, informs Deputy Ministers' Committee about the developing flood threat, action taken and recommendations for further action	MEMO/ Departments
9	Elements of the provincial emergency response structure are alerted and response personnel briefed	MEMO
10	Provincial Emergency Coordination Centre is made ready and coordinating	MEMO/Departments Staff are briefed
11	MECC telephone communications installed and checked	Tele-Comm Services/ Government Services
12	Information news release procedures are set up and media advised	MEMO Coordinator/ Director of Communications Services
13	Preliminary contractual arrangements made with commercial firms for dyking operations	Engineering & Construction - Natural Resources
14	Arrange special financial appropriation and coding	Finance
15	Arrangements made with transportation authorities for the movement of grain, fodder and livestock	Agriculture/ Highways & Transportation/ EPC
16	Arrangements made to obtain assistance of Canadain Force	MEMO/Canadian Forces
17	Arrangements made for the provision of railway water tank cars to transport drinking water to threatened communities	MEMO/EPC

Phase III Limited Flood Emergency

1	Daily operations flood forecasts issued	Water Resources - Natural Resources
2	Central Task Team meets regularly to review flood operations and plan further action	MEMO Coordinator/Departments
3	Provincial on-site response teams are dispatched as necessary to the affected municipalities.	MEMO/CTT/Departments
4	Municipalities respond in accordance with their procedures for a flood emergency	Municipalities
5	Provincial response in support of municipal operatons is coordinated as necessary by the MEMO	Departments/MEMO

Phase IV General Flood Emergency

1	Daily operational flood forecasts and information on water levels and flow are issued	Water Resources - Natural Resources
2	Central Task Team meets daily, briefs and makes recommendations to Deputy Minister's Committee	MEMO Coordinator/ CTT
3	Deputy Ministers' Committee and the Minster meet as necessary	Deputy Ministers'/ Minster
4	Elements of the provincial emergency response structure are activated	MEMO Coordinator/ Departments
5	Emergency Operation Centre is activated and provides the coordination for the provincial and provincial/municipal response	MEMO Coordinator/ Departments
6	Issue operations telephone lists to municipalities, departments and agencies	MECC
7	Coordinate and control public information	MEMO Coordinator/ Director of Communications Services
8	Departments and agencies activate and staff their twenty-four hour a day emergency telephone	Departments/Agencies
9	Provincial on-site response teams are dispatched by the Central Task Team to advise and assist local authorities in the flood threatened areas	MEMO/ CTT/Departments
10	Canadian Forces are dispatched to designated localities	MEMO/ Canadian Forces
11	Municipalities conduct flood operations, evacuate citizens, hospitals, are homes as necessary, assisted by provincial and municipal on-site response teams	Municipal/Provincial On-Site Response Teams/ ESS/EHS/RCMP
12	Assistance is provided to evacuatees at reception centres by the designated reception communities	Municipalities/ ESS/EHS
13	Departments and agencies support municipal flood operations in accordance with departmental and agency response procedures	Departments/ Agencies
14	Implement and coordinate arrangements for the shutting down of utilities/services in the evacuated areas	Municipalities/ CTT/MECC
15	Advise and assist school authorities in flooded areas in arrangements for school closing and	Education

	continuing education requirements	
16	Arrange and coordinate the provision of transport to supplement municipal resources	Highways & Transport/ Government Services
17	Arrange through EPC the adjustment of postal service to flooded areas	CTT
18	Maintain regular patrol of all property in the flooded areas	RCMP

Phase V Post-Emergency

1	Initiate preparatory arrangements for re-entry	Municipalities/Provincial On-Site Response Teams/ CTT/RCMP
2	Support and where necessary coordinate municipal re-entry preparations	CTT/MECC
3	Initiate re-entry information program	MEMO Coordinator/ Director of Communications Services/ Departments
4	Ensure that municipal preparations for re-entry are complete and that provincial responsibilities have been discharged	CTT
5	Implement re-entry operations when communities are prepared to receive returning citizens	Municipalities/Provincial On-Site Response Teams
6	Support municipal re-entry operations and coordinate as necessary	Departments/MECC
7	Arrange for flood damage estimation	MDAB/Departments
8	Process claims for compensation	Local Authorities/MDAB
9	Process Departmental claims	Government Services/ MEMO/MDAB
10	Process operations costs	Finance

Source: Manitoba EMO, Emergency Planning Guideline, Section 8.