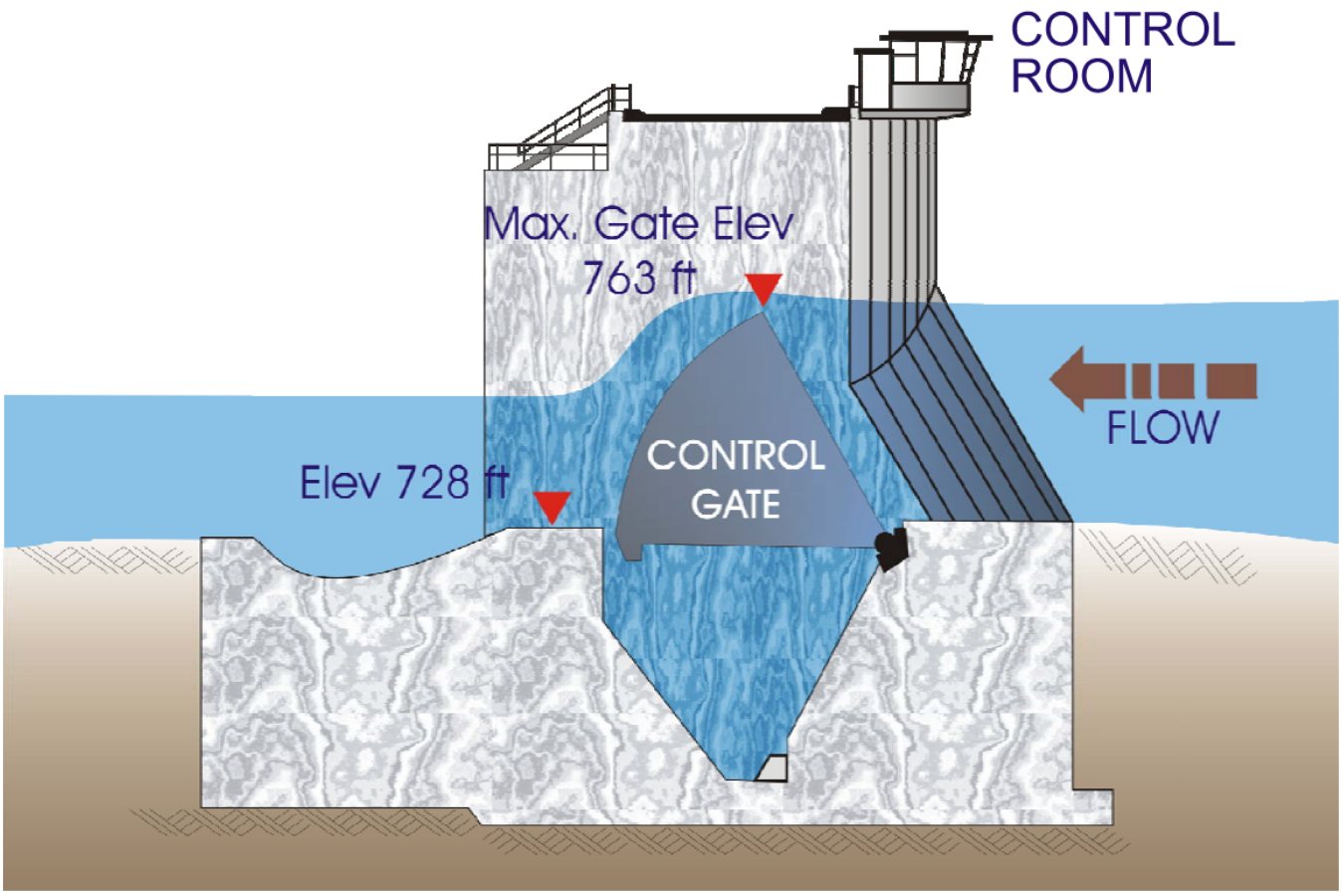
Red River Floodway Operation Report

Spring 2006



THE RED RIVER FLOODWAY INLET CONTROL STRUCTURE

SUBMITTED TO:
The Hon. Steve Ashton, Minister
Manitoba Water Stewardship

SUBMITTED BY:
Water Science and Management Branch
Ecological Services Division
Manitoba Water Stewardship

June, 2006

Manitoba

Manitoba

Water Stewardship ***Ecological Services Division*** ***200 Saulteaux Crescent, Box 11***

Winnipeg MB R3J 3W3
CANADA
Phone: (204) 945-1967
Fax: (204) 945-7419

June 30, 2006

The Honorable Steve Ashton, Minister
Manitoba Water Stewardship

Dear Minister:

I am pleased to provide a report documenting the 2006 spring operation of the Red River Floodway. The *Red River Floodway Act* requires that a report be presented to the Minister of Water Stewardship by June 30 in any year in which the floodway is operated during the spring runoff period. In 2006 the floodway was operated from April 5 until May 9. This report documents that operation.

Don Norquay, Assistant Deputy Minister

c: Gerry Berezuk
Dwight Williamson

FOREWORD

From its completion in 1968 until 2006 the Red River Floodway has been operated in 25 of the intervening years. Operation of the floodway has saved many millions of dollars in damage in the City of Winnipeg. However on occasion the operation has aggravated flooding outside of the City of Winnipeg.

In 2005 the *Red River Floodway Act* was proclaimed. One requirement under that Act is the preparation of a report detailing spring floodway operation and determining if the operation caused Red River levels at the floodway channel inlet to exceed the computed natural level. This report details the operation of the Red River Floodway in the spring runoff period of 2006.

All flows and levels in this report are shown in imperial units. Flows can be converted from cubic feet per second (cfs) to cubic metres per second (m^3/s) by dividing by a factor of 35.3148. River levels can be converted from feet to metres by dividing them by a factor of 3.28084.

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

INTRODUCTION

During the spring of 2006 the Red River Floodway was operated during the period from 5:30 PM on April 5 to 8:30 AM on May 9. Table 1 lists all of the gate operations during that period. The peak recorded level at the floodway entrance (Water Survey of Canada station 05OC026) was 763.48 feet at 1:00 PM on April 18. The computation of the natural level is described in a later section of the report.

Table 1 – April 2006 Floodway Gate Operations

Date	Time*	Start of Operation	End of Operation	Date	Time	Start of Operation	End of Operation
April 5, 2006	5:30 PM	728.00	738.04	April 26, 2006	12:20 PM	748.17	747.99
April 6, 2006	2:05 PM	738.04	739.48	April 26, 2006	11:00 PM	747.99	747.81
April 6, 2006	6:05 PM	739.48	741.10	April 27, 2006	10:50 AM	747.81	747.63
April 6, 2006	11:00 PM	741.10	742.53	April 27, 2006	4:35 PM	747.63	747.45
April 7, 2006	6:30 AM	742.53	744.41	April 28, 2006	12:30 AM	747.45	747.18
April 7, 2006	1:45 PM	744.41	745.44	April 28, 2006	10:35 AM	747.18	746.91
April 8, 2006	12:05 AM	745.44	746.82	April 28, 2006	11:10 PM	746.91	746.63
April 8, 2006	2:05 PM	746.82	747.54	April 29, 2006	10:50 AM	746.63	746.27
April 9, 2006	12:05 AM	747.54	748.44	April 29, 2006	6:50 PM	746.27	746.18
April 9, 2006	1:20 PM	748.44	749.06	April 30, 2006	12:20 AM	746.18	745.81
April 10, 2006	12:05 AM	749.06	748.71	April 30, 2006	10:30 AM	745.81	745.53
April 10, 2006	6:30 AM	748.71	748.44	April 30, 2006	5:00 PM	745.53	745.25
April 10, 2006	9:15 PM	748.44	749.15	April 30, 2006	10:40 PM	745.25	744.78
April 11, 2006	11:00 AM	749.15	750.20	May 1, 2006	11:15 AM	744.78	744.60
April 12, 2006	5:45 PM	750.20	749.77	May 1, 2006	10:50 PM	744.60	744.32
April 13, 2006	12:05 AM	749.77	749.42	May 2, 2006	11:00 AM	744.32	743.66
April 13, 2006	11:00 PM	749.42	749.77	May 2, 2006	10:35 PM	743.66	742.90
April 14, 2006	5:15 PM	749.77	750.12	May 4, 2006	12:05 AM	742.90	742.42
April 14, 2006	11:15 PM	750.12	750.38	May 4, 2006	9:10 AM	742.42	741.67
April 16, 2006	11:30 AM	750.38	750.20	May 4, 2006	2:55 PM	741.67	741.39
April 16, 2006	11:10 PM	750.20	750.03	May 4, 2006	10:35 PM	741.39	741.10
April 17, 2006	10:35 PM	750.03	749.94	May 5, 2006	4:25 PM	741.10	740.81
April 18, 2006	4:40 PM	749.94	749.77	May 6, 2006	12:05 AM	740.81	739.95
April 18, 2006	10:55 PM	749.77	749.59	May 6, 2006	10:40 AM	739.95	739.38
April 20, 2006	5:00 PM	749.59	749.50	May 6, 2006	4:50 PM	739.38	738.81
April 21, 2006	12:45 PM	749.50	749.42	May 6, 2006	10:55 PM	738.81	738.23
April 21, 2006	11:00 PM	749.42	749.24	May 7, 2006	4:55 PM	738.23	737.85
April 22, 2006	10:55 AM	749.24	749.06	May 7, 2006	11:25 PM	737.85	736.81
April 22, 2006	2:50 PM	749.06	748.89	May 8, 2006	9:40 AM	736.81	735.29
April 22, 2006	10:55 PM	748.89	748.71	May 8, 2006	4:30 PM	735.29	732.33
April 24, 2006	11:00 PM	748.71	748.53	May 9, 2006	8:30 AM	732.33	728.04
April 25, 2006	8:35 PM	748.53	748.17				

* Time of start of gate operation

During this period of operation the approved rules of operation were followed in adjusting the gates. The rules are listed in Appendix A.

2006 SPRING RUNOFF

The 2006 spring flood on the Red River from Emerson to the floodway inlet was one of the largest observed spring floods since systematic records began in the early 1900s. Only the floods in 1997, 1979 and 1950 were significantly larger. The flood of 1996 was slightly larger and that of 1966 was slightly smaller than the 2006 flood. An exception is the area from Selkirk to Breezy Point where the 1996 flood was the largest on record due to a major ice jam. The peak water level in the City of Winnipeg was the second highest since operation of the Red River Floodway began in 1969, second only to that of 1997.

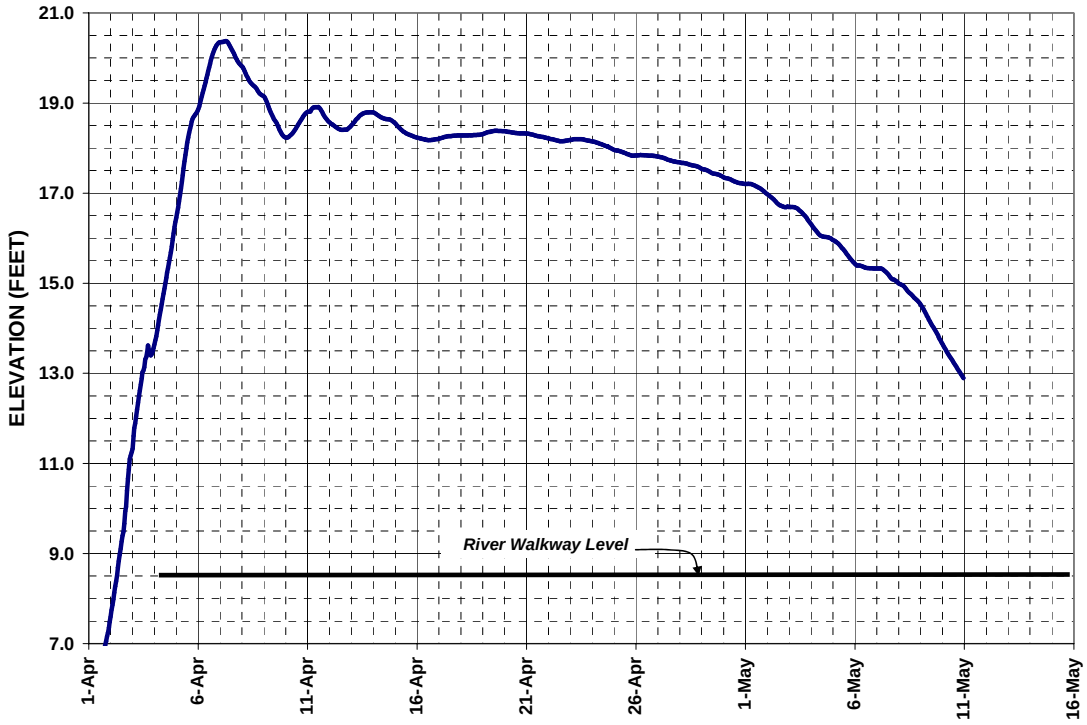
The high runoff resulted from high soil moisture levels remaining from the unusually wet summer of 2005, a moderate snowpack, substantial spring rain at the worst time and unfavourable north-south timing of the runoff due to an early rapid melt in the portion south of Grand Forks. A rainstorm of 20 to 50 mm on top of melting snow on March 30 to 31 produced much additional runoff and greatly increased peak river flows and levels. The March spring flood outlook had indicated that adverse (upper decile) spring weather could result in a 1996 magnitude flood. Runoff was heavy both in the United States portion and the Manitoba portion. Heavy local runoff on streams near Winnipeg, such as the Seine River, La Salle River, Sturgeon Creek and the lower Assiniboine produced an early crest in downtown Winnipeg on April 7, about one foot higher than had been predicted.

The river was above flood stage from early April to early May and at the height of the flood on April 20 the river was about 15 km wide from Letellier to Morris. There was extensive flooding of agricultural lands and disruption of transportation due to road closures. Highway 75 was closed to traffic in the Morris area April 10 to 28 and people residing in the floodplain had difficulty accessing their properties. Flooding of buildings was minimal due to extensive flood proofing done after the 1997 flood under a Canada-Manitoba Agreement.

Significant actions were taken by provincial and municipal officials and by individuals to prevent flooding or to reduce its impacts. This included operation of major flood control works, closure of ring dykes at valley towns, operation of smaller diversions, emergency dyking and pumping. Despite unusually high water levels serious flooding in the City of Winnipeg was generally avoided by operation of the Red River Floodway, emergency dyking, use of available freeboard, pumping, and other City activities.

Red River levels in Winnipeg at James Avenue during the period of operation are shown on Figure 1.

Figure 1 – Recorded River Levels at James Avenue



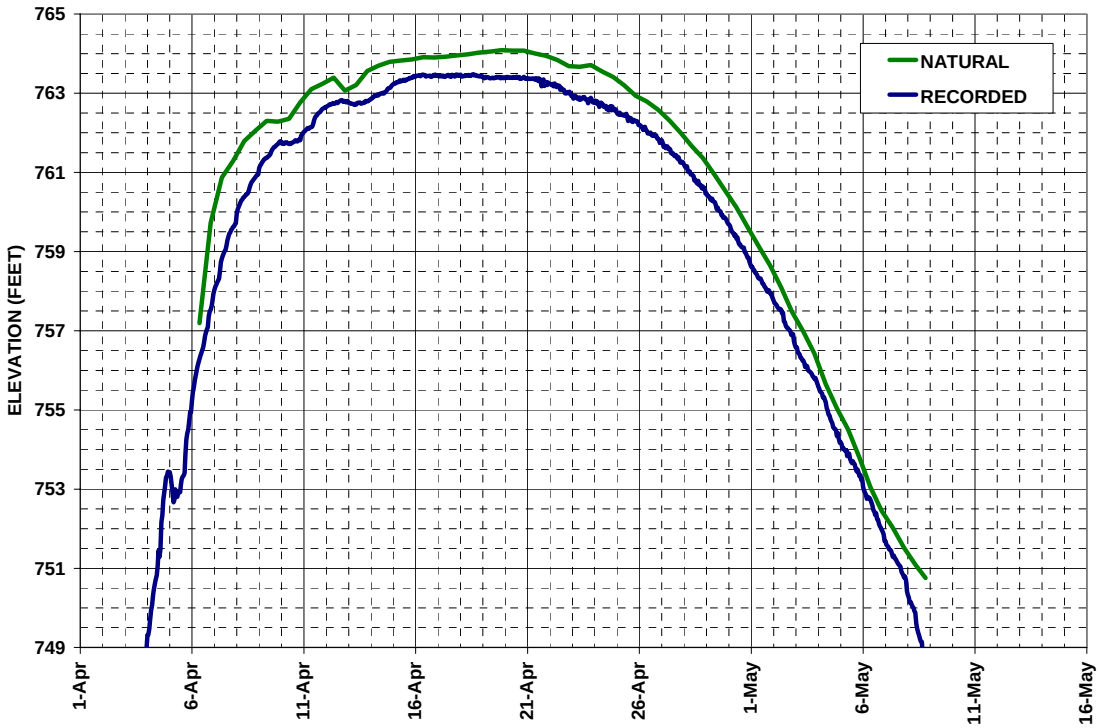
The Red River Floodway was operated from April 5 to May 9. The peak flow at the inlet was 80,200 cfs on April 20 and the peak diverted flow was 34,000 cfs on April 16. The recorded peak stage at the floodway inlet was 763.48 feet on April 18 while the computed natural peak was 764.11 feet. The peak level downstream of the structure was 754.84 feet on April 6 while the peak level at James Avenue in Winnipeg was 20.38 feet early on April 7. The high crest in Winnipeg was due to high uncontrolled local flows including the lower Assiniboine River. Levels at James Avenue were above 18 feet from April 5 to April 24, above 15 feet until May 7 and above 8.5 feet until May 29, an unusually long period of high water.

NATURAL LEVELS

The natural water level on the Red River at the Floodway entrance is defined as the water level that would have occurred at this location in the late 1950s, if the flood control works had not been built. These works include Winnipeg's Primary Dykes, the Red River Floodway, the Portage Diversion, Shellmouth Reservoir, and the Assiniboine River dykes. The natural water level is the water level that is 'targeted' in the floodway operation rules, for normal floodway operation (see Appendix A). That is, during normal floodway operation, the floodway is operated so as to keep water levels on the Red River at the floodway inlet at or below the natural water level.

The recorded and natural levels at the floodway entrance are plotted in the following figure.

Figure 2 – Recorded and Natural Levels at Floodway Entrance



During the 2006 spring floodway operation, the natural water levels were calculated using the relationship developed by Acres Manitoba Limited in 2004 [*"Re-Computation of Natural Water Levels at the Floodway Inlet (Final Report)", April 2004*]. This relationship requires two input values to calculate this water level. The two input values are the natural flow on the Red River downstream of the Assiniboine River (at James Avenue), and the natural flow of the Assiniboine River into the Red River. These two input values, as well as the natural and actual water levels on the Red River at the floodway inlet, are shown for the 2006 spring flood in Table 2 below.

Table 2 – Computed 2006 Natural Flows and Levels

Date/Time	Natural Red River Flow Below Assiniboine River (cfs)	Natural Assiniboine River Flow at the Forks (cfs)	Recorded River Level at Floodway Entrance (feet)	Computed "Natural" River Level at Floodway Entrance (feet)
05-Apr-2006 4:00 PM	59,366	11,184	753.33	754.48
06-Apr-2006 8:00 AM	68,011	11,040	756.22	757.20
07-Apr-2006 8:00 AM	81,146	11,504	758.73	760.87
08-Apr-2006 8:00 AM	86,327	14,108	760.34	761.80
09-Apr-2006 8:00 AM	89,268	15,816	761.35	762.30
10-Apr-2006 8:00 AM	90,522	17,591	761.73	762.35
11-Apr-2006 8:00 AM	95,962	20,832	762.13	763.10
12-Apr-2006 8:00 AM	96,772	19,969	762.72	763.39
13-Apr-2006 8:00 AM	92,494	14,486	762.74	763.21
14-Apr-2006 8:00 AM	94,852	14,737	762.95	763.70
15-Apr-2006 8:00 AM	95,399	14,647	763.29	763.83
16-Apr-2006 8:00 AM	95,575	14,225	763.44	763.91
17-Apr-2006 8:00 AM	95,077	13,136	763.43	763.92
18-Apr-2006 8:00 AM	95,175	12,783	763.42	763.98
19-Apr-2006 8:00 AM	95,507	12,797	763.38	764.05
20-Apr-2006 8:00 AM	95,620	12,792	763.38	764.08
21-Apr-2006 8:00 AM	95,337	12,908	763.35	764.00
22-Apr-2006 8:00 AM	94,769	13,318	763.20	763.83
23-Apr-2006 8:00 AM	94,163	13,665	762.93	763.66
24-Apr-2006 8:00 AM	93,755	13,918	762.76	763.55
25-Apr-2006 8:00 AM	92,274	14,213	762.46	763.19
26-Apr-2006 8:00 AM	90,430	14,224	762.10	762.79
27-Apr-2006 8:00 AM	88,553	14,320	761.65	762.32
28-Apr-2006 8:00 AM	85,930	14,335	761.01	761.67
29-Apr-2006 8:00 AM	83,314	14,754	760.30	760.96
30-Apr-2006 8:00 AM	80,135	15,116	759.41	760.12
01-May-2006 8:00 AM	76,795	15,071	758.39	759.13
02-May-2006 8:00 AM	73,421	15,227	757.55	758.09
03-May-2006 8:00 AM	69,922	15,601	756.23	756.98
04-May-2006 8:00 AM	65,631	15,530	755.26	755.66
05-May-2006 8:00 AM	61,963	15,575	753.89	754.51
06-May-2006 8:00 AM	57,311	15,395	752.70	753.04
07-May-2006 8:00 AM	54,065	15,101	751.35	752.02
08-May-2006 8:00 AM	51,178	14,970	749.89	751.09

Appendix B contains a detailed explanation of how the natural flows in Table 2 were computed.

The recorded river level at the floodway entrance was maintained below the computed natural level an average of 0.75 feet throughout the entire period of floodway operation. However, in the early stages of the flood, the difference was as much as 2.1 feet. The reasons for this situation are described in the next section.

OPERATIONAL ISSUES

Flow Estimation and Gate Operation

Normally, ice is gone from the main waterways before serious flooding occurs. However, this year's peak in the city occurred on April 7, very early in the event. Ice and debris made it difficult for federal and provincial hydrometric technicians to directly measure flows in the floodway channel prior to April 6 and on the Red River before April 10. This circumstance resulted in not having real-time flow measurement data to guide the operation of flood control works in the early stages.

Reliable flow estimates are critical to the operation of the floodway to maintain inlet levels relatively close to natural. The magnitude of the difference between actual and natural levels at the inlet reflects the confidence the operator has in the estimates – for example, the larger the magnitude the less confidence in the estimates.

Therefore, gate change decisions before measurements were taken had to be based on flows estimated using last year's spring and summer operations when flow conveyance in the floodway channel was greatly reduced by the growth of willows in the channel. Flow measurements during the 2005 events reflected a conveyance between 65% and 80% of the 2001 capacity. Although some of the willow growth had been removed after last summer's flood event, hydraulic calculations performed before this spring's runoff indicated that this removal work was insufficient to cause a significant improvement in the conveyance.

The floodway measurement on April 6 indicated that the conveyance had increased to 94% of the 2001 capacity. The operator used 80 % in setting the gates. If 94% had been used to set the gates, the peak level in the city at James Avenue would have been 19.5 feet, or about one foot lower than the actual recorded level of 20.4 feet, while maintaining a difference between actual and natural levels of 0.5 feet at the inlet.

After a few more measurements of the floodway flows in days subsequent to April 7, it became apparent that the channel conveyance had in fact increased very close to that which had existed in 2001. Apparently, the removal of the willows was quite effective.

Acoustic Doppler Current Profiler (ADCP) Flow Meter

An ADCP (Acoustic Doppler Current Profiler) flow meter was purchased prior to the spring runoff to improve flow measurement capabilities. The 2006 Flood provided an excellent opportunity to test the application of this technology. After some initial difficulties, which the manufacturer was able to resolve, the ADCP was applied successfully to obtain flow measurements on the Red River Floodway. Excellent agreement was found between the traditional manual Price Current Meter and ADCP measurements for the floodway. However, on the Red River at Chief Peguis Bridge in Winnipeg, problems were encountered with either a moving bed or the ADCP not quite reaching the bottom. If it is determined that the problem is a moving bed, a GPS for the ADCP will have to be purchased, so that a satellite can be used instead of the bottom tracking method to track the position of the ADCP. The ADCP saves time in obtaining reliable flow measurements required for

floodway operations. The ADCP also addresses workplace health and safety concerns with the individual conducting flow measurements.

Ice Jams

Ice runs on the Red River and the Assiniboine River were relatively minor but did add to peak flows and levels. There was no significant ice jamming at points north of Winnipeg, possibly due to ice breaking by the Amphibex.

Operating Rules

There was no special floodway operation to reduce the risk of sewer backup in Winnipeg as an analysis by Manitoba Water Stewardship showed the risk of heavy thunderstorms in May to be relatively low, resulting in a low benefit/cost ratio.

Gate Operations

This spring gate operations were made to follow the natural rise in water levels through a series of small steps. This was done to address concern about large gate raises causing sudden sharp changes in water levels above and below the floodway control structure. The average gate adjustment was 0.5 feet during the period that floodway flows were affected by gate operation.

CONCLUSIONS AND RECOMMENDATIONS

Operation of the Red River Floodway inlet control structure during the spring of 2006 resulted in a peak river level at the floodway entrance of 763.48 feet which was 0.63 feet lower than the computed natural peak level.

It is recommended that vegetation in the floodway channel be cut down each fall to ensure that maximum conveyance of the channel is maintained.

APPENDIX A

Red River Floodway Rules of Operation

Rules of Operation
Red River Floodway Control Structure

Normal Operation:
1. Maintain natural[1] water levels on the Red River at the entrance to the floodway channel, until the water surface elevation at James Avenue reaches 24.5 feet (7.46 metres), or the river level anywhere along the Red River within the City of Winnipeg reaches two feet below the Flood Protection Level of 27.83 feet (8.48 m).

Major Flood Operation:
2. Once the river levels within Winnipeg reach the limits described in Rule 1, the level in Winnipeg should be held constant while levels south of the control structure continue to rise. Furthermore if forecasts indicate that levels at the entrance to the floodway channel will rise more than two feet (0.6 metres) above natural, the City of Winnipeg must proceed with emergency raising of the dikes and temporary protection measures on the sewer systems in accordance with the flood level forecasts within Winnipeg. The levels in Winnipeg should be permitted to rise as construction proceeds, but not so as to encroach on the freeboard of the dikes or compromise the emergency measures undertaken for protecting the sewer systems. At the same time the Province should consider the possibility of an emergency increase in the height of the floodway embankments and the West Dike. At no time will the water level at the floodway channel's entrance be allowed to rise to a level that infringes on the allowable freeboard on the floodway west embankment (Winnipeg side) and the West Dike.

Extreme Flood Operation:
3. For extreme floods, where the water level at the floodway channel's entrance reaches the maximum level that can be held by the floodway west embankment and the West Dike, the river level must not be permitted to exceed that level. All additional flows must be passed through Winnipeg.

Initial Gate Operation with Ice:
The floodway gates should not be operated until ice on the river is flowing freely, unless flooding in Winnipeg is imminent.

Final drop of Gates:
To minimize bank slumping along the river in Winnipeg and at the same time reduce the probability of sewer backup problems, final gate operations, once the level at the entrance to the floodway channel recedes to elevation 752 feet (229 metres), shall be carried out in consultation with the City of Winnipeg.

Operation of Horn:
The horn at the floodway structure shall only be operated once, before the first gate operation of the year. The horn should be sounded a half-hour before the first gate operation to alert residents that the floodway structure is being put into operation. For ongoing information a 1-800 number should be established that would provide current information of gate operations, potential impacts on water levels, and forecasts for the next few days. The information should also be included on the existing Water Stewardship internet site.

[1] The term natural refers to the level that would have occurred in the absence of the flood control works, with the level of urban development in place at the time of the construction of these works.

Emergency Operation to Reduce Sewer Backup in Winnipeg

4(1) This rule defines the circumstances under which the Minister of Water Stewardship ("the Minister") may determine that emergency operation of the floodway is necessary to prevent widespread basement flooding and resulting risk to health and damage to property within the City of Winnipeg.

4(2) This rule applies after the spring crest from snowmelt runoff at Winnipeg, whenever high river levels substantially impair the capacity of Winnipeg's combined sewer system.

4(3) As long as the Department of Water Stewardship ("the Department") forecasts that river levels for the next 10 days will be below 14 feet James Avenue Pumping Station Datum (JAPSD), the Department will not operate the floodway control structure.

4(4) When the Department forecasts that river levels for the next 10 days are expected to rise to 14 feet JAPSD or higher, the Department will prepare a report that describes:

(a) The basis of the Department's river level forecasts and its risk assessment;

(b) The risk of basement flooding in Winnipeg, including the following factors:

(i) The predicted peak river level in the next 10 days;

(ii) The length of time the Department forecasts the river level will be at 14 feet JAPSD or higher;

(iii) The risk of an intense rainfall event in Winnipeg in the next 10 days;

(c) The benefits and costs of floodway operation, including:

(i) The extent of basement flooding and damage to property expected from various combinations of intense rainfall events and high river levels;

(ii) The risk to the health of Winnipeg residents from sewer back-up;

(iii) Economic loss and damage caused by artificial flooding south of the inlet control structure;

(iv) Impacts of operation on fish and wildlife and their habitat and on water quality;

(v) The risks and potential costs of riverbank instability that may be caused by artificial river level changes, both upstream and downstream of the inlet control structure;

(vi) During construction of the floodway expansion, costs and risks associated with any resulting delays of that construction, including the potential average annual expected damages associated with an additional period of risk of a flood event that would exceed the current capacity of the floodway;

(vii) Such other benefits and costs of operation of which the Department is aware at the time of the preparation of the report, excluding benefits associated with recreational or tourism activities or facilities; and

(d) measures that may be taken to mitigate the costs and impacts of the operation under consideration, including:

(i) minimizing the rate at which river levels are changed both upstream and downstream of the floodway inlet control structure;
(ii) providing means to assure fish passage.

4(5) The Department will present a draft of the report prepared under rule 4(4) to the Floodway Operation Review Committee and provide an opportunity for the Committee to provide input, before finalizing the report and making recommendations respecting floodway operation.

4(6) The Department will not recommend operation of the floodway unless the expected benefits of doing so clearly and substantially outweigh the expected costs.

4(7) The Department will present its report and recommendations to the Minister, who, subject to rule 4(8), will make a decision respecting floodway operation based on his consideration of the report.

4(8) The Department will not operate the floodway control structure under this rule:

(a) to raise river levels immediately upstream of the control structure to an elevation higher than 760 feet above sea level;

(b) to achieve a river level of less than 9 feet JAPSD; or

(c) except in circumstances of extreme urgency, to lower river levels more than one foot per day.

4(9) The Department will issue a news release announcing a decision to operate the floodway at least 24 hours before commencing operation.

4(10) The Department will ensure every reasonable effort is made to personally notify landowners who may be directly affected by flooding due to floodway operation in advance of the operation.

4(11) The Department will sound the horn at the floodway inlet control structure one-half hour before operation commences.

4(12) The Department will maintain a program of compensation for damages suffered by landowners arising from flooding caused by floodway operation under this rule.

APPENDIX B

Computation of Natural Flows and Levels

Computation of Natural Flows and Levels
On the Red and Assiniboine Rivers

Table 2 in the main report lists the natural flows on the Red River below the confluence with the Assiniboine River and on the Assiniboine River at the Forks. This Appendix describes how those flows were determined, and explains how the relationships developed in the Acres 2004 study were applied to compute the natural level at the floodway entrance.

Table B-1 lists the recorded and computed flows and levels for each time step. Columns 1 to 7 list the flows used in computing the natural flows on the Assiniboine River, and columns 8 to 10 list the flows used for computing the natural flows on the Red River.

NATURAL ASSINIBOINE RIVER FLOW

The natural flows on the Assiniboine River are altered by operation of the Shellmouth Dam, the Portage Diversion, and by the presence of dykes along the Assiniboine River.

The Shellmouth Dam can decrease flows below natural by adjusting the control gates so that reservoir outflows are lower than the inflows. In this case the reservoir levels rise, and excess water is stored behind the dam.

The Portage Diversion can be used to reduce flows in the lower Assiniboine River by diverting some of the river flow north to Lake Manitoba.

The Assiniboine River dykes were constructed to prevent overflows from the river onto the surrounding lands. Because of the height of the river and the slope of the land much of this overflow did not return to the Assiniboine River. Therefore the dykes have the effect of increasing flows entering Winnipeg on the Assiniboine River during periods of high flow.

Referring to Table B-1, column 1 lists the flow reductions at Winnipeg resulting from storage behind the Shellmouth Dam. It is important to recognize that these flow changes at the dam take some time to reach Winnipeg. The Department uses the Muskingum routing procedure to compute this flow attenuation.

Column 2 shows the flows diverted to Lake Manitoba via the Portage Diversion. Again the flows are routed to Winnipeg to apply the time delay.

Column 3 shows the recorded flows at the hydrometric station at Headingley. These first three columns are summed to determine the total natural flow before applying the natural breakouts that would have occurred if the dykes were not in place.

Column 4 lists the computed breakouts that would have occurred at those flows if the dykes had not been constructed.

Column 5 lists the computed natural flows at Headingley. These are computed by adding the three adjustments to the recorded flows at Headingley.

There is some additional local inflow entering the Assiniboine River between Headingley and the Forks. Most of this flow is recorded on Sturgeon Creek. In column 6 the recorded flows on Sturgeon Creek are increased to include unmeasured local inflows.

Finally columns 5 and 6 are added together to give the computed natural flows of the Assiniboine River at the Forks, as listed in column 7.

NATURAL RED RIVER FLOW

On the Red River the primary flow adjustment is caused by the Red River Floodway. During periods of extensive flooding there can also be a flow change resulting from changes in the storage of floodwaters on the land, but as long as flood levels at the floodway entrance are held at natural that change would be negligible.

Column 8 lists the recorded flows in the floodway channel, and column 9 shows the recorded flows at James Avenue. Column 10 sums the flows in those two columns and adds the three flow adjustments on the Assiniboine River to give the total natural flow on the Red River at James Avenue, which is downstream of the Forks.

NATURAL RIVER LEVELS AT THE FLOODWAY INLET

Table B-2 is a reproduction of Table 4-7 from the Acres report "*Re-Computation of Natural Water Levels at the Floodway Inlet (Final Report), April 2004*". The table provides natural elevations at the inlet based upon the relative contribution of natural flow at the Forks from the Red and Assiniboine Rivers. The *combined* flow is represented by the values in the left-hand column entitled Red River at James Avenue. The Assiniboine River Contribution amount is shown across the top and is the flow in the Assiniboine River at the Forks.

The natural water level at the inlet can vary by a few feet dependent upon the amount of flow coming from the Assiniboine River (Assiniboine River Contribution). This phenomenon is referred to as a variable backwater effect.

This concept can be illustrated by using the example of 100,000 cfs flow for the Red River at James Avenue in various combinations of Red and Assiniboine River flows. One combination could have 95,000 cfs as Red River flow upstream of the Forks and 5,000 cfs as Assiniboine River Contribution; this combination results in a level at the inlet of 765.6 feet as shown in Table B-2. Similarly, another combination, while still yielding a total James Avenue flow of 100,000 cfs, could be 70,000 cfs as Red River flow upstream of the Forks and 30,000 cfs as Assiniboine River Contribution; the resulting inlet level would be 762.9 feet. The difference in the inlet water elevation between these two flow combinations is 2.7 feet, with the lower elevation occurring when there is relatively more flow on the Assiniboine River.

Natural levels are determined by using the natural Red River flows at James Avenue listed in column 10 of Table B-1, and the natural Assiniboine River flows listed in column 7 of Table B-1 and interpolating between the values listed in Table B-2 to determine the natural levels. These natural levels are listed in column 11 of Table B-1. For comparison, column 12 of Table B-1 lists the recorded levels at the floodway inlet (station 05OC026).

Table B-1 Spring 2005 Flows and Levels

Column =>	1	2	3	4	5	6	7	8	9	10	11	12
	Assiniboine Flows							**Red River Flows**				
	Shellmouth Flow Changes (Routed to Headingley)	Portage Diversion flow (Routed to Headingley)	Actual Assiniboine R. flow at Headingley	Natural breakouts from river	Natural Assiniboine River flow at Headingley	Sturgeon Cr. Flow plus other local inflows	**Natural Assiniboine R. flow into Red River**	Red River Floodway flow	Red River flow at James Ave.	**Natural Red River flow at James Avenue**	Natural water level on Red R. at Floodway Inlet (feet)	Recorded Water level on Red R. at Floodway Inlet (feet)
Date / Time	*Recorded*	*Recorded*	*Recorded*	*Computed*	*=1+2+3-4*	*Rec. & Est.*	***=5+6***	*Recorded*	*Recorded*	***=1+2-4+8+9***	*Computed*	*Recorded*
05/Apr/2006 4:00 PM	-1100	873	8,476	0	8,249	2,935	**11,184**	4,397	55,196	**59,366**	754.48	753.33
06/Apr/2006 8:00 AM	-1100	930	8,122	0	7,953	3,087	**11,040**	8,988	59,193	**68,011**	757.20	756.22
06/Apr/2006 8:00 PM	-1100	1,902	8,122	0	8,924	3,207	**12,131**	13,882	62,632	**77,315**	759.73	757.47
07/Apr/2006 8:00 AM	-1100	1,873	7,593	0	8,366	3,137	**11,504**	17,136	63,237	**81,146**	760.87	758.73
07/Apr/2006 8:00 PM	-1080	4,092	7,593	0	10,605	2,849	**13,454**	19,593	61,329	**83,934**	761.29	759.56
08/Apr/2006 8:00 AM	-1060	5,562	7,063	0	11,565	2,543	**14,108**	22,094	59,730	**86,327**	761.80	760.34
08/Apr/2006 8:00 PM	-1060	6,435	7,063	0	12,438	2,272	**14,710**	23,790	58,527	**87,692**	762.06	760.86
09/Apr/2006 8:00 AM	-1040	7,954	6,703	0	13,617	2,198	**15,816**	25,498	56,856	**89,268**	762.30	761.35
09/Apr/2006 8:00 PM	-1040	8,696	5,932	0	13,588	2,128	**15,716**	26,725	54,748	**89,129**	762.28	761.69
10/Apr/2006 8:00 AM	-1040	10,101	6,594	74	15,581	2,010	**17,591**	26,902	54,633	**90,522**	762.35	761.73
10/Apr/2006 8:00 PM	-1030	12,862	7,626	907	18,551	2,047	**20,598**	27,103	56,279	**94,306**	762.77	761.80
11/Apr/2006 8:00 AM	-1020	12,588	8,200	1000	18,768	2,064	**20,832**	28,177	57,217	**95,962**	763.10	762.13
11/Apr/2006 8:00 PM	-1002	11,500	8,001	643	17,856	2,056	**19,912**	29,883	56,293	**96,031**	763.24	762.57
12/Apr/2006 8:00 AM	-984	12,645	7,187	735	18,113	1,856	**19,969**	30,549	55,297	**96,772**	763.39	762.72
12/Apr/2006 8:00 PM	-958	7,881	7,125	0	14,049	1,719	**15,768**	30,648	55,037	**92,609**	763.07	762.79
13/Apr/2006 8:00 AM	-931	6,696	7,141	0	12,907	1,579	**14,486**	30,537	56,192	**92,494**	763.21	762.74
13/Apr/2006 8:00 PM	-1051	7,387	7,071	0	13,407	1,458	**14,866**	31,212	56,769	**94,318**	763.56	762.79
14/Apr/2006 8:00 AM	-850	7,404	6,939	0	13,493	1,245	**14,737**	31,962	56,336	**94,852**	763.70	762.95
14/Apr/2006 8:00 PM	-786	7,410	6,800	0	13,425	1,071	**14,496**	32,544	56,004	**95,173**	763.79	763.12
15/Apr/2006 8:00 AM	-724	7,865	6,605	0	13,747	900	**14,647**	33,235	55,023	**95,399**	763.83	763.29
15/Apr/2006 8:00 PM	-629	7,862	6,315	0	13,548	757	**14,305**	33,679	54,445	**95,357**	763.85	763.39
16/Apr/2006 8:00 AM	-533	8,046	6,057	0	13,569	656	**14,225**	33,934	54,128	**95,575**	763.91	763.44
16/Apr/2006 8:00 PM	-397	7,590	5,875	0	13,067	560	**13,627**	33,934	54,099	**95,226**	763.90	763.43
17/Apr/2006 8:00 AM	-261	7,126	5,772	0	12,637	499	**13,136**	33,854	54,359	**95,077**	763.92	763.43
17/Apr/2006 8:00 PM	-81	6,920	5,664	0	12,503	446	**12,949**	33,840	54,460	**95,139**	763.96	763.46
18/Apr/2006 8:00 AM	99	6,679	5,559	0	12,337	446	**12,783**	33,894	54,503	**95,175**	763.98	763.42
18/Apr/2006 8:00 PM	306	6,670	5,493	0	12,468	424	**12,893**	33,948	54,532	**95,455**	764.03	763.44
19/Apr/2006 8:00 AM	570	6,449	5,419	0	12,437	360	**12,797**	33,638	54,849	**95,507**	764.05	763.38
19/Apr/2006 8:00 PM	852	6,212	5,364	0	12,427	326	**12,753**	33,638	54,951	**95,653**	764.09	763.38
20/Apr/2006 8:00 AM	1137	5,971	5,354	0	12,462	330	**12,792**	33,706	54,806	**95,620**	764.08	763.38
20/Apr/2006 8:00 PM	1459	5,742	5,345	0	12,546	303	**12,849**	33,760	54,691	**95,651**	764.08	763.37
21/Apr/2006 8:00 AM	1780	5,507	5,313	0	12,600	308	**12,908**	33,504	54,546	**95,337**	764.00	763.35
21/Apr/2006 8:00 PM	2140	5,505	5,290	0	12,935	272	**13,206**	33,248	54,315	**95,208**	763.94	763.30

Table B-1 Spring 2005 Flows and Levels (*continued)*

Column =>	1	2	3	4	5	6	7	8	9	10	11	12
	Assiniboine Flows							Red River Flows				
Date / Time	Shellmouth Flow Changes (Routed to Headingley) *Recorded*	Portage Diversion flow (Routed to Headingley) *Recorded*	Actual Assiniboine R. flow at Headingley *Recorded*	Natural breakouts from river *Computed*	Natural Assiniboine River flow at Headingley *=1+2+3-4*	Sturgeon Cr. Flow plus other local inflows *Rec. & Est.*	**Natural Assiniboine R. flow into Red River** ***=5+6***	Red River Floodway flow *Recorded*	Red River flow at James Ave. *Recorded*	**Natural Red River flow at James Avenue** ***=1+2-4+8+9***	Natural water level on Red R. at Floodway Inlet (feet) *Computed*	Recorded Water level on Red R. at Floodway Inlet (feet) *Recorded*
22/Apr/2006 8:00 AM	2500	5,268	5,278	0	13,046	273	**13,318**	32,945	54,056	**94,769**	763.83	763.20
22/Apr/2006 8:00 PM	2825	5,032	5,271	0	13,128	265	**13,392**	32,312	53,954	**94,123**	763.69	763.06
23/Apr/2006 8:00 AM	3150	5,036	5,219	0	13,405	260	**13,665**	31,820	54,157	**94,163**	763.66	762.93
23/Apr/2006 8:00 PM	3460	5,034	5,164	0	13,658	256	**13,914**	31,768	54,247	**94,510**	763.71	762.86
24/Apr/2006 8:00 AM	3770	4,789	5,109	0	13,667	251	**13,918**	31,209	53,987	**93,755**	763.55	762.76
24/Apr/2006 8:00 PM	4035	4,785	5,080	0	13,900	246	**14,146**	30,850	53,569	**93,239**	763.41	762.63
25/Apr/2006 8:00 AM	4310	4,541	5,122	0	13,973	240	**14,213**	30,241	53,182	**92,274**	763.19	762.46
25/Apr/2006 8:00 PM	4520	4,062	5,187	0	13,768	239	**14,007**	29,572	52,843	**90,996**	762.94	762.33
26/Apr/2006 8:00 AM	4730	4,053	5,234	0	14,017	207	**14,224**	28,608	53,039	**90,430**	762.79	762.10
26/Apr/2006 8:00 PM	4890	3,822	5,249	0	13,961	187	**14,148**	27,837	52,966	**89,515**	762.58	761.89
27/Apr/2006 8:00 AM	5050	3,817	5,255	0	14,123	197	**14,320**	26,902	52,784	**88,553**	762.32	761.65
27/Apr/2006 8:00 PM	5170	3,819	5,264	0	14,253	189	**14,442**	25,860	52,493	**87,341**	762.01	761.32
28/Apr/2006 8:00 AM	5290	3,586	5,265	0	14,142	194	**14,335**	24,718	52,335	**85,930**	761.67	761.01
28/Apr/2006 8:00 PM	5390	3,825	5,260	0	14,475	193	**14,667**	23,563	52,104	**84,883**	761.36	760.67
29/Apr/2006 8:00 AM	5490	3,822	5,256	0	14,568	186	**14,754**	22,274	51,728	**83,314**	760.96	760.30
29/Apr/2006 8:00 PM	5670	3,825	5,252	0	14,747	186	**14,933**	20,818	51,400	**81,714**	760.54	759.87
30/Apr/2006 8:00 AM	5850	3,825	5,255	0	14,931	185	**15,116**	19,424	51,036	**80,135**	760.12	759.41
30/Apr/2006 8:00 PM	5915	3,828	5,263	0	15,007	189	**15,196**	18,035	50,708	**78,487**	759.61	758.92
01/May/2006 8:00 AM	5780	3,827	5,274	0	14,880	190	**15,071**	16,577	50,611	**76,795**	759.13	758.39
01/May/2006 8:00 PM	5840	3,828	5,274	0	14,942	193	**15,135**	15,471	50,114	**75,253**	758.65	757.98
02/May/2006 8:00 AM	5900	3,830	5,298	0	15,036	191	**15,227**	14,333	49,350	**73,421**	758.09	757.55
02/May/2006 8:00 PM	5960	3,833	5,289	0	15,084	198	**15,282**	12,920	48,680	**71,396**	757.47	756.96
03/May/2006 8:00 AM	6020	4,063	5,250	30	15,304	297	**15,601**	11,240	48,628	**69,922**	756.98	756.23
03/May/2006 8:00 PM	6065	4,058	5,221	31	15,313	266	**15,579**	10,264	47,735	**68,091**	756.41	755.83
04/May/2006 8:00 AM	6110	4,060	5,193	33	15,330	200	**15,530**	9,071	46,423	**65,631**	755.66	755.26
04/May/2006 8:00 PM	6145	4,057	5,195	38	15,358	183	**15,541**	7,511	45,977	**63,652**	755.04	754.46
05/May/2006 8:00 AM	6180	4,055	5,199	43	15,391	184	**15,575**	6,451	45,321	**61,963**	754.51	753.89
05/May/2006 8:00 PM	6185	3,814	5,214	14	15,199	168	**15,367**	5,482	44,127	**59,594**	753.80	753.39
06/May/2006 8:00 AM	6190	3,820	5,220	16	15,214	181	**15,395**	3,873	43,444	**57,311**	753.04	752.70
06/May/2006 8:00 PM	6158	3,811	5,229	12	15,185	181	**15,366**	2,314	43,234	**55,505**	752.45	752.02
07/May/2006 8:00 AM	6125	3,558	5,239	0	14,922	179	**15,101**	1,239	43,142	**54,065**	752.02	751.35
07/May/2006 8:00 PM	6048	3,573	5,245	0	14,866	181	**15,047**	636	42,237	**52,493**	751.51	750.81
08/May/2006 8:00 AM	5970	3,578	5,240	0	14,787	183	**14,970**	103	41,528	**51,178**	751.09	749.89
08/May/2006 7:00 PM	5860	3,575	5,223	0	14,658	182	**14,840**	0	40,641	**50,075**	750.76	748.52

Table B-2 Floodway Inlet Natural Rating Table

		ASSINIBOINE RIVER CONTRIBUTION (cfs)										
	cfs	0	5,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000	45,000	50,000
RED RIVER AT JAMES AVENUE (cfs)	20,000	742.1	740.4	738.7	737.4							
	30,000	746.6	745.2	743.9	742.6	741.5						
	40,000	750.4	749.2	748.0	746.9	745.8	744.9					
	50,000	753.8	752.7	751.7	750.7	749.7	748.8	747.9				
	60,000	756.8	755.9	754.9	754.0	753.1	752.2	751.4				
	70,000	759.7	758.8	758.0	757.1	756.3	755.5	754.7				
	80,000	762.4	761.6	760.8	760.1	759.3	758.5	757.8				
	90,000		763.9	763.2	762.6	761.9	761.2	760.6	759.9			
	100,000		765.6	765.3	764.8	764.1	763.5	762.9	762.3			
	110,000		766.7	766.3	765.9	765.5	765.2	764.7	764.2			
	120,000		767.6	767.5	767.2	766.8	766.5	766.1	765.7	765.4		
	130,000		768.5	768.2	768.0	767.7	767.5	767.3	767.0	766.6		
	140,000			768.7	768.7	768.6	768.4	768.1	767.9	767.6	767.4	
	150,000			769.1	769.0	768.8	768.7	768.6	768.5	768.5	768.3	
	160,000			769.6	769.4	769.2	769.1	768.9	768.8	768.7	768.5	768.5
	170,000			770.1	769.9	769.8	769.6	769.5	769.3	769.2	769.0	768.8
	180,000			770.5	770.4	770.3	770.2	770.0	769.9	769.7	769.5	769.4
	190,000				770.5	770.5	770.5	770.5	770.3	770.2	770.1	769.9
	200,000				770.7	770.6	770.6	770.5	770.5	770.5	770.5	770.5
	210,000				770.9	770.8	770.7	770.7	770.6	770.6	770.5	770.5
	220,000				771.1	771.0	770.9	770.8	770.7	770.7	770.6	770.5
	230,000				771.2	771.2	771.1	771.0	770.9	770.8	770.7	770.7
	240,000					771.5	771.4	771.3	771.2	771.1	771.0	770.9
	250,000					771.8	771.7	771.6	771.6	771.5	771.4	771.3
	260,000					772.1	772.0	772.0	771.9	771.8	771.7	771.6
	270,000					772.4	772.4	772.3	772.2	772.1	772.1	772.0
	280,000					772.8	772.7	772.6	772.5	772.5	772.4	772.3
	290,000					773.1	773.0	772.9	772.8	772.8	772.7	772.6
	300,000					773.3	773.3	773.2	773.1	773.1	773.0	772.9

Notes:
- Steady state conditions
- Open water conditions (no ice)