



International Joint Commission
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**RED RIVER BASIN
STAGE-DAMAGE CURVES UPDATE
AND PREPARATION OF FLOOD DAMAGE
MAPS**

FINAL REPORT

JANUARY, 2000

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EXECUTIVE SUMMARY

The Red River originates in the United States and flows northward into Manitoba where it enters Lake Winnipeg approximately 50 miles north of the City of Winnipeg. Floods greater than the bank full capacity on the Red River upstream from Winnipeg have occurred on a number of occasions, including peak discharges of 94,000 cfs in 1950, 90,000 cfs in 1979, and 139,000 cfs in 1997.

While the 1997 flood was the largest flood during the past century, floods greater than the 1997 flood have occurred during the past 200 years, including the 1826 flood which had a peak discharge of approximately 225,000 cfs at Redwood Bridge in Winnipeg (180,000 to 190,000 cfs at Inlet Control Structure). The estimate of the 1:1000 year flood on the Red River is 295,000 cfs (252,400 cfs at the Inlet Control Structure). At these higher discharges, the present flood protection works would be compromised resulting in significant flooding to structures protected by these works both in the Red River Valley as well as in the City of Winnipeg.

Estimates of damages from floods of a magnitude at or greater than the 1997 flood requires the development of a stage-damage model, which considers the spatial and temporal impact of the flood on the Valley. The development of an up-to-date integrated stage-damage curve for the Valley will serve a number of valuable functions including planning and design of flood protection measures; real-time emergency management; and flood recovery.

The terms of reference identified four primary tasks for this study, which included the review of existing stage-damage curves, review of damage information from the flood of 1997, development of current stage-damage curves for the area bounded by the 1826 flood, and the use of the updated curves to develop map products to demonstrate the spatial variability of:

- flood damage risks in the Red River Basin;
- 1997 flood damages; and
- estimates of damages for a repeat 1826 flood event.

The terms of reference were to consider structural, infrastructure and agricultural damage estimates only. Other direct and indirect damages were not to be included.

Geographical Information System (GIS) technology was used to fulfil the objective of presenting the estimated spatially distributed damages. Together with the development of updated depth-damage relationships, the GIS is well suited to present and manipulate geographical data to determine damages in the Valley. Input to the GIS required the collection of the appropriate data, which is located geographically (geo-referenced).

As shown on Figure ES-1, the various data sources were compiled through the use of the GIS and the database data model. The updated curves were also used in the model to calculate the damages. The raw data was obtained in digital and hardcopy formats, and significant effort was required to format and link the various sources within the GIS and data model. Since the typical depth-damage curve relates dollars of damage to flooding referenced to the first floor elevation, the data model must determine the depth of flooding at each building location.

The updated depth-damage relationships were developed using data of actual damages paid as a result of the 1997 flood. The shape of the updated curves is consistent with curves obtained from other sources, but produces higher damage estimates than previously developed relationships. The estimates produced by the developed relationships are also higher than those commonly used elsewhere in North America.

In general, the structural damages estimated for the Valley for the 1997 flood were greater than the MEMO claims paid because the data model did not consider any temporary dyking/flood fighting efforts by the Valley residences. It may be inferred that the difference between the estimated damage and the actual damages paid is the money saved by the flood fighting effort. However, the model predictions for the 1997 flood at the periphery of the study area were somewhat less than the MEMO claims paid, primarily because the flood levels produced by the hydrodynamic model did not fully reach to the actual flood extents. The data model predicted damages for a repeat 1997 flood event to be approximately \$106 million, \$47.5 million and \$14.7 million for structural, infrastructure and agricultural damages in the Red River Valley respectively. Adding the estimated \$67.4 million dollars damage for the City of Winnipeg, the total estimated damages for the study area is approximately \$235.6 million.

The total damages for an 1826 type flood event were estimated to be approximately \$7.94 billion, which consists of estimates of \$7.47 billion for the City of Winnipeg, as well as \$336.8, \$65.6 and \$66.5 million for structural, infrastructure and agricultural damages in the Valley. The estimate of damages for a repeat 1826 flood in the City of Winnipeg is considered to be a cursory estimate based upon general assumptions consistent with the approach taken in the Valley. It is recommended that the use of the cursory damage estimate for a repeat 1826 flood in the City of Winnipeg be limited to a comparison of those damages calculated for the rest of the Red River Valley.

The damage distribution maps produced for 1997 and 1826 type floods show spatial distribution of damages consistent with actual damages experienced during the 1997 flood. Damages were mapped as dollars of damage per acre to "normalize" the presentation of the data, and range from \$0 to \$47,000 per acre for the repeat 1997 flood event, and up to \$267,000 per acre for the repeat 1826 flood.

Some of the data sets provided by government departments were noted to be incompatible for use in the data model. This led to the need to establish rules to accommodate data that was not considered to be geographically accurate. The rules incorporated were made flexible to accommodate both accurately and non-accurately positioned data. To eliminate inconsistencies in the data and refine the data model, the geographical building information available from the Survey and Mapping Branch should be updated and made consistent with the Rural Development Tax Assessment Database.

The use of the GIS and data model has been shown to be an effective, predictive tool for use in stage-damage analysis, which in turn can be adapted for benefit-cost analyses for future flood protection works. The tool may also be used to define areas requiring pre and post flood emergency assistance.

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1.0 INTRODUCTION

1.1 BACKGROUND

The Red River originates in the United States and flows northward into Manitoba where it enters into Lake Winnipeg approximately 50 miles north of the City of Winnipeg. The natural drop in water surface elevation of the Red River at bankfull capacity (40,000 cfs) between Emerson and the Floodway Inlet is approximately 40 feet and 70 feet to Lake Winnipeg. The capacity of the river in the Manitoba reach varies from approximately 40,000 cfs at Emerson to 50,000 cfs in the City of Winnipeg. Floods greater than the bank full capacity on the Red River upstream from Winnipeg have occurred on a number of occasions, including peak discharges of 94,000 cfs in 1950, 90,000 cfs in 1979, and 139,000 cfs in 1997.

Following the floods in 1950, 1979 and 1997, a number of flood control measures were implemented to control the flooding in the Red River Valley. These measures include the construction of ring dykes to protect Towns in the Valley, the construction of the City of Winnipeg flood control works, and the provision of flood protection to individual farms and residences by ring dykes or by raising of the structures above the design flood level. As a result of these works, a majority of the structures within the Red River Valley are now, or will soon be protected, when the present program is completed, to a minimum of the 1997 flood plus freeboard.

While the 1997 flood was the largest flood during the past century, floods greater than the 1997 flood have occurred during the past 200 years, including the 1826 flood which had a peak discharge of approximately 225,000 cfs at Redwood Bridge in Winnipeg (185,000 to 190,000 cfs

at Inlet Control Structure). The estimate of the 1:1000 year flood on the Red River, according to a Manitoba Water Resources report, is 295,000 cfs (252,400 cfs at the Inlet Control Structure). At these higher discharges, the present flood protection works would be compromised which would result in significant flooding to structures protected by these works both in the Red River Valley as well as in the City of Winnipeg. For a flood of the 1826 magnitude the discharge through Winnipeg would exceed the capacity of the existing primary dykes and would result in extensive flooding within the City of Winnipeg.

Estimates of damages from floods of a magnitude at or greater than the 1997 flood requires the development of a stage-damage model, which considers the spatial and temporal impact of the flood on the Valley. Although stage-damage relationships for individual structures have been developed in the past, the integration of the damages over the Valley has not been practical. The development of an up-to-date integrated stage-damage curve for the Valley will serve a number of valuable functions including:

1. ***Planning and design of flood protection measures***

- determine expected annual flood damage without the implementation of a flood control measure
- determine expected annual flood damage with the implementation of a flood control measure
- use the difference between the two to represent the benefit from a measure
- complete a benefit-cost analysis for a measure

2. ***Real-time emergency management***

- determine flood levels and inundation levels at each location in the flood plain
- calculate the damage at each location based on the stage-damage information
- develop priority schedule and level for temporary protection

3. ***Flood recovery***

- determine the inundation levels for damaged properties

1.2 TERMS OF REFERENCE

Based on the above requirements for stage-damage relationships, specific study objectives and deliverables were identified to demonstrate the application of the updated stage-damage curves. Four primary tasks were identified in the terms of reference:

1. Review of existing stage-damage curves and analysis of shortfalls
2. Review of available stage-damage curve information from the 1997 flood and identification of data gaps.
3. Development of current stage-damage curves for the area bounded by the 1826 flood.
4. Development of map products which demonstrate the spatial variability of:
 - flood damage risks in the Red River Basin;
 - 1997 flood damages; and
 - estimates of damages for a repeat 1826 flood event.

The primary focus of the study was on the Red River basin from Winnipeg to the US - Canada border. Similar work in the US portion of the basin was reviewed to ensure consistency of methodology across the border.

This study considers damages to buildings (structural), infrastructure (transportation and municipal infrastructure, dykes, flood fighting costs and overhead) and agricultural crops. The study does not attempt to assess damages to intangible damages such as grief, stress, disruption to life, economic losses, loss of heritage buildings and environmental impacts as these were not included in the terms of reference.

Development of the Stage-Damage relationships and map products requires a significant amount of current data. Data was made available through the International Joint Commission and the Province of Manitoba for the study as follows:

- all existing stage-damage curves
- high water marks in the 1997 inundation area
- 1997 flood damage data
- 1826 simulation results

Based upon the terms of reference and initial consultations with the Steering Committee, the following overall approach to prepare the stage-damage relationships and map products was developed and agreed upon.

1.3 OVERALL APPROACH

Geographical Information System (GIS) technology was used to fulfil the objective of presenting the estimated spatially distributed damages. Together with the development of updated depth-damage relationships, the GIS is well suited to present and manipulate geographical data to determine damages in the Valley. Input to the GIS required the collection of the appropriate data, which is located geographically (geo-referenced).

The Province of Manitoba has completed much of the work in compiling digitally geo-referenced data throughout the province. Other current digital databases, such as the Manitoba Rural Development Tax Assessment database, exist only in tabular format, and some of the data is not maintained in any usable electronic format. The overall approach developed by KGS Group to estimate the flood damage utilizes a relational database and a GIS program to assemble and manipulate the available data.

As shown on Figure 1, the various data sources were connected through the use of the GIS and the Database Data Model. The updated curves were "plugged-in" to the model to calculate the damages. The raw data was attained in digital and hardcopy formats, and significant effort was required to format and link the various sources within the GIS and data model. Since the typical depth-damage curve relates dollars damage to flooding referenced to the first floor elevation, the data model is required to determine the depth of flooding.

For the computation of structural damages, individual structures within the Valley were geographically located. Rules were developed within the data model to consider assumptions regarding existing flood protection and the elevation of the first floor (the reference floor) above the ground surface. The geographic data is queried for the inputs to the data model, which calculates the depth of flooding based upon the flood level information, the ground surface elevation and the data model rules. The depth of flooding is then related to estimated damage via the depth-damage relationship. Once damage for individual buildings was calculated, it was mapped using the GIS.

Damages to infrastructure were estimated on the basis of calibrating a functional relationship using reported damages for 1997. The relationship could then be extended to floods of various magnitudes, and for purposes of this study used to estimate damages for the 1826-type flood.

Infrastructure includes the following items:

- Municipal Infrastructure Including Sewer and Water
- Roads, Bridges, Culverts and Drainage maintenance and repairs
- Utilities including electricity, telephone and natural gas

Municipal Infrastructure would also include work to close and repair community ring dikes where they exist. Relationships were developed for relating infrastructure damage to the density of infrastructure works and population density of the flooded area. Ring dike communities were treated separately to account for closure costs, and infrastructure losses after dikes were overtopped.

The location of agricultural lands and the corresponding duration of flooding determined the agricultural damages. The delay in seeding due to flooding was related to the anticipated yield. A loss of yield can be equated to dollars of crop damage. Since the buildings and agricultural land were considered to be distributed throughout the Valley as discrete areas, the damages were summed based upon the quarter-section/river-lot grid system. The maps were then produced showing dollars, which include damage per acre of land for each land parcel in the grid.

Details associated with the compilation of the components of the stage-damage model are described in Section 2.0 and 3.0. Section 2.0 describes our review of the existing depth-damage relationships, and the development of the updated depth-damage relationships. The implementation of the geographical information system, database and data model for calculating the flood damages and developing the damage maps is described in Section 3.0.

A comparison and discussion of the modelled damages of this study to claim data from the Manitoba Emergency Management Organization's Disaster Financial Assistance program is given in Section 4.0. Section 5.0 discusses the limitations of the data available and the model, and identifies potential improvements, which could be incorporated in the future. A summary of the studies findings and recommendations are outlined in Section 6.0.

2.0 DEPTH-DAMAGE RELATIONSHIPS

2.1 APPROACH

Recent (1997) damage data was used to develop the depth-damage relationship(s) wherever possible. In fulfilment of the terms of reference, this provides real cost data for flood protection and rehabilitation or rebuilding. Previous studies utilizing depth-damage relationships were reviewed to provide background data for the updated relationships. The Province had considered a number of different damage relationships for past flood reduction studies. The majority of the existing curves were, however, not developed specifically for Manitoba or the Red River Valley. They were adopted from studies in Southwestern Ontario, Alberta and the United States. The only depth-damage relationship developed specifically for Manitoba was for the 1958 Royal Commission on Flood Cost-Benefit ("Templeton Curve")ⁱ. This study considered the past work, and analyzed the new damage data to create more representative curves. The updated depth-damage relationships also considered recent surveys by the US Army Corps of Engineers for Red River flood damage in Grand Forks and North Dakota.

2.2 STRUCTURAL DEPTH-DAMAGE RELATIONSHIPS

2.2.1 Data Sources

Although the methodology relied significantly upon the data from 1997 flood claims, other sources of data were considered, including studies performed by Manitoba Natural Resources and the US Army Corps of Engineers. A compilation of historic curves and a critique of their usage within Manitoba was completed in 1991 by the Department of Natural Resources. The

critique and compilation was attached as an appendix to the Riverton Flood Reduction Studyⁱⁱ, and included curves from several sources from Canada, the U.S. and previous Manitoba Studies.

The US Army Corps of Engineers (USACE) was also consulted based upon the recent work performed in North Dakota after the 1997 flood. The development of these damages did not consider any disaster financial assistance or insurance claims, but rather a more conventional method of estimating damages based upon national price indexing for repairs to buildings. It became apparent that these damage estimates were more conservative (lower) than data obtained from 1997 damage flood claims in Canada.

The primary source of damage data was obtained from the Manitoba Emergency Management Organization (MEMO). Since the flood of 1997, the organization has processed approximately 5000 flood damage claims, the majority of them private. Due to the limitations of the Freedom of Information Act, KGS Group was not allowed direct access to the files, and MEMO does not have a comprehensive computerized database of information. Through consultation with Mr. Murray Brown, Recovery Advisor (MEMO), damage data from a subset of the residential and farm property claims were obtained. Based upon input from the Steering Committee, it was decided that the depth-damage relationship should be developed exclusively from the MEMO data, and have a similar shape to existing curves.

2.2.2 Depth-Damage Curve Development Methodology

Damage claim data was forwarded by MEMO to KGS Group for review and analysis. Representative claims were selected on a random basis by the Manitoba Emergency Management Organization (MEMO). A total of 186 out of 5000 claims were provided for the development of the updated depth-damage relationships. The methodology for preparation of depth-damage curves for structure flood damages considered the following:

- The structures were separated into specific categories with similar characteristics. Typical structure categories included single storey residential, multi-storey residential, mobile home and commercial/industrial/public buildings.
- Residences were generally considered to have basements. Commercial, industrial and institutional buildings were considered to not have basements.
- The assessed market value of each structure was determined from the tax assessment database or from MEMO records.
- MEMO flood claims were used to determine the value of the contents losses as a percent of the building value.
- The curves developed included three components of loss as defined by MEMO: foundation, structure components and moveables. Moveables were considered to include building contents; individual pre-emptive flood fighting costs; crop inventory losses; yard restoration and other losses.

Damages were referenced to depth of flooding above the first floor level (the reference level). The relationships developed provide an estimate of damages as a percent of the market value of the structure for all depths of flooding above or below the reference level. The market value was assumed to be equal to the Assessed Value of the structure as determined by the Manitoba Rural Development Tax Assessment Branch. This general relationship then allows the application of the damage function to any structure in the building category as long as the market or assessed value of the structure is known.

The Manitoba Rural Development tax assessment database was utilized to define all possible building types. Approximately 375 unique class descriptors exist in this database defining the general classes and sub-classes of buildings. These descriptors were used to group the buildings into more general categories for application of the depth-damage relationships. The groups derived from the database are considered to be consistent with previously developed relationships utilized in previous studies by the Province. Thirteen categories were considered applicable for the analysis as they are consistent with previous work. They include:

1. Single Storey Residences
2. Multiple Storey Residences
3. Bi-level Residences
4. Mobile Home Residences
5. Attached Buildings - Residential
6. Attached Buildings (Multi Storey) - Residential (Second Storey Additions & Balconies)
7. Detached Buildings - Residential
8. Agricultural Buildings - Barns (Hog, Poultry, Dairy & Horse)
9. Agricultural Buildings - Out Buildings Granaries, Tanks, Shops, Shelters, Quonsets
10. Commercial Buildings - Apartments
11. Commercial Buildings - General
12. Commercial Buildings - Agricultural & Service
13. Government Buildings

It became apparent that the 1997 Flood damage data would not support the construction of updated depth-damage relationships for all of the above categories. The capability to input the various relationships was, however, incorporated into the model should future relationships be developed.

Attempts were made to acquire as much damage claim data for each structural category, but two significant problems with the MEMO data became apparent as the data was being transferred.

- MEMO's records did not distinguish between the desired types of structures effectively within the claim file. The claim data was compared to the tax roll to ensure that the damage data was assigned to the proper residential category.
- No claims were forwarded from MEMO for bi-level residences. Since the data did not vary significantly between single and multi-storey residences, damages for bi-level residences were estimated using the single storey residence depth-damage relationship.

Very few commercial/industrial claims were processed, and the information forwarded to KGS Group for the study was considered not to be representative of typical commercial buildings. Since no new depth-damage curves in this category could be developed using MEMO data, the single storey residential curve was used as a basis to estimate damages. This approach was considered reasonable for the following reasons:

- Previous studies indicate that "few differences between structural damages to residential and commercial buildings and only slight differences were evident for damages to commercial buildings of wood exterior and brick, stone or concrete block exteriors"ⁱⁱⁱ.
- In rural areas, construction of commercial and light industrial buildings is considered to be similar in nature to housing and agricultural buildings (i.e., wood frame construction).
- Previous studies indicate that commercial/industrial buildings should be assessed on a case by case basis. This approach was considered to be beyond the scope of this project, but could be considered in future refinements of the model for estimating damages.
- Although MEMO does not necessarily accept claims from all types of businesses and industry, once accepted, the claim is handled similarly to all other types of claims. Therefore, it is anticipated that claims paid would also be similar.
- Precedent has been set for the application of the residential curve to commercial buildings by the Ad Hoc Task Force on Manitoba Flood Mitigation Projects^{iv}.

2.2.3 Depth-Damage Relationships

Figures 2 to 6 show the damage data from the 1997 flood, and the curves used for this study. As can be seen significant scatter exists in the data, making the development of the relationships difficult. To be consistent with previous studies, the general shape of the curve was assumed to be similar to other depth-damage relationships. Damage data points, which deviate significantly from the chosen relationship line, are considered to be outliers.

In general, the depth-damage relationships developed show that the damages exceed the market (assessed value) of the home as the flood depth increases beyond the first floor. This trend is consistent with previous studies, but the slope of the MEMO data relationship is greater than previous curves. As an example, the single storey residence curve developed for this study is shown on Figure 7 in comparison to the "Templeton Curve" developed for the Royal Commission on Flood Cost-Benefit. The new relationship has significantly higher percentages of damages up to 6 feet above the first floor. The largest variation occurs at the first floor level where the new curve predicts damages at approximately 110 percent of market value as opposed to approximately 30 percent for the "Templeton Curve". There are likely a number of reasons for the differences including the increase in developed basements in homes, and a changing political view of compensation for flooding upstream of Winnipeg.

As can be seen in the curves, the relationships were developed as "piece-wise" linear relationships. These relationships were digitized for use in the computer data model and related the depth of flooding to the assessed value of the structure. As described above, no curves could be developed from the data for commercial, industrial or institutional buildings. The

damages for these building were calculated based upon the single storey residence curve shown on Figure 2.

Two possible relationships were developed for agricultural out buildings based upon the 13 data points provided by MEMO (see Figure 6). It was decided to calculate damages based on both curves to test the sensitivity of the results to the data model. Since this category of building does not constitute a large value with respect to the total value of all buildings, it was assumed that the results will not be particularly sensitive to a large variation in the damages shown by the two curves on Figure 6. The results of the sensitivity analysis are provided in Section 4.0.

2.3 INFRASTRUCTURE DAMAGE RELATIONSHIPS

Reported Infrastructure damages for 1997 were used to develop relationships for estimating damages for floods of various magnitudes. Infrastructure damages were assessed to include all transportation and civil infrastructure, as well as utility infrastructure. Transportation and civil infrastructure damages include community ring dikes, roads, bridges, culverts, drains, ditches, and municipal infrastructure such as sewer and water works.

Relationships were developed to relate infrastructure damage to the density of infrastructure works and population density of the flooded area. Ring dike communities were treated separately to account for dike closure costs, and infrastructure losses after the dikes are overtopped.

2.3.1 Data Sources

Municipal infrastructure damages were based on claims made to MEMO. The claim files are not in digital form, but total claims paid to each municipality were readily available. Claims were paid for the actual costs of repairs made to infrastructure under the jurisdiction of the municipality including municipal roads, sewer and water, dikes, drains, culverts and bridges. Claims were categorized as site specific and non-site specific, and each category comprised a significant portion of the total claims paid. All claims are in paper files, only municipal totals were digitally logged. MEMO personnel provided a partial breakdown of infrastructure damages by Municipality. The breakdown included general categories for pre-emptive flood fighting costs; transportation and municipal infrastructure damages; as well as overhead.

The Manitoba Departments of Highways and Conservation provided data for the balance of the civil infrastructure damages. The Highways Department has a summary of work performed, which details all post 1997 flood repair works. Manitoba Conservation maintained a database of information, which was specific to each sub-drainage basin in the Valley. This data was then grouped by municipality.

The utilities (MTS, Centra Gas and Manitoba Hydro) did not receive compensation under the MEMO disaster financial assistance program, but they made their records available. The information from the utilities was limited, and not site specific. In general, the utilities were able to save most of their infrastructure with effective pre-emptive flood fighting. The utilities provided information at a general level specifying total dollars spent both for flood fighting and repair.

Table 1 lists the reported infrastructure damages provided by each agency:

Table 1: Reported 1997 Infrastructure Damages by Data Source

<i>Agency</i>	<i>Total Damages Reported</i>
Manitoba Emergency Management Organization	\$ 33,494,430
Department of Highways	\$ 8,905,000
Department of Conservation	\$ 3,414,000
Manitoba Telecom Services	\$ 1,276,814
Centra Gas	\$ 170,000
Manitoba Hydro	\$ 120,000
Total	\$ 48,480,045

As can be seen in the table, the damages to utility infrastructure are a small percentage of the total infrastructure damages. The damages reported by Centra Gas and Manitoba Hydro may not be complete, but is based on the available data provided. The total value of reported infrastructure damages shown on the table represents the estimated infrastructure damages within the study area. Damages were also recorded and paid for in areas outside the flooded area, such as damages to road crossings and drainage channels to upstream tributaries of the Red River. Damages outside the 1997 flooded area were not included because they were considered to be outside the flooded area.

Since the data from all sources was not in digital form and each agency logged the location information differently, or not at all, it was necessary to aggregate reported infrastructure damages by municipality. Since the level of damage was known only for each municipal jurisdiction, the spatial distribution of damages was estimated using functions, which relate the distribution of infrastructure to the flooded area.

2.3.2 Methodology

Since the data was provided with varying levels of detail and information regarding the location of damages, the information was divided into three categories to prepare a damage function. The data was arranged such that rural municipalities, community ring-dike towns, and utility damages could be divided separately by jurisdiction. Table 2 itemizes the expenses for each category.

Table 2: Reported 1997 Infrastructure Damages by Jurisdiction

<i>Jurisdiction</i>	<i>Reported Damage</i>
Rural Municipalities	\$ 42,797,962
Community Ring Dike Towns	\$ 4,115,268
Utilities	\$ 1,566,814
Total	\$ 48,480,045

Each jurisdiction was treated separately to provide a better assessment of damages throughout the study area.

The data was analyzed to determine the damage relationship factors that are best correlated to recorded damages. The following factors were considered:

- Extent of Flooding
- Depth of flooding
- Duration of flooding
- Amount of infrastructure works
- Population density

Relationships were developed on the basis of aggregate damage over the municipality, and the above factors. Table 3 below lists the infrastructure damage costs for each municipality separated into the two main categories of costs – Pre-emptive flood fighting (diking and cleanup) and infrastructure (roads, bridges, culverts, ditches, sewer and water).

Table 3: Reported 1997 Infrastructure Damages by Municipality

	Damage Costs		
	Diking, Cleanup & Misc.	Roads, Ditches, Crossings, S&W	Total
De Salaberry	\$ 211,615	\$ 634,587	\$ 846,202
Franklin	\$ 196,881	\$ 2,322,633	\$ 2,519,514
Hanover	\$ 21,038	\$ 546,958	\$ 567,996
MacDonald	\$ 953,449	\$ 2,454,972	\$ 3,408,421
Montcalm	\$ 562,688	\$ 2,934,481	\$ 3,497,169
Morris	\$ 2,980,659	\$ 11,844,831	\$ 14,825,490
Rhineland	\$ 399,567	\$ 722,854	\$ 1,122,421
Ritchot	\$ 7,767,764	\$ 6,815,891	\$ 14,583,655
Springfield	\$ 264,670	\$ 316,839	\$ 581,509
Tache	\$ 449,339	\$ 396,248	\$ 845,587
	\$ 13,807,670	\$ 28,990,294	\$ 42,797,964

Following a review of the related factors, it was apparent that the best correlation of damages to infrastructure works (shown on Figure 8) exists with the total length of roads in the flooded area of the municipality. This is because road, ditch and water crossing repairs make up the largest portion of the damage costs. As can be seen on Figure 8, the length of roads flooded in each municipality correlates well with recorded damages.

Figure 9 shows a graph relating the number of residences in the flooded area of each municipality to the amount of pre-emptive and post-flood fighting costs incurred by the municipality. The number of residences flooded correlates well with the pre-emptive and post flood costs. The relationships shown on Figures 8 & 9 were used the basis for distributing

infrastructure damages throughout the municipalities. Because the amount of infrastructure and the number of residences flooded is directly related to the extent of flooding, the relationships developed can be utilized for simulating damages for other flood magnitudes.

For the community ring-dike towns, a depth-damage function was developed to estimate incremental damages to the town's infrastructure. As shown generically on Figure 10, the damages are shown as a percentage of the reported 1997 damages, which are primarily pre-emptive and post-flood clean-up costs. The 1997 flood damages are considered representative of 100 percent of flood fighting costs because most community ring dikes were at their design limit, and some had to be temporarily increased in height.

Base level costs at incipient flooding are estimated to be 5 percent of the total closure costs. The costs or damages then rise linearly to the 100 percent of the 1997 damage at the top of the dike. This relationship was developed based on a review of the Town of Morris Ring Dike Operations Manual, which indicates that at incipient flood levels minor costs are incurred for dike inspections and pump testing. As flood waters rise the dike is closed at successive intervals, which are estimated to increase the total costs linearly.

Should a larger flood breach the dike, infrastructure damages were assumed to be \$17,000,000.00 per square mile where infrastructure is concentrated within the dike, not necessarily the total area enclosed by the dike. The damage per square mile is based upon the US Army Corps of Engineers (USACE) estimate of infrastructure damages in Grand Forks, and is considered representative of the Valley towns, which have similar topographical conditions and distribution of infrastructure. The same figure was used for the Winnipeg Flood Risk

Assessment Study (KGS Group 1999/2000), and includes damages to transportation infrastructure, sewer and water plus utilities.

Although it may be possible to temporarily raise community dikes above the 1997 levels, once a dike is breached the level of infrastructure damage is assumed to be constant as shown on Figure 10. The vertical line at the right of the chart represents the infrastructure damages shown as a variable percentage (X%) of the 1997 flood costs. Table 4 lists the 1997 damages for the community ring-dike towns, and the total potential damages after the dyke is breached. The total potential damages are also expressed as a percentage of the 1997 costs, which can then be equated to the vertical line on Figure 10. The table shows a wide variation in the amount of damages to each town. Therefore, each town will be considered independently within the damage model.

Table 4: Infrastructure Damages to Community Ring-Dike Towns

Community	Total Reported 1997 Damages	Total Potential Infrastructure Damages	% Total of 1997 Infrastructure Damages
Emerson	\$ 1,231,490	\$ 5,389,990.25	438%
St. Jean-Baptiste	\$ 300,000	\$ 3,299,015.08	1100%
Morris	\$ 1,011,100	\$ 12,533,935.97	1240%
Lettelier	\$ 190,000	\$ 2,070,111.95	1090%
Brunkild	\$ 175,000	\$ 612,007.70	350%
Rosenort	\$ 260,000	\$ 2,264,804.40	871%
St. Adolphe	\$ 515,000	\$ 4,142,702.00	804%
Dominion City	\$ 205,000	\$ 3,384,148.41	1651%
Niverville	\$ 227,678	\$ 7,332,294.26	3220%
Roseau River*	N/A	\$ 5,966,730.60	
	\$ 4,115,268	\$ 46,995,740.63	

* 1997 Damages were not reported.

2.4 AGRICULTURAL DAMAGE RELATIONSHIPS

The assessment of agricultural flood damages was similar to the approach used in 1958 by the Royal Commission on Flood Cost Benefit. The damage assessment calculates damages to crops as a result of typical or average flood conditions. Damages assessments are based upon the delay to seeding as a result of flooding, and the corresponding effect of the delay on the crop yield.

Damage data from the 1997 flood was not considered to be representative of a "typical flood" because the flood receded much more rapidly than previous large floods. As a result, farmers were able to plant shortly after the flood recession. As well, the fall weather of 1997 was favourable, and crop yields were above average. Following discussions and review by the Steering Committee, it was decided not to calibrate the damage model to the 1997 flood since the actual agricultural damages incurred were negligible. On the basis of a review of the data and discussion with the Steering Committee, a more general approach to assess damages for average flood conditions using average post flood conditions, and average crop yield relationships based upon historical data was considered.

It was assumed that the yield curves account for all possible variables that can effect a crop including spring flooding, precipitation, frost and all other weather conditions which have an effect on yield production of crops. The yield curves account for historical trends in the production of crops as a function of the earliest seed date, and thus are considered representative for the analysis.

2.4.1 Data Sources

Data sources for crop yield, crop distribution, crop prices and land use data were available from various governmental departments in Manitoba. The Manitoba Crop Insurance Corporation (MCIC) provided background information for the general crop distribution for the Red River Valley. The entire study area is considered to be within the MCIC Risk Area 12 as shown on Figure 11. The department also provided historical average yield curves for the major crops planted in the region, and average pricing for the years from 1997 to 1999. The Manitoba Department of Agriculture was also consulted on pricing and provided similar data to that forwarded by MCIC.

The Surveys and Mapping Branch of the Department of Natural Resources provided land use classification maps digitized from remote sensing images. The maps were used to determine the areas of cropland in the study area.

2.4.2 Methodology

Agricultural damages were based upon a relationship that related depth of flooding to the first date of seeding and the expected yield for the crops. The percent yield was then related to damages via reduction in yield and loss of crop income.

Assessment of damages needs to consider the spatial and temporal variability of the Stage hydrograph. As floods recede, the highest points of land in the Valley become exposed first and are ready to seed before land, which is lower and closer to the river. Illustrated schematically on Figure 12, as the water recedes from parcels of varying ground elevation (Parcel 1 prior to

Parcel 2) a higher average yield for crops on the land for Parcel 1 can be expected, and therefore, less damage due to flooding.

A drying period is added after recession of the flood from the land. A period of fourteen days was used, which included the likelihood of at least one rainfall event during the drying period. This assumption is less conservative than the approach used by the Royal Commission, which assumed 4 weeks of drying time before seeding could take place. The sensitivity of agricultural flood damages to this parameter could be considered in future work. For example, if a more detailed analysis of post flood precipitation and soil conditions justifies lengthening the drying period, the parameter can be extended. By manipulating the drying period parameter the model can be used to re-assess agricultural damage for a particular post flood scenario.

It was originally proposed to segregate the Red River Valley into reaches, and apply a single hydrograph (such as shown in the figure for Morris, MB) for each reach to assess damages. As part of a separate study, Klohn-Crippen developed a 1-D hydrodynamic model of the Red River Valley. Through discussions and the approval of the Technical Steering committee, it was agreed that the results of the MIKE-11 hydrodynamic model would be incorporated into methodology for calculating agricultural damage using the GIS model. The Mike-11 model produces hydrographs at each location (within a grid) in the Valley using a geographical information system (GIS) module. The grid was linked to each parcel of land, which was in turn used to determine the flood recession date.

Using this approach, the value of damage per acre for each type of crop can then be related to a given flood event. Since the methodology depends upon the Stage hydrograph for a given flood, it can be dynamically linked to the flood simulation output from the Mike-11 model.

2.5 CITY OF WINNIPEG

The terms of reference for the study included the preparation of a cursory damage estimate for the City of Winnipeg. The approach taken utilized the City of Winnipeg GIS system and was similar to that considered in the Valley. The City of Winnipeg Water and Waste Department provided flooded area maps and building inventory information from their geographical information system to be used for the estimate. The 1997 flood damage estimate was calculated from reported costs for flood fighting efforts and subsequent infrastructure damage costs by the City, as well as flood fighting costs estimated for the involvement of the Canadian Military. Flood claim amounts paid by MEMO were also added into the damage costs. All damages for the 1997 flood were assumed to occur within the primary line of defence (PLD) dyke system.

A summary of the building inventory within the 1826 flooded area was also provided. The flooded area was estimated to be at an equivalent elevation of 30.3 feet James Avenue (sloping gradient throughout Winnipeg) as calculated using the existing flood protection water surface profiles in the City (the reference level at James Avenue is 727.57 feet above mean sea level). The flooded area shown on Figure 13 was established in consultation with the City of Winnipeg, the Water Resources Branch and the Steering Committee. Although the actual elevation could range from 29.5 to 31.5 feet depending upon a more detailed analysis, this level was considered to be representative of conditions which would be experienced during a repeat 1826 flood event.

An additional perimeter area representing basements within 6 feet of elevation of the flood level (shown in yellow on Figure 13) was included in the analysis to account for basement flooding of residences due to inundation of the wastewater sewer system and the associated sewer backup. Although there would be no overland flooding in this area, the basements of homes

could be flooded as they would be below the flood level. This flood scenario is illustrated in Figure 14. The data transferred to KGS Group from the City's Water and Waste Department is included in Appendix A.

Sewer backup protection was not considered in the estimate since there was no way of determining which buildings were protected. The estimate is, therefore higher than what may be expected, but represents an estimate of highest potential damage.

To prepare the cursory estimate of damages based on generalized flooded area and building inventory, a number of assumptions were made while maintaining consistency with the methodology used for the Red River Valley to the south. These assumptions include the use of the depth-damage functions developed for the Valley and are listed below:

- The single storey residential depth-damage curve was used for all single family dwellings, and other residential buildings. No distinctions between residential building types were possible with the data provided. The depth-damage curve used is considered representative, as the damage function for single and multiple storey residences are similar in shape and magnitude of damage.
- Total assessed value for commercial, industrial and institutional buildings was assumed to reflect actual market value although the majority of these buildings are assessed based upon an income derived formula.
- Since the total assessed value provided in the data includes the value of the land. Average land values for each building category were obtained from the Tax Assessment Department and subtracted from the total assessed value.
- The average depth of flooding in the inundated area (30.3 James Avenue) for residences was considered to be 1 foot above the first floor level, which corresponds to a damage factor of 125 percent for the building and contents.
- The average depth of flooding in the basement flooded area was considered to be -6 feet below first floor level, which corresponds to a damage factor of 50 percent for the building and contents.
- Commercial, industrial and institutional buildings were assigned similar damage factors as residential buildings based upon the application of the depth-damage relationships for the rest of the study area. These factors are also consistent with

MEMO guidelines and other US Federal Insurance Agency (FIA) studies, which have found that damages range from 50 to 125 percent for equipment and inventory alone. When the building structural damage is considered in conjunction with equipment and inventory at an average flooding depth of 2.5 feet, a 145 percent damage factor is believed to be reasonable.

3.0 DAMAGE CALCULATIONS AND MAPPING

3.1 OVERALL APPROACH

The terms of reference for the study include the presentation of the damage estimates for repeated floods of the same magnitude as 1997 and 1826. Geographical Information Systems (GIS) is an effective software tool, which can be used for the presentation and manipulation of spatial and temporal data for products of this type. Arcview version 3.1 GIS software was used to assemble and present the geographical data, and link it to the external database and data model. It was necessary to utilize an external database to prepare data for input to the model due to limitations in the available data. The primary function of the GIS was to link the spatial attributes of the data, and present computed results for mapping purposes.

Once all damages are assessed for both structural and non-structural losses, the damages can be presented in a thematic map of the Red River Valley including the City of Winnipeg. The approach taken to calculate a damage estimate for each flood, and preparation of the maps using geographical information systems is described below.

3.2 STRUCTURAL DAMAGES IN THE RED RIVER VALLEY

3.2.1 Data

To calculate the damage at any building site the following data is required:

- Type of building
- Assessed value
- Reference flood elevation (i.e. first floor of building elevation)
- Elevation of dyke (where applicable)
- Elevation of water
- Depth-Damage Relationship

Data was obtained from several sources including Manitoba Natural Resources Surveys and Mapping Branch, as well as the Water Resources Branch. The primary source of building inventory in the Red River Valley was obtained from the tax assessment roll, which was provided by Manitoba Rural Development.

The Surveys and Mapping Branch provided the quarter-section / river lot grid, which represents the Dominion Land Survey (DLS) grid of the Valley. It was used to aggregate all data, and is representative of the resolution of the calculated damages which can be practically attained for mapping purposes.

Surveys and Mapping also provided digitized land parcel maps for several towns and villages in the Valley. The data represented a unique Parcel Identification Number for each land parcel in the following towns:

- Ste. Agathe
- St. Adolphe
- St. Jean Baptiste
- Morris
- Emerson
- Grande Pointe including the Floodway Area (attribute data not currently available)

The data was used to more precisely locate buildings in the GIS providing accurate positional information for the buildings associated with each land parcel.

The tax assessment or building information database was received in tabular format that has only location descriptors and no exact reference geographically. Each building has been categorized, and has a 1995 assessment value assigned to it. The location of the buildings is represented by a legal description, which for most buildings (approximately 70%), can be referenced in the GIS by river lot/quarter section or lot-block-plan description. In the case of lot-block-plan description, damages were calculated based upon the location of the land parcel, but aggregated to the river lot/quarter section grid. Since this data set has the most current inventory of buildings in the Valley, which are categorized and assigned a value, it was decided to use this data as the primary source of building information.

Approximately 70 percent of the buildings listed in the Rural Development database were linked to the GIS as described above. The remaining 30 percent were geographically located by manually interpreting paper based parcel maps, and in consultation with regional Rural Development personnel. The resulting process linked nearly 100 percent (89 of 56966 buildings were not referenced) of all buildings in the study area to the GIS quarter-section and river lot grid system.

The Rural Development database was linked to the GIS system by one of two identifiers: Quarter Section / River Lot Grid or Land Parcel ID (lot-block-plan). Thus, a portion of the buildings were considered to have an accurate position (5%), while the rest could only be considered to be at the centre of a particular quarter-section or river lot. Over time and with the commitment by the responsible government departments, this data could be upgraded to be 100% accurately geo-referenced where every building has exact positional information (i.e. UTM co-ordinates plus a reference elevation).

The Surveys and Mapping branch have geographically located (in GIS format) constructed dykes and pads in the Valley, which have an associated, permit record. The data file contains both dyke & pad height elevations, as well as ground surface elevations both inside and outside of the dyke. In addition to private or individual dykes or pads, community dykes were digitized from as-built drawings and digital ortho images provided by Natural Resources.

The geographical referencing is illustrated on Figure 15, which shows building centroids located in and around Morris, Manitoba. As can be seen on the figure, building centroids in the Town of Morris are situated within their respective property limits. The buildings outside Morris, however, cannot be located better than the centroid of the quarter-section or river lot because the tax assessment information is not consistent or does not correlate with the quarter-section / river lot grid. In some cases, the building position does not correlate well with the positioning of the flood protection structures. With additional data, it would be possible to address these discrepancies to better correlate building location and flood protection structures. This work was considered to be beyond the scope of this study, but should be considered for future improvements to the model.

Because a majority of the buildings are not accurately positioned, rules and assumptions were developed to relate the position of the building to other required information to calculate damages such as, depth of flooding and flood protection status.

Other data which was available from the Surveys and Mapping Branch was geo-referenced, but was considered inappropriate because it was not up-to-date (1988-1990). As well, the building information in this data set was not classified in a consistent manner with the tax assessment data, and no building value attribute was associated with the data.

Ground and flood levels were forwarded from Klohn-Crippen in GIS grid format. The digital elevation model (DEM) and peak flood levels were used to determine the depth of flooding throughout the study area.

3.2.2 Damage Calculation Model

The damage calculation model is required to determine the depth of flooding at each structure, which was then related to damage through the established depth-damage relationships. The depth of flooding calculation considered three inputs to determine the depth of flooding at each building:

1. Flood Protection Status
2. Reference floor elevation
3. Ground and water surface elevations

The flow diagram shown on Figure 16 illustrates the process for calculating the damages based upon the models' rules and assumptions. The objective of the model is to account for the flood protection status of all buildings regardless of whether or not they are accurately positioned geographically. The basic steps are as follows:

- Establish flood protection level, if any
- Calculate the depth of flooding based upon the digital elevation model, flood data, and first floor height of the building
- Apply the appropriate depth-damage relationship to determine the damage as a percent of market value, and then multiply this factor by the assessed value of the building to calculate damages
- Apply a damage adjustment factor based upon the position accuracy of the building

As can be seen on Figure 16, buildings are not automatically assumed to be protected if a flood protection structure exists on the land. Although the dykes and pads were accurately positioned within the GIS, approximately 95 percent of buildings were not. Rules regarding the number of buildings or structures within a dyke or pad were based upon information from the permit applications for flood protection structures filed at the Water Resources Branch.

Damage adjustment factors for each type of building were developed based upon the above information. For example, if 8 agricultural out buildings (granaries, sheds, etc.) existed on a quarter-section with one dyke, the probability of the buildings being protected within the dyke was assumed to be 95%. Damages were then calculated assuming no protection, and then reduced by the damage adjustment factor. All damage adjustment factors are provided in Appendix B.

Regardless of the building's flood protection status, the flood protection level for the parcel of land is determined next. No damage adjustment factors were applied to buildings if the flood level was above the flood protection level.

Using the flood protection level, the ground surface elevation, the flood level and the height of the building's first floor above the ground, a depth of flooding above first floor can be computed. Where building position was not considered to be accurate, average elevations were used for the land parcel and input into the model. Otherwise, the elevations relevant to the position of the building were used. The depth of flooding was determined by considering if the protection structure was overtopped. If not, the damage was automatically set to zero. If the flood protection structure was overtopped, or non-existent, the depth of flooding above the first floor was calculated as follows:

$$DOF = WS - (GR + FFH)$$

where: *DOF* = depth of flooding above first floor
WS = water surface elevation
GR = ground surface elevation
FFH = height of first floor above ground surface

The depth of flooding calculation is executed at all locations where the water surface elevation is greater than the ground surface. That is, if no flooding of the land exists at a particular building location, it is assumed that no damage occurs. This statement is valid for buildings, which are both protected and unprotected by permanent flood protection structures.

Rules were also developed to estimate the height of the first floor of a building above the ground elevation. The flood protection structure application also contained information regarding the first floor elevation. From the sample reviewed, floor heights for the chosen building categories were developed based upon the averages from the samples. Since floor heights differed for buildings within dykes as opposed to those on top of elevated pad structures heights rules were generated for each possible situation. For example, homes inside dyke structures were assigned a first floor height of 4.5 feet above the ground, but were assigned a value of 3 feet if they were built on top of an elevated pad. Homes with no flood protection were assumed to be 4.5 feet above the ground. The estimated floor heights for all building types are included in Appendix C.

The last step utilizes the depth-damage relationship for the building to compute the damage as a percent of the buildings assessed value. This percentage is multiplied with any applicable adjustment factor and the assessed value to determine the estimate damage for the building.

The adjustment factor considered that the tax assessment data is based upon 1995 values. Damages were adjusted to 1997 values using a Consumer Price Index (CPI) of 1.033.

3.2.3 Infrastructure Damages

To calculate and distribute damages to infrastructure throughout the municipalities, total infrastructure damages for each municipality were calculated using the relationships shown on Figures 8 and 9. The functions are provided below:

$$CIVDAM = 18.889 * L^2 + 261.25 * L + 300000$$

$$PREDAM = 2.55 * (NUMRES)^2 + 4280 * (NUMRES)$$

where:

CIVDAM = Total Civil Work Damages in the Municipality including roads, bridges, culverts, drainage channels and sewer and water infrastructure

L = Total Length of Roads in the Municipality within the flood zone

PREDAM = Total Pre-Emptive and Post Flood Recovery damages in the Municipality including administration overhead

NUMRES = Total Number of Residences in the Municipality within the flood zone

After calculating total damages for the Rural Municipalities, the damages were distributed spatially based upon the density of the civil works, and houses that require flood fighting. Infrastructure damages calculated for each municipality were distributed to each quarter section or river lot in the flooded area. The total infrastructure damage per quarter section or river lot was assessed on the amount of infrastructure (roads, etc.) and residential buildings associated with the land parcel. Damages assigned to each parcel were based upon the following ratios:

- Transportation and Civil Works Damages per quarter section/river lot parcel was estimated on the basis of the ratio of the length of roads on the parcel and the total length of roads in the Municipality. The ratio was then multiplied by the total Transportation and Civil Works Damages calculated for the Municipality from the function shown on Figure 8.
- Pre-emptive and Post Flood Recovery damages were assessed based on the ratio of the number of houses on a particular land parcel and the total number of houses in the municipalities flooded area. The ratio was then multiplied by the total Pre-emptive and Post Flood recovery damage calculated for the Municipality from the function shown on Figure 9.

To be consistent with the structural damage calculations, infrastructure damages were normalized over the parcel area, and presented as damage per acre of flooded area.

Since most rural mile roads lie between land parcels (quarter sections), it was necessary to associate east-west roads with the quarter section to the north. North-south roads that are west of the Red River were associated with the quarter section to the west, and roads on the east side of the Red River were associated with the land parcel to the east of the road. These association rules were necessary to ensure that duplication of damages was not included for adjacent parcels.

The prorated damages were calibrated for the 1997 flood, and calculated for the 1826 flood using the same relationships on Figures 8 and 9 over the larger flood extents. Although the relationships shown on the figures are exponential equations, they represent the best correlation to the data obtained. It is possible that the extrapolation of the curves may over estimate infrastructure damages, but the estimates would be consistent with the established relationship. Future work to improve the model could review the relationships to determine the accuracy of any extrapolated damage estimates.

The GIS system was used to distribute damages based upon road and population (related to residential building) density throughout the study area. Future refinements could be used to incorporate a more detailed analysis of infrastructure damages.

Infrastructure damages to utilities in the Valley amount to 3.3 percent of the total infrastructure damages. This percentage was added directly to the damages assessed to each land parcel in the flooded area for all municipalities.

Total infrastructure damages for the ring diked communities were calculated by adapting the reported and potential damages shown on Table 4 into the generic depth-damage relationship shown on Figure 10. For example, The model shows that for a repeat 1826 flood, the St. Adolphe ring dike is over-topped, which would result in total infrastructure damages of approximately \$4.1 million (804% greater than 1997 damages). The total damage number was then divided by the total area of the dike to express it as **dollars damage per acre**. The normalized damage figure was then assigned to each land parcel within the dike for mapping purposes.

3.2.4 Agricultural Damages

The general approach to calculate agricultural damages due to flooding was described in Section 2.3. Incorporation of the methodology within the data model utilized the following spatial data within the GIS:

- Land use classification from satellite imagery
- Results of the Mike-11 hydrodynamic simulation

As well, the data model utilized the table for typical crop distribution and pricing in the valley. These, together with the yield curves, were considered by the Manitoba Crop Insurance Corporation as having a typical crop distribution as shown on Table 5. Also, shown on the table is average pricing for 1997, 1998 and 1999.

It was assumed that each land parcel would have the potential to have any of the crops within the distribution, so the same distribution was given to the area of agricultural land within each quarter-section or river lot. The land-use classification satellite imagery was interpreted to calculate the agricultural area on every quarter-section and river lot in the study area.

The Mike-11 results were interpreted to determine the first date that the flood receded from the inundated land. The Mike-11 model did not accurately predict the recession of the flood. As can be seen in Figure 17, the model stage hydrograph at Morris shows a recession limb, which recedes faster than that actually measured during the 1997 flood. The amount of error varies as the stages decrease. The shape of the hydrograph shown in Figure 17 was assumed to be consistent for all points in the Valley, and a factor to adjust the date of flood recession from the land was developed from the comparison of the two hydrographs. The adjustment factor was a function of the date that the model predicted, and it ranged from 0 to 9 days.

After the date of recession was adjusted, 14 additional days were added to the date to allow the land to dry sufficiently before being available for seeding. The seed date was then related to the expected yield by the curves. The damage was calculated as follows:

$$D = \sum_{crop} [(1 - YIELD) * (CP) * A * PRICE]$$

where:

- D* = agricultural damages (\$/acre)
- YIELD* = expected yield (fraction of optimum) as a function of seed date (bushels/acre)
- CP* = crop percentage of typical distribution
- A* = area of cropland (acres)
- PRICE* = three year average price of crop (\$/bushel)

Hundred-weight or other yield measurements were substituted for bushels where applicable.

The damages were aggregated over the desired grid of quarter-section and river lots, and for mapping purposes were normalized as **dollars damage per acre** for the land parcel. The damages could then be added to the normalized structural damages.

3.2.5 City of Winnipeg

Damages for the City of Winnipeg were based upon the approach described in Section 2.3. Damage estimates were computed for the 1997 and 1826 floods.

For 1997, the flooded area was assumed to be contained within the City's primary dyking system with some additional flooding south of the floodway. The damage estimate was calculated from actual costs incurred by the City and EMO claims paid out.

The 1826 flood damage estimate was based upon assumptions for average flood depth and the application of the depth-damage relationship developed for single storey residences in the Valley. For a repeat 1826 flood, damages were calculated for the inundated area, as well as a perimeter area, which accounts for the possibility of basement flooding.

The damages were then normalized over the respective flood zone areas and presented as dollars damage per flooded acre to be consistent with the methodology for presenting the damages in the Red River Valley. The damage estimate includes damages for building structures and contents only. Agricultural damages inside the City were considered negligible in comparison to the structural damages and were not included in the estimate.

4.0 DAMAGE ESTIMATES AND MAP PRODUCTS

4.1 1997 FLOOD DAMAGE SIMULATION

A summary of the structural damage estimates produced by the stage-damage model simulation for a repeat 1997 flood is shown on Table 6. The damages are summarized by municipality and compared to MEMO claims paid. The total for MEMO claims paid shown on the table is a portion of claims paid within the study area. Since the disaster financial assistance program was administered province wide, the total claims paid by MEMO is larger than the total shown below.

Table 6: Estimated Structural Damages for a Repeat 1997 Flood

Municipality	MEMO	Estimated Damages for 1997		Maximum Difference
	Claims Paid	(1)	(2)	
De Salaberry	\$ 2,160,358	\$ 7,671,845	\$ 7,685,541	\$ 5,525,183
Franklin	\$ 1,805,183	\$ 1,288,088	\$ 1,499,369	\$ (517,095)
Hanover	\$ 284,859	\$ 365,409	\$ 365,409	\$ 80,549
Montcalm	\$ 6,573,068	\$ 6,573,040	\$ 7,204,071	\$ 631,003
MacDonald	\$ 3,583,974	\$ 4,286,223	\$ 4,404,378	\$ 820,404
Morris	\$ 11,787,223	\$ 26,196,091	\$ 27,858,052	\$ 16,070,829
Ritchot	\$ 38,958,346	\$ 58,044,751	\$ 58,707,044	\$ 19,748,698
Rhineland	\$ 1,741,432	\$ 381,558	\$ 385,663	\$ (1,355,769)
Springfield	\$ 306,406	\$ 75,109	\$ 75,109	\$ (231,297)
Tache	\$ 1,461,609	\$ 255,390	\$ 255,390	\$ (1,206,219)
Town of Emerson	\$ 180,877	\$ 732,038	\$ 732,899	\$ 552,022
Town of Morris	\$ 92,492	\$ 125,249	\$ 125,249	\$ 32,757
Town of Niverville	\$ 12,985	\$ -	\$ -	\$ (12,985)
Total	\$ 68,948,812	\$ 105,994,789	\$ 109,298,172	\$ 40,349,361

Notes:

1. Estimated Damages for Agricultural Out-buildings was based upon Curve #1 - Figure 6
2. Estimated Damages for Agricultural Out-buildings was based upon Curve #2 - Figure 6

There is considerable variation in the difference between the claims paid by MEMO and the estimates for flood damages calculated by the model. The model appears to over estimate the damages except for the municipalities on the periphery of the flooded area. The municipalities of Franklin, Rhineland, Tache and Springfield show estimates below the claims paid, because the Mike-11 results under estimate the flooded area compared to what actually occurred in 1997.

Although the model accounts for permanent flood protection structures, the other municipalities show damage estimates greater than the MEMO claim values. This is especially evident in De Salaberry, Morris, Ritchot, and the Town of Emerson where the damage estimate is up to 3.6 times greater than the claims paid. Calculated damages are high because the data model does not account for possible damage reductions due to pre-emptive flood fighting measures taken before a flood occurs. Since many temporary dykes were constructed at the time of the 1997 flood, many buildings were saved from damage. With the exception of the Town of Niverville, temporary dyking during the flood is not considered in the model, because no documentation exists which can be readily adapted into the model. The results indicate the reduced damages, which occur as a result of the flood fighting efforts of the Valley residents. Further analyses could incorporate more of the pre-emptive flood protection structures if data was available.

The model includes approximately 1013 permanent flood protection structures, which include residential pads and dikes, as well as the existing community ring dikes. The data set represents known structures as of April 15, 1999, and much work has been done since then to improve the flood protection status of many buildings in the Valley. The Province is also progressing towards further protection for many of the Valley Towns and Villages including: Rosenort; Ste. Agathe, Niverville and Grande Pointe. Once these projects are completed under

the Canada-Manitoba Partnership Agreement on Red River Valley Flood Protection, they should be implemented as input in the model, to determine their impact on damage estimates.

For the Town of Niverville a temporary dyke was constructed during the flood of 1997. As reported by the Town's Chief Administrative Officer, Mr. Jim Buys, temporary dykes were built around the entire Town as well as around a number of the residences adjacent to the west, which are in Ritchot Municipality. The dyke was built to an elevation of 777 feet, and was not overtopped during the flood. Since the temporary dyke was well defined, it was simulated in the model, and the damage estimate of \$0.00 is comparable to the \$12,984 paid by MEMO.

Two damage estimates are shown, which incorporate the different depth-damage relationships for agricultural out-buildings. The table shows that the use of the two different depth-damage relationships for agricultural out-buildings does not have a significant impact on the total damage estimate. Since the model was not particularly sensitive to the use of either curve for this building type, the depth-damage Curve #1 was used for the analysis of the repeat 1826 flood damage simulation resulting in a lower estimate.

For comparison, a summary of estimated damages by building type is given in Table 7. The table shows that the approximate percentage of total damage was calculated to be 68.5, 4.6 and 26.9 percent for the residential, agricultural and commercial type buildings respectively. This supports the lack of sensitivity of the model towards variation in the agricultural building curves, which are the smallest portion of damages.

Table 7: 1997 Flood Simulation Damage Estimate Summary by Building Type

Municipality	Residential Buildings	Agricultural Buildings	Commercial Industrial Institutional Buildings	Total
De Salaberry	\$ 2,041,902	\$ 128,411	\$ 5,501,532	\$ 7,671,845
Franklin	\$ 876,462	\$ 109,289	\$ 302,337	\$ 1,288,088
Hanover	\$ 281,684	\$ -	\$ 83,725	\$ 365,409
Montcalm	\$ 4,163,240	\$ 264,801	\$ 2,144,998	\$ 6,573,040
MacDonald	\$ 3,347,280	\$ 727,613	\$ 211,331	\$ 4,286,223
Morris	\$ 19,519,761	\$ 2,171,783	\$ 4,504,547	\$ 26,196,091
Ritchot	\$ 41,651,106	\$ 1,562,981	\$ 14,830,663	\$ 58,044,751
Rhineland	\$ 333,721	\$ 4,706	\$ 43,130	\$ 381,558
Springfield	\$ 75,109	\$ -	\$ -	\$ 75,109
Tache	\$ 255,390	\$ -	\$ -	\$ 255,390
Town of Emerson	\$ 140,316	\$ 510	\$ 591,211	\$ 732,038
Town of Morris	\$ 12,290	\$ 1,395	\$ 111,564	\$ 125,249
Town of Niverville	\$ -	\$ -	\$ -	\$ -
	\$ 72,698,262	\$ 4,971,488	\$ 28,325,039	\$ 105,994,789

Infrastructure damages estimated by the model for a repeat 1997 flood are compared to the reported damages for 1997 on Table 8. Also shown on the table are the estimated values for the civil infrastructure damage and estimates for pre and post flood fighting costs. The table indicates that the functions developed to assess damages provide an accurate calibration to reported damages. The damage estimate could be improved with by further classifying roads and drains, and incorporating their respective repair cost into a revised damage model.

Because the model relates damage to parameters, which are proportional to the extent of flooding the model will tend to under predict damages as long as the water surface data used is not consistent with the actual flood event. As noted previously, the Mike-11 water surface data did not cover the same flooded area as was apparent on the satellite imagery. This inaccuracy is a function of the accuracy of the digital elevation model used.

Infrastructure damages estimated for the ring dike communities include an estimate for the Roseau River First Nation community, where reported infrastructure damages for 1997 were not obtained.

Table 8: 1997 Flood Simulation Infrastructure Damage Estimate by Municipality

Municipality	Estimated Civil Infrastructure Damages*	Estimated Pre and Post Flood Fighting Damages	Total Estimated Infrastructure Damages	Reported 1997 Damages
De Salaberry	\$ 865,204	\$ 775,558	\$ 1,640,763	\$ 846,202
Franklin	\$ 2,273,091	\$ 913,090	\$ 3,186,181	\$ 2,724,514
Hanover	\$ 317,284	\$ 38,726	\$ 356,010	\$ 567,996
Montcalm	\$ 3,535,765	\$ 1,327,374	\$ 4,863,139	\$ 3,987,169
MacDonald	\$ 3,152,103	\$ 794,265	\$ 3,946,368	\$ 3,583,421
Morris	\$ 12,744,197	\$ 2,861,105	\$ 15,605,302	\$ 15,085,490
Rithchot	\$ 6,154,957	\$ 8,040,566	\$ 14,195,523	\$ 15,098,655
Rhineland	\$ 350,209	\$ 166,319	\$ 516,528	\$ 1,122,420
Springfield	\$ 316,201	\$ 8,570	\$ 324,771	\$ 581,509
Tache	\$ 316,323	\$ 60,419	\$ 376,742	\$ 845,587
Town of Emerson	\$ -	\$ 1,231,490	\$ 1,231,490	\$ 1,231,490
Town of Morris	\$ -	\$ 1,011,100	\$ 1,011,100	\$ 1,011,100
Town of Niverville	\$ -	\$ 227,679	\$ 227,679	\$ 227,679
Utilities				\$ 1,566,814
Total	\$ 30,025,334	\$ 17,456,260	\$ 47,481,594	\$ 48,480,045

Note: *Civil Infrastructure Damages account for Damages to Utilities

The estimated 1997 infrastructure damages for each of the communities with a ring dike are equal to the damages reported for each community as shown on Table 4. The damage estimates are included in the above table under the applicable municipality. Damages to the Roseau River ring dike were estimated based upon relating its size and configuration to the other dikes.

The agricultural damage estimate for a repeat 1997 flood is summarized by municipality in Table 9. The table shows that the total damage estimate for a repeat 1997 flood with average

post flood conditions and expected yield would be approximately \$14.6 million. This equates to dollars damage per acre ranging from approximately \$2.50 to \$40.50. Compared to an average revenue of \$335 per acre, the damage can represent 10 to 12 percent of the total annual agricultural revenue.

Table 9: Estimated Agricultural Damages for a Repeat 1997 Flood

Municipality	Estimated Agricultural Damage	Average Damage Per Acre
De Salaberry	\$ 415,721.35	\$ 11.46
Franklin	\$ 917,587.51	\$ 14.52
Hanover	\$ 15,061.37	\$ 7.54
MacDonald	\$ 3,069,381.09	\$ 40.47
Montcalm	\$ 2,031,479.75	\$ 23.72
Morris	\$ 5,487,221.40	\$ 37.27
Rhineland	\$ 30,165.29	\$ 2.46
Ritchot	\$ 2,716,416.79	\$ 36.89
Springfield	\$ 1,058.90	\$ 6.72
Tache	\$ 7,604.17	\$ 6.74
Total	\$ 14,691,697.63	

The 1997 damage estimate for the City of Winnipeg is based upon actual flood fighting costs incurred by the City, and damages paid by MEMO. The estimated damages are approximately \$67.4 million or approximately \$6,100 per acre. The total damage is based upon an estimated \$43.7 million in costs to the City Corporation, \$14.5 million for military costs, and approximately \$9.2 million in MEMO claims paid to City residents.

The total estimated damages calculated by the data model for the Red River Valley including the City of Winnipeg is approximately \$233.6 million. The total includes the damage estimates for structural, infrastructure and agricultural damages.

4.2 1826 FLOOD DAMAGE SIMULATION

Table 10 lists the estimated structural damages for a repeat 1826 flood in the Red River Valley. The damages are summarized by municipality and are compared to the estimate for the 1997 flood.

Table 10: Estimated Structural Damages for a Repeat 1826 Flood

Municipality	Estimated Damages		Difference
	1826	1997	
De Salaberry	\$ 13,266,312	\$ 7,671,845	\$ 5,594,468
Franklin	\$ 1,687,848	\$ 1,288,088	\$ 399,759
Hanover	\$ 3,098,308	\$ 365,409	\$ 2,732,899
Montcalm	\$ 7,944,124	\$ 6,573,040	\$ 1,371,084
MacDonald	\$ 8,556,150	\$ 4,286,223	\$ 4,269,927
Morris	\$ 30,960,706	\$ 26,196,091	\$ 4,764,616
Ritchot	\$ 181,067,697	\$ 58,044,751	\$ 123,022,947
Rhineland	\$ 597,548	\$ 381,558	\$ 215,991
Springfield	\$ 6,435,662	\$ 75,109	\$ 6,360,553
Tache	\$ 23,863,422	\$ 255,390	\$ 23,608,033
Town of Emerson	\$ 1,373,372	\$ 732,038	\$ 641,334
Town of Morris	\$ 125,498	\$ 125,249	\$ 249
Town of Niverville	\$ 57,785,694	\$ -	\$ 57,785,694
Total	\$ 336,762,342	\$ 105,994,789	\$ 230,767,553

The largest increase in damages, compared to the 1997 flood simulation, is estimated to occur in the Municipalities of Hanover, MacDonald, Ritchot, Springfield, Tache and the Town of Niverville. All of these municipalities are on the northern portion of the basin most influenced by any backwater effects caused by the control of water into the floodway with the assumed current floodway operation rules. The damage estimate for Niverville is representative of the entire building inventory of the Town. Future use of the model could be used to assess the benefits of flood protection measures for such large flood events.

To provide a comparison of damages for the 1826 flood by building type, the estimated damages are listed for each municipality in Table 11. The ratio of damages by building type are

consistent with those predicted for the 1997 flood simulation showing residential building damages to be approximately 73 percent of the total estimate. Agricultural and commercial buildings are estimated to be 5 and 22 percent of total damages respectively.

Table 11: 1826 Flood Simulation Damage Estimate Summary by Building Type

Municipality	Residential Buildings	Agricultural Buildings	Commercial Industrial Institutional Buildings	Total
De Salaberry	\$ 5,182,692	\$ 1,068,743	\$ 7,014,877	\$ 13,266,312
Franklin	\$ 1,214,782	\$ 141,143	\$ 331,923	\$ 1,687,848
Hanover	\$ 2,098,062	\$ 190,480	\$ 809,765	\$ 3,098,308
Montcalm	\$ 5,223,900	\$ 455,256	\$ 2,264,968	\$ 7,944,124
MacDonald	\$ 6,954,422	\$ 1,374,663	\$ 227,065	\$ 8,556,150
Morris	\$ 23,378,110	\$ 2,808,799	\$ 4,773,797	\$ 30,960,706
Ritchot	\$ 149,243,942	\$ 8,749,605	\$ 23,074,150	\$ 181,067,697
Rhineland	\$ 528,467	\$ 21,778	\$ 47,303	\$ 597,548
Springfield	\$ 5,226,372	\$ 83,184	\$ 1,126,106	\$ 6,435,662
Tache	\$ 23,580,035	\$ 26,768	\$ 256,619	\$ 23,863,422
Town of Emerson	\$ 224,784	\$ 883	\$ 1,147,705	\$ 1,373,372
Town of Morris	\$ 12,539	\$ 1,395	\$ 111,564	\$ 125,498
Town of Niverville	\$ 28,726,888	\$ 67,492	\$ 28,991,313	\$ 57,785,694
Total	\$ 251,594,996	\$ 14,990,191	\$ 70,177,155	\$ 336,762,342

Infrastructure damages were estimated by extrapolating from the relationships developed for civil infrastructure damages, as well as damages for pre-emptive flood fighting and post flood recovery. Table 12 lists the estimated infrastructure damages for a repeat 1826 flood, and includes the separate columns for the above two categories of infrastructure damages.

Estimated Infrastructure damages to the ring-dike communities for a repeat 1826 flood are listed on Table 13. The estimates show that 1997 damages levels are not exceeded except in the communities of Ste. Adolphe and Niverville, where the projected flood levels would breach the dikes at their existing protection levels.

Table 12: 1826 Flood Simulation Infrastructure Damage Estimate by Municipality

Municipality	Estimated Civil Infrastructure Damages*	Estimated Pre and Post Flood Fighting Damages	Total Estimated Infrastructure Damages
De Salaberry	\$ 1,377,569	\$ 894,682	\$ 2,272,251
Franklin	\$ 2,585,674	\$ 954,110	\$ 3,539,784
Hanover	\$ 346,882	\$ 215,837	\$ 562,719
MacDonald	\$ 3,610,863	\$ 809,176	\$ 4,420,039
Montcalm	\$ 3,798,265	\$ 1,368,992	\$ 5,167,257
Morris	\$ 12,797,256	\$ 2,874,505	\$ 15,671,761
Rhineland	\$ 360,138	\$ 184,254	\$ 544,392
Ritchot	\$ 11,088,034	\$ 9,771,517	\$ 20,859,550
Springfield	\$ 366,768	\$ 405,836	\$ 772,603
Tache	\$ 397,759	\$ 1,828,294	\$ 2,226,052
Town of Emerson	\$ -	\$ 1,231,490	\$ 1,231,490
Town of Morris	\$ -	\$ 1,011,100	\$ 1,011,100
Town of Niverville	\$ 7,332,294	\$ -	\$ 7,332,294
Total	\$ 44,061,502	\$ 21,549,790	\$ 65,611,292

Note: *Civil Infrastructure Damages account for Damages to Utilities

Table 13: 1826 Flood Simulation Infrastructure Damages for Ring-dike Communities

Community Dike	Estimated Infrastructure Damages
Morris	\$ 1,011,100
Rosenort	\$ 260,000
St. Jean Baptiste	\$ 300,000
Letellier	\$ 190,000
Dominion	\$ 205,000
St. Adolphe*	\$ 4,142,702
Brunkild	\$ 175,000
Roseau River	\$ 487,721
Emerson	\$ 1,231,490
Niverville*	\$ 7,332,294
Total	\$ 15,335,307

*Dyke over-topped

Table 14 summarizes the agricultural damage estimate by municipality for a repeat flood of the magnitude equal to the 1826 flood. The table shows the total agricultural damage estimate was

calculated to be approximately \$66.6 million. This equates to a damage per acre ranging from approximately \$75 to \$136. The considerable increase in damages calculated for a 1826 type flood is primarily due to the extended duration of the flood, which is a function of the magnitude of the peak discharge.

Table 14: Estimated Agricultural Damages for a Repeat 1826 Flood

Municipality	Estimated Agricultural Damage	Average Damage Per Acre
De Salaberry	\$ 5,310,304.93	\$ 109.51
Franklin	\$ 7,259,940.35	\$ 105.72
Hanover	\$ 683,875.30	\$ 98.90
MacDonald	\$ 10,628,775.37	\$ 133.98
Montcalm	\$ 10,734,457.54	\$ 119.65
Morris	\$ 20,433,195.63	\$ 135.83
Rhineland	\$ 1,011,445.04	\$ 75.72
Ritchot	\$ 8,421,376.29	\$ 119.25
Springfield	\$ 788,237.81	\$ 87.16
Tache	\$ 1,324,295.41	\$ 94.12
Total	\$ 66,595,903.67	

Flood damages estimated for the City of Winnipeg were based upon the analysis of the data from the Water and Waste Department. Table 15 shows the total damages calculated for the inundated flood zone and the basement flood zone as calculated from the data provided. The Table also shows the dollars damage per acre for each zone. Tables illustrating the methodology for calculating damages for each type of building within the inundated zone and the basement flooding zone respectively are provided in Appendix D.

Table 15: Estimated Damages in the City of Winnipeg for a Repeat 1826 Flood

Flood Zone	Estimated Damage	Flooded Area	Average Damage Per Acre
Inundated Area	\$ 3,139,428,770	25546	\$ 122,893
Basement Flooding	\$ 4,332,369,325	39596	\$ 109,413
Total	\$ 7,471,798,095		

As can be seen on Table 15, the total estimated damages for the City of Winnipeg is approximately \$7.5 billion. This estimate is based upon the cursory methodology described above, and the use of the estimate at this time should be limited to a comparison of potential damages in the City to those estimated for the Red River Valley. Infrastructure Damages were not estimated for the City of Winnipeg because the analysis was considered to be out of the scope of this study.

A more rigorous assessment of the City of Winnipeg damage is being conducted under a separate study by KGS Group dealing with the Flood Risk Assessment for the City of Winnipeg. It is anticipated that the estimate generated by this study will be lower since the depth-damage relationships were derived from a more conservative approach than the MEMO derived depth-damage curve.

When total estimates for structural, infrastructure and agricultural damages in the Red River Valley, which are approximately \$337 million, \$66 million and \$67 million respectively, are added to the above estimate for the City of Winnipeg, the total estimated damages for a repeat 1826 type flood are \$7.95 billion. The damage attributed to the Red River Valley is approximately 6.3 percent of the total damage estimate.

4.3 DAMAGE MAPS

4.3.1 1997 Flood Simulation

The damage maps are included as an attachment of the report. They illustrate the distribution of total damages for a repeat 1997 flood, and consider total structural, infrastructure and agricultural damages.

As can be seen on the 1997 map, the distribution compares well with the actual areas that suffered considerable losses during the flood. The Rural Municipality of Ritchot just south of Winnipeg shows more damaged areas than the other municipalities to the south. The Rosenort area in the RM of Morris, however shows similar damages which is consistent with actual damages from the 1997 flood. Some areas that show damages may not actually have suffered losses to the degree shown, because the model does not account for pre-emptive flood fighting measures, which may significantly reduce actual damages occurring at a particular location.

The map indicates that most areas suffer some damage due to flooding. This is primarily due to methodology for calculating infrastructure and agricultural damages. The methodology for prorating infrastructure damage as a function of the density of the infrastructure is rational and consistent with the damages paid. The model does not consider, however, the size and/or type of infrastructure works in the flooded area since this information was not readily discernible from the data.

Although most areas in 1997 did not have any agricultural damages, if time of seeding and growing conditions had been more representative of a "normal year" the damages would be similar to those shown on the map.

4.3.2 1826 Flood Simulation

The damage distribution map produced for a flood of the same magnitude as the 1826 flood shows a greater distribution of damages throughout the Valley. Damages are more densely distributed especially along the Red River. This is primarily due to the failure of many of the private flood protection structures that would occur at this level.

Based upon current levels of protection the towns of Niverville, Ste Agathe, St. Adolphe and Ile des Cheines would be inundated. Although the Province is currently constructing a perimeter dyke around Ste. Agathe, it has not been incorporated into the model.

The map also illustrates that the damages in the City of Winnipeg compare to certain areas of similar density in the Valley. Damages are estimated to be \$110,000 per acre (basement flood zone) and \$123,000 per acre (inundated flood zone) in the City, which is comparable to damages calculated in St. Adolphe, which range from \$16,550 to \$267,000 per acre.

5.0 FLOOD DAMAGE MODEL STATUS

5.1 Model Assumptions and Limitations

Although the data model provides damages which reflect realistic estimates that would occur, the model can be refined with improvements to the input data and additional parameters to enhance the models predictions. The data model for calculating structural damages makes several assumptions in the calculation process with respect to the following:

- Geographic Location of Buildings
- First Floor Height above Ground Elevation
- Permanent Flood Protection Status
- No pre-emptive flood fighting

As described in Section 3.2.2, rules were developed within the model to address the limitations of the input data, and provide a means for calculating damages based upon average conditions within the Valley. A number of recommendations for improvements to the input data, which would reduce the model's dependence on rules are discussed below:

Geographic Location of Buildings - Detailed geographical location information of the building inventory in the Valley can be obtained by updating the existing 1988/90 building GIS information compiled by the Surveys and Mapping branch to be consistent with the Rural Development Tax Assessment Database. The task would consist of both updating the inventory (removing and adding buildings as required) and re-classifying the geographic data to be more consistent with the tax assessment building classification system. The updated GIS building data would also be made consistent with the flood protection structure data.

Building First Floor Height – The data set could be improved by including measurements of first floor heights, and the adjacent ground elevation. This has been done to some degree by the Province of Manitoba as owners flood proof their properties and register for permits with the Water Resources Branch. Therefore, the first step would

be to enter the data for protected properties first, and then extend the data to other properties in the Valley

Permanent Flood Protection Status – At the same time that the flood protection permit records are reviewed to enter building first floor height, the flood protection status attribute could be entered into the data model.

Pre-emptive Flood Fighting – The data model could be enhanced to accept a parameter, which accounts for the potential reduction of damages due to individuals who attempt to protect their property by raising temporary dykes and taking other pre-emptive flood fighting measures. The parameter could be based on data processed through claims information, and/or through a survey of Valley residents. A sensitivity analysis of the calculated damages could be completed by allowing users to input a “Pre-emptive Flood Fighting Variable” into the model.

Assumptions were also made when distributing infrastructure damages throughout the Valley. Although the distribution of damages was related to the density of infrastructure works, no consideration was given to the size and/or type of infrastructure and its relevance to repair costs. Additionally, the geographic location of damages to infrastructure was not readily discernible from the data sources. Further analysis could relate size and/or type of infrastructure to other flooding variables such as depth and duration of flooding.

The suggested improvements would minimize the need for some of the assumptions and rules, which are built into the model. The data model developed is flexible enough, however, to incorporate improved data as more sophisticated data becomes available. It would not be necessary to revise and improve all the data at one time before re-computing damages.

The Stage-Damage model predictions were also subject to function and data accuracy. A number of these limitations and methods to improve the accuracy are discussed below:

Depth-Damage Curves - The updated depth-damage curves developed from the 1997 flood damage data provided by MEMO could be improved, because the development of the curves was based on a small percentage of the claim files. If a larger portion of the claims were reviewed, it is likely that the curves could be better defined. The actual files should also be examined to ensure that the data extracted is appropriate for the development of the depth-damage relationship.

Since very few claims were made for commercial, industrial and institutional buildings, future work to refine the accuracy of this portion of the damage estimate should include the development of relationships known as “synthetic” curves. These curves are made in the absence of real damage data, and are based on established methodologies for calculating repair/replacement costs of buildings based upon type, construction materials and contents. The formulas would require input data from price indices relevant to Manitoba.

It is also understood that MEMO is currently entering the claim forms in a digital database format. The digital records should include type of structure, and flood level information with each claim. Once in a digital format the data will be more readily transferable without infringing on the rights to privacy because personal information would be easily removed from the data set.

Digital Elevation Model (DEM) – The DEM used for this study was developed by Klohn-Crippen from contour maps prepared in the 1950’s and supplemented with additional data on roads and railways. The accuracy of the model is approximately ± 1 metre, and is directly related to the water depths calculated by the Mike-11 hydrodynamic model. The International Joint Commission has begun to improve the DEM as it has commissioned the production of a detailed DEM (LIDAR scenes with accuracy of ± 0.15 metres) in the area directly south of the floodway. At the time of producing the damage estimates this data was not available, but has since been completed. Merging the data into the GIS model would improve the accuracy of the damage estimate.

Hydrodynamic Model – The results of the Mike-11 hydrodynamic model produce a water surface that was incorporated into the GIS flood damage model. The predicted flooded area of the model is not exactly consistent with the actual flooded area, and is generally less extensive. The smaller area of the predicted water surface causes the flood damage model to predict structural damages that are lower than claims paid (at the periphery) because it doesn’t consider a number of homes which were actually flooded. Although the disparity may be primarily caused by the accuracy of the DEM, the model doesn’t thoroughly account for tributary flow to the Red River. Future enhancements of the Mike-11 model, or possibly a two-dimensional model, would better correlate the predicted flood extent with actual recorded flood extents. The results would likely show improved damage estimates at the periphery of the flood zone.

The hydrodynamic model also predicts a hydrograph with a quicker recession than actually occurred, which impacts the Flood Damage Model’s estimations for agricultural damages. Improved calibrations of the Mike-11 flood recession would remove the necessity to assume certain hydrodynamic model adjustment factors in the Flood Damage Model.

Should the above tasks be considered to be too large to be considered at one time or as a single project, they could be implemented on a smaller or local level. This type of analysis could assist the benefit-cost analysis associated with the flood protection projects of individual communities such as those planned for Ste. Agathe, Rosenort and Grande Pointe.

5.2 Other Considerations for Future Model Uses

In addition to improving the existing data model, the approach for calculating damages could be expanded to include socio-economic damage estimates. Although not considered part of this study, flooding catastrophes have a broader impact than direct damage to structures and agricultural crops. The estimate of socio-economic losses, such as business revenue losses, due to flooding could be related to the duration of flooding. The function could have a number of parameters including type and size of economic activity in a given area, which could be incorporated in the GIS model developed for this project.

Relationships for determining the social impacts or damages may not be directly shown from a mathematical model, but by demonstrating the distribution of damage in the Valley, agencies providing social services could be directed to the areas of greatest need prior to or after a flood event. As part of a real-time emergency management program, the Stage-Damage model could be used to direct agencies to the areas where the greatest need is anticipated.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Based upon the work completed to assemble the data and develop a model to calculate damages, the following conclusions and recommendations are made:

6.1 CONCLUSIONS

1. The overall approach to calculate damages due to flooding in the Red River Valley shows that the geographical information system (GIS) technology is an effective tool for calculating and showing the spatial and temporal impacts of flooding in the Red River Valley.
2. The depth-damage relationships developed using new flood damage data are consistent with actual damages paid as a result of the 1997 flood. The shape of the updated curves is consistent with existing curves, but produces higher damage estimates than previously developed relationships. The estimates produced by the developed relationships are also higher than those commonly used elsewhere in North America.
3. Depth-damage relationships based upon 1997 flood damage data were developed for residential and agricultural type buildings.
4. Depth-damage relationships could not be developed for commercial, industrial or institutional buildings due to a lack of claims processed by the Manitoba Emergency Management Organization (MEMO). Residential curves were considered to be representative, and were used to estimate updated depth-damage curves for these structures.
5. Infrastructure damages were included in the model and calibrated to reported 1997 flood damage levels. Relationships were developed, which can be used to extrapolate the damage estimate to other floods of differing magnitudes.
6. Agricultural damage estimates can be calculated by relating the duration of flooding (first available date for seeding) to the expected average yield of crops in the Red River Valley.
7. The calculation of structural damages using the GIS and the data model is considered representative because it accounts for permanent flood protection structures in the Red River Valley, which are permitted by the Water Resources Branch. This includes the community ring dykes.
8. Damage distribution maps produced for repeat 1997 and 1826 floods show spatial distribution of damages consistent with actual damages experienced during the 1997

flood. Damages were mapped as dollars damage per acre to "normalize" the presentation of the data.

9. Damages estimates within the study area range from \$0 to \$47,000 per acre for the repeat 1997 flood event, and up to \$267,000 per acre for a repeat 1826 flood.
10. For a repeat 1997 flood event damages were estimated to be approximately \$106 million, \$47.5 million and \$15 million for structural, infrastructure and agricultural damages in the Red River Valley respectively. Adding the estimated \$67.4 million dollars damage for the City of Winnipeg brings the total estimated damages for the study area to approximately \$235.6 million.
11. In general, the structural damages estimated for the Red River Valley for the 1997 flood were greater than the MEMO claims paid because the data model did not consider temporary diking / flood fighting efforts of the Valley residences. It may be inferred that the difference between the estimated damage and the actual damages paid is the money saved by the flood fighting effort of individuals.
12. The model predictions for the 1997 flood at periphery of the study area were somewhat less than the MEMO claims paid, primarily because the flood levels produced by the hydrodynamic model did not fully reach to the actual flood extents.
13. The total damages for a repeat 1826 flood event were estimated to be approximately \$7.94 billion dollars, which consists of estimates of \$7.47 billion for the City of Winnipeg, as well as \$337, \$66 and \$67 million for structural, infrastructure and agricultural damages in the Valley.
14. Estimated damages by building type were approximately 70 percent for residential buildings, 25 percent for commercial/industrial/institutional buildings, and 5 percent for agricultural buildings.
15. The data model was made flexible to incorporate most types of data input. The damage estimates can be used for planning and design of flood protection structures, real-time emergency management and flood recovery.

6.2 RECOMMENDATIONS

1. It is recommended that the use the cursory damage estimate for a repeat 1826 flood in the City of Winnipeg be limited to a comparison of these damages against those calculated for the rest of the Red River Valley.
2. To eliminate inconsistencies in the data and refine the data model, the geographical building information available from the Survey and Mapping Branch should be updated and made consistent with the Rural Development Tax Assessment Database.

3. Depth-damage relationships for residential and farm buildings should be improved following review of more information from the MEMO 1997 flood damage data. The review would require scrutiny of the actual files to ensure consistency of the data.
4. Because there were only a few claims processed by MEMO for commercial, industrial or institutional establishments, it is recommended that a synthetic depth-damage relationship be developed for these building types. The synthetic curve(s) would be based upon accepted methodologies for calculating repair or replacement costs using pricing indices applicable to Manitoba.
5. Future use of the model should incorporate additional permanent flood protection structures such as those planned for construction at Ste. Agathe, Rosenort, Grande Pointe and Niverville. Future permanent private flood protection structures should also be incorporated into the data input model.
6. Further review of the infrastructure damages should be completed to determine if a better relationship exists between the size and/or type of infrastructure work and the damages can be determined and incorporated into the model.
7. Further studies of the agricultural damages should be completed to better define agricultural damages in terms of all relevant factors, including post flood weather conditions.
8. If data refinements cannot be performed over the entire study area under a single project, it is recommended to perform refinements to the data and the data model at a local level. This is possible because the model is able to handle situations where the geographical location data is very accurate or not accurate.
9. The digital elevation model of the Valley and the hydrodynamic model should be refined to improve the calculations for depth of flooding and the estimate of the flood extents.

REFERENCES

- ⁱ Report of the Royal Commission of Flood Cost Benefit, Winnipeg, Manitoba, 1958.
- ⁱⁱ Manitoba Natural Resources, Water Resources Branch, 1991, Riverton Flood Damage Reduction Study.
- ⁱⁱⁱ Acres Limited, 1968. Guidelines for Analysis – Streamflows, Flood Damages, Secondary Flood Control Benefits, Volume 2 – Flood Damages. A Report to the Joint Task Force on Water Conservation Projects in Southern Ontario, Governments of Canada and Ontario
- ^{iv} Ad Hoc Task Force on Manitoba Flood Mitigation Projects, 1980, Report on Manitoba Flood Mitigation Projects: Red River Valley Ring-Dyke Communities, Carman, Ste Rose du Lac, Gimli. Governments of Canada and Manitoba.