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Updated Flood Extents for the Waterford River

October 1998

Water Resources Management Division
Department of Environment and Labour
Government of Newfoundland and Labrador

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Table of Contents

List of Figures

List of Tables

Appendices

Summary

There have been suggestions that 'flooding' is more frequent now than 10 to 15 years ago, especially along the Waterford River valley in the Mount Pearl area. The purpose of this study was to update the flood risk mapping analysis carried out in 1988, with particular emphasis on the Donovans Park to Kilbride stretch of the Waterford River. The scope of the study was limited to using updated recorded flow information for the Waterford River to re-calculate the predicted flood extents. The methodology, except for using a revised version of HEC2, namely, HEC-RAS, and other technical data were similar to the 1988 study.

Analysis of the current flow records indicate that the updated 20-year and 100-year flood flows at the hydrometric station 02ZM010 in Mount Pearl are higher at 33.4 m^3/s and 45.5 m^3/s, respectively, compared to the design 20-year and 100-year peak flows of 26.2 m^3/s and 36.2 m^3/s, respectively, used in the 1988 study. The presence of a trend in the flow record from 1974 to 1996 at hydrometric station 02ZM008 near Kilbride suggested that, for the purposes of this study, the design 20-year and 100-year flood flows of the 1988 study should be used until an assessment of the trend can be done.

Using the new hydraulic model, HEC-RAS, the results of the 1988 study were replicated except for a few sections located near bridges. The differences in elevations ranged mainly between +3 and -3 cm, but more importantly, the differences in sections close to areas such as Forest Avenue and Riverview Avenue, areas where the topography is flat and where higher flood flows would change the previous flood extents considerably, the differences were less than 1 cm and in several instances close to zero.

The results on flood levels obtained using HEC-RAS with the updated 20-year and 100-year flood flows indicate that, on the average, the new 20-year and 100-year flood levels are, respectively, about 15 cm and 17 cm higher that those extracted from the 1988 flood risk maps.

Although the 100-year flood line moved outwardly, because of the higher flood levels, the migration was comparatively less than the migration of the 20-year flood line. For the 20-year flood line, wherever the topography allowed it, the extent moved considerably more and hence came closer to the 100-year flood line.

1.0 Introduction

The main tributary of the Waterford River extends westward from St. John's Harbour, through Mount Pearl and further west toward the headwaters near Bremigens. A second tributary, South Brook, joins the main tributary below Bowring Park at Kilbride.

There have been suggestions that 'flooding' is more frequent now than 10 to 15 years ago, especially along the Waterford River valley in the Mount Pearl area [1]. In addition, during peak flow periods, higher water flow velocities have been noted. These changes are attributed to an increase in urbanized areas within the watershed.

The purpose of this study is to update the hydrotechnical analysis carried out in 1988 [2], with particular emphasis on the Donovans Park to Kilbride stretch of the Waterford River. The analysis will include re-calculations of the 1:20 year and 1:100 year flood flows and water levels.

Since the required engineering surveys and calibration/validation procedures for hydrologic and hydraulic modelling for the Waterford River for flood extent determination have already been done as part of the 1988 study, the reader is referred to that study for technical details. The scope of this study will be limited to using updated recorded flow information for the Waterford River to re-calculate the predicted flood extents. While the effects of any land use changes in the watershed will be reflected in recorded flows in the Waterford River, the modelling and investigation of causes of any of the changes in the flow patterns and/or magnitudes are outside the scope of this particular study.

2.0 Hydrologic Analysis

2.1 Data

There are two hydrometric stations on the Waterford River of interest for this study, namely:

(1) 02ZM008 - Waterford River at Kilbride with a flow record from 1974 to 1996, and

(2) 02ZM010 - Waterford River at Mount Pearl with a flow record from 1981 to 1995 (this station has been closed since 1996).

The recorded annual maximum instantaneous flows at these two hydrometric stations are given in Tables 1 and 2.

Table 1 Annual Extreme Flows of Waterford River at Kilbride - Station 02ZM008

Year	Month	Maximum Instantaneous (m^3/s)	Month	Maximum Daily (m^3/s)
1974	AUG	30.9	DEC	17.2
1975	AUG	21.8	MAY	13.2
1976	JAN	28.3	JAN	22.6
1977	DEC	40.2	DEC	24.7
1978	JAN	30.9	JAN	18.7
1979	JAN	34.5	JAN	28.5
1980	OCT	22.7	DEC	14.8
1981	NOV	66.1	NOV	27.8
1982	OCT	53.4	OCT	25.3
1983	OCT	41.7	OCT	18.8
1984	FEB	36.6	APR	24.5
1985	(MAY)	(48.8)***	MAY	32.5
1986	APR	62.7	APR	38.2
1987	APR	31.1	APR	27.1
1988	(FEB)	(37.5)	FEB	25.0
1989	DEC	44.3	FEB	22.6
1990	MAR	45.4	MAY	28.3
1991	FEB	56.3	FEB	45.2
1992	MAR	58.7	MAR	27.8
1993	FEB	54.5	FEB	27.5
1994	(MAR)	(43.5)	MAR	29.0
1995	JAN	50.8	JAN	36.5
1996	SEP	67.5	SEP	21.5

*** Flow values and month of occurrence in brackets have been inferred from the maximum daily flow data and date of occurrence.

Table 2 Annual Extreme Flows of Waterford River at Mount Pearl - Station 02ZM010

Year	Month	Maximum Instantaneous (m^3/s)	Month	Maximum Daily (m^3/s)
1981	NOV	26.7	...	...
1982	OCT	11.0	OCT	5.90
1983	OCT	15.9	OCT	7.76
1984	FEB	14.0	APR	7.80
1985	MAY	16.8	MAY	11.1
1986	APR	25.5	APR	12.5
1987	APR	10.4	APR	9.11
1988	FEB	16.5	FEB	11.2
1989	DEC	13.3	FEB	5.91
1990	MAR	11.3	MAR	9.12
1991	FEB	17.1	FEB	14.6
1992	MAR	11.5	MAR	7.74
1993	FEB	29.8	FEB	13.3
1994	MAR	28.9	MAR	9.39
1995	JAN	28.3	JAN	19.1
1996	...	...	...	...

2.2 Analysis of Recorded Flood Flows

2.2.1 Station 02ZM010 - Waterford River at Mount Pearl

Figure 1 shows the annual maximum instantaneous flows of the Waterford River at Mount Pearl. Statistical analysis of the 15-year annual maximum instantaneous flow record at 02ZM010 indicates that the series does not display any significant serial dependence, and does not display significant trend. It is therefore suitable for frequency analysis.

Table 3 shows the results of a frequency analysis of the flood flows for different periods of record. For the 1981-95 record, the 20-year and 100-year flood flows are 33.4 m^3/s and 45.5 m^3/s respectively. These can be compared to the results from the other periods, namely, 1981-87, 1981-95, 1988-95. The probability distribution used for fitting the data was the Log-Pearson Type III (LPT3) distribution. The results from the different periods seem to be consistent with one another. However, the design 20-year and 100-year peak flows of 26.2 m^3/s and 36.2 m^3/s, respectively, used in the 1988 study at 02ZM010 are relatively significantly lower. It should be noted that these flows were obtained from hydrologic simulation of precipitation events from 1959 to 1986 because the flow record at 02ZM010 was not long enough at the time of the 1988 study for reliable frequency analysis.

For the purposes of the study, the updated 20-year and 100-year flood flows are therefore 33.4 m^3/s and 45.5 m^3/s respectively

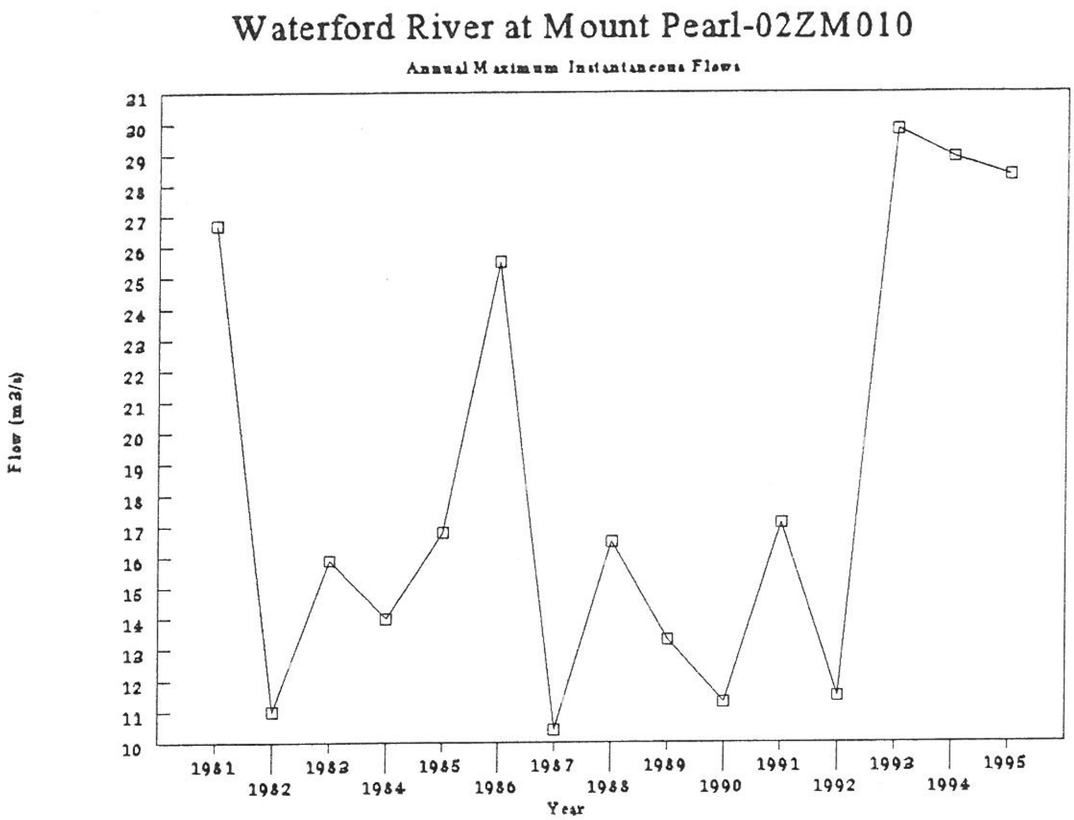

Figure 1 **Recorded Flood Flows at Mount Pearl**

Table 3 Summary Results at 02ZM008 and 02ZM010

	02ZM010	02ZM008
	1959-86 Simulated	1959-86 Simulated
Design 2-year Peak Flow	---	41.5 3PLN
Design 20-year Peak Flow	26.2 3PLN	83.3 3PLN
Design 100-year Peak Flow	36.2 3PLN	118.0 3PLN
	1981-87 Observed	1974-87 Observed
2-year Peak Flow	15.9 LPT3	34.0 3PLN
20-year Peak Flow	30.8 LPT3	70.6 3PLN
100-year Peak Flow	41.9 LPT3	104.0 3PLN
	1981-95 Observed	1974-96 Observed
2-year Peak Flow	16.9 LPT3	43.1 3PLN
20-year Peak Flow	33.4 LPT3	67.2 3PLN
100-year Peak Flow	45.5 LPT3	78.6 3PLN
	1981-87 Observed	1974-85 Observed
2-year Peak Flow	15.9 LPT3	35.2 3PLN
20-year Peak Flow	30.8 LPT3	65.7 3PLN
100-year Peak Flow	41.9 LPT3	88.0 3PLN
	1988-95 Observed	1986-96 Observed
2-year Peak Flow	17.9 LPT3	50.7 3PLN
20-year Peak Flow	36.7 LPT3	67.4 3PLN
100-year Peak Flow	50.6 LPT3	73.5 3PLN
		1959-86 Simulated 1987-96 Observed
2-year Peak Flow		43.7 3PLN
20-year Peak Flow		77.7 3PLN
100-year Peak Flow		101.0 3PLN

2.2.2 Station 02ZM008 - Waterford River at Kilbride

Figure 2 shows the annual maximum instantaneous flows of the Waterford River at Kilbride. Statistical analysis of the 23-year annual maximum instantaneous flow record at 02ZM008 indicates that the series displays serial dependence at the 5% level of significance, but not at the 1% level of significance. However, the record shows a significant temporal trend. Analysis of the time series of peak flows indicates that the early part of the record (from 1974 to 1980) was dominated by relatively lower flood flows, compared to relatively higher flood flows from 1981 onwards. This trend merits to be analysed further, but lack of digital information on land use changes prevented the incorporation of the analysis into this study. The presence of a significant trend in the record does not permit a reliable frequency analysis, and any result from such an analysis should be used with caution.

Table 3 shows the results of a frequency analysis of the flood flows for different periods of record, although such an analysis is strictly not suitable for design purposes. For the 1974-96 record, the 20-year and 100-year flood flows are 67.2 m^3/s and 78.6 m^3/s respectively. These are much lower than the design 20-year and 100-year peak flows of 83.3 m^3/s and 118.0 m^3/s, respectively, used in the 1988 study at 02ZM008. It should be noted that these flows were obtained from hydrologic simulation of precipitation events from 1959 to 1986. The results for the 1974-87 record, (this record most closely matches the simulated 1959-86 period), are however comparable to, although still lower than, the design flows.

The presence of a trend in the flow record from 1974 to 1996 at 02ZM008 suggests that, for the purposes of this study, the design 20-year and 100-year flood flows of the 1988 study should be used until an assessment of the trend can be done.

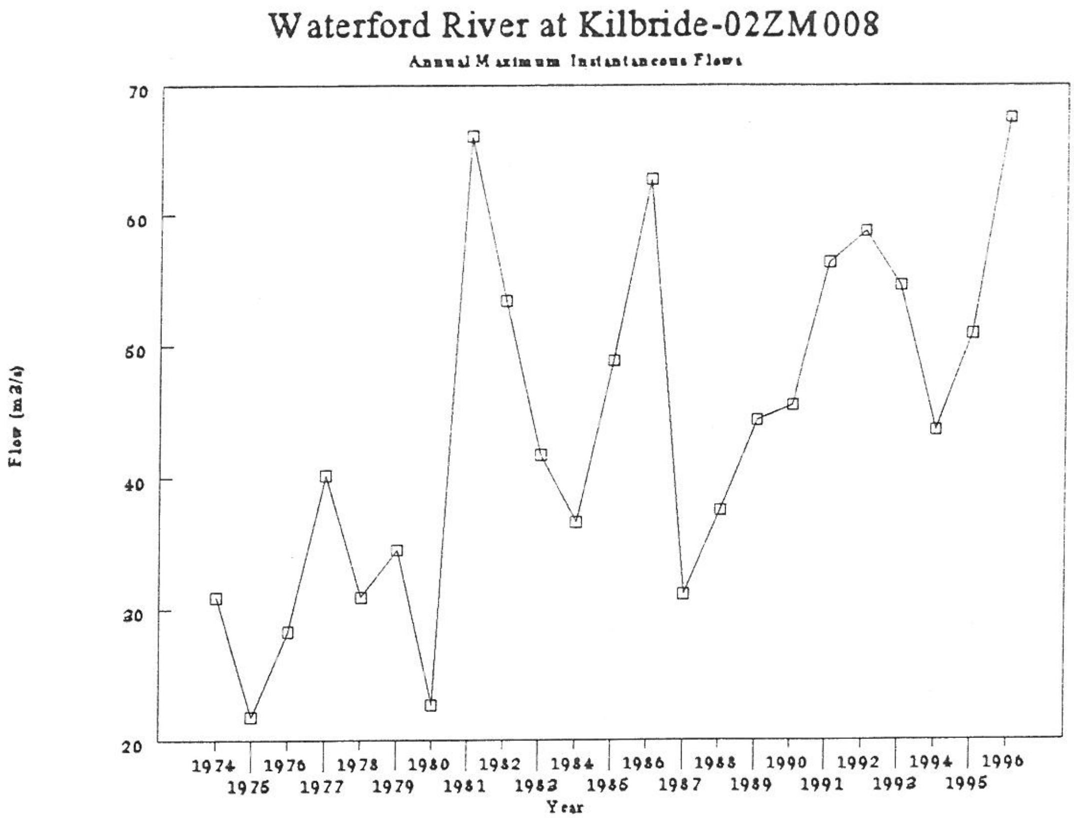

Figure 2 **Recorded Flood Flows at Kilbride**

3.0 Hydraulic Modelling

The hydraulic modelling of flood flows for the Waterford River followed the same procedure as that performed in 1988 [2], with the exception that an updated version of HEC, namely, HEC-RAS, was used. HEC-RAS is a completely new software (see HEC-RAS River Analysis System User's Manual, [3]). The hydraulic routines have been completely re-written. Also, HEC-RAS provides improved graphical capabilities for entering, editing and viewing data.

The first step in the application of HEC-RAS was to verify that the results of 1988 could be replicated. The 1988 HEC file with cross-section and flow data was imported into HEC-RAS. Table A.1 in Appendix A shows a comparison of flow levels generated from HEC-RAS with the flow levels extracted from the 1988 flood risk maps. Except for a few sections located near bridges, the differences range between +3 and -3 cm. Excluding the bridge sections, the average absolute difference for the 20-year flood event was 3 cm, while for the 100-year event it was 4 cm. More importantly, the differences in sections close to areas such as Forest Avenue and Riverview Avenue, areas where the topography is flat and where higher flood flows would change the previous flood extents considerably, the differences were less than 1 cm and in several instances close to zero. The differences at sections other than bridge sections can be traced to the different way of calculating conveyance in HEC-RAS. HEC-RAS was run in HEC mode as far as conveyance computation was concerned, and the differences were reduced to about 1 - 2 cm. However, it was decided to stay with the HEC-RAS as the conveyance routine therein has been suggested to be more accurate.

The major disagreements are at the bridge sections and these can be traced to a significantly different algorithm used in HEC-RAS for simulating flow at bridge sections. Moreover, bridge sections are defined differently in HEC-RAS and this caused some problems in the translation of HEC data to HEC-RAS format. Some of the more obvious problems were corrected. Some others may still exist. Matching the elevations at bridges would require adjustment of pressure flow coefficients, contraction and expansion coefficients, among others, and this will mean a complete re-calibration of the HEC-RAS model. These would take far more time to resolve for the purposes of this study. In any case, the differences in flood levels did not extend far beyond the bridge sections. And most of the areas of interest were the relatively "flat"areas which were some distance from the nearest bridges. For these reasons, as long as results at the critical sections of interest could be replicated and results at the few sections with discrepancies in the definition of the bridge sections could be disregarded, no attempt was made to investigate the differences further.

The second step in the hydraulic modelling using HEC-RAS was to substitute the 20-year and 100-year flood flows with the values calculated using the updated flow data. As given in Table 3, the 20-year flood flow at Hydrometric Station 02ZM010 - Waterford River at Mount Pearl - was 33.4 m^3/s, and the 100-year flood flow was 45.5 m^3/s. As discussed previously, the 20-year and 100-year flood flows at Hydrometric Station 02ZM008 - Waterford River at Kilbride - were the same as used in the 1988 study. The flood flows at the HEC-RAS river sections, other than at the two gauged sections, were in exactly the same relative magnitudes as used in the 1988 study.

Table A.2 in Appendix A gives the flood levels obtained using HEC-RAS with the updated 20-year and 100-year flood flows. The results (again, ignoring water levels at bridge sections) indicate that, on the average, the new 20-year and 100-year flood levels are, respectively, about 15 cm and 17 cm higher that those extracted from the 1988 flood risk maps.

3.1 Summary 20-Year and 100-Year Flood Levels

Table 4 summarizes the revised 20-year and 100-year flood levels at several sections along the Waterford River. These levels were used to generate the updated flood extents.

4.0 Plotting of 20-Year and 100-Year Flood Extents

The plotting of the updated 20-year and 100-year flood extents was done in 3 steps:

(a) The digital map of the study area of Mount Pearl was loaded on the Division's GIS. The topographic layer, with 2-metre contours, was converted into a 1-m grid elevation layer. The water elevations at the HEC-RAS sections (assuming constant water level across each cross-section) were similarly converted into a 1-m grid flood elevation layer. The topographic and water elevation layers were intersected to determine the flood extents. However, because the elevation contours were at 2-m intervals, the delineated flood extents were not as accurate as could have been obtained from 0.5-m contour intervals, which is the resolution of the hard-copy 1988 flood risk maps.

(b) To compensate for the relative coarseness of the elevation data, as discussed in part (a), the locations of the flood extents at each river section used in the HEC-RAS model (excluding bridge sections) were determined using the cross-sectional elevation data and flood levels. These were then plotted on the digital extent obtained in part (a). Using these locations as guide, the flood extents were adjusted digitally.

(c) Finally, the flood extents were adjusted on the basis of several spot elevations surveyed by the City of Mount Pearl and also on the basis of known structural constraints, such as buildings and railway tracks.

The updated flood extents are shown on the accompanying D-size plots. The significant difference between the new flood extents and those in the 1988 flood risk maps is the movement of the 20-year flood line. Under the updated 20-year flood scenario, it is much closer to the 100-year flood line. Although the 100-year flood line moved outwardly, because of the higher flood levels, the migration was slight because of the topography along the river banks. For the 20-year flood line, wherever the topography allowed it, the extent moved considerably more and hence came closer to the 100-year flood line.

Table 4 Updated 20-Year and 100-Year Flood Levels

Section	Q20-1998 (m)	Q100-1998 (m)
12408	136.06	136.39
12384	136.11	136.47
12369	135.97	136.24
12365	135.90	136.03
13720	156.32	156.37
13629	154.04	154.09
13607	153.34	153.40
13579	153.18	153.21
13569	153.17	153.21
13470	151.82	151.86
13445	150.42	150.49
13330	147.37	147.41
13229	146.00	146.00
13200	145.41	145.43
13146	144.92	145.06
13117	144.39	144.47
13090	144.16	144.27
13002	143.40	143.35
12763	141.67	141.83
12747	141.71	141.86
12735	141.50	141.57
12593	140.00	140.06
12572	139.73	139.77
12458	137.83	137.92
12354	136.13	136.28
12338	135.99	136.13
12323	135.57	135.69
12312	135.59	135.78
12302	135.54	135.70
12244	135.40	135.57
12235	135.37	135.55
12233	135.22	135.52
12227	135.20	135.51
12200	135.19	135.51
12124	135.18	135.50
12045	135.14	135.47
11942	135.13	135.46
11938	135.00	135.29
11933	134.99	135.25
11930	134.89	135.02
11924	134.93	135.09
11918	134.96	135.14
11873	134.85	135.00
11758	133.32	133.71
11650	132.81	133.29
11480	130.51	130.64
11340	129.10	129.25
11050	126.00	126.13
10840	124.75	124.96
10582	122.71	122.95
10247	113.93	114.08

Table 4 (cont.) Updated 20-Year and 100-Year Flood Levels

Section	Q20-1998 (m)	Q100-1998 (m)
9851	111.74	113.00
9836	110.75	110.98
9645	108.93	109.11
9415	106.41	106.53
9260	105.42	105.53
9048	104.64	104.73
8988	104.43	104.52
8896	103.94	104.06
8842	103.72	103.86
8776	103.44	103.61
8629	103.17	103.38
8606	103.12	103.34
8508	103.02	103.25
8357	102.94	103.16
8232	102.88	103.10
8120	102.85	103.06
8022	102.83	103.05
7963	102.77	102.98
7947	102.70	102.89
7697	100.70	100.81
7363	87.63	87.65
7193	85.44	85.85
7070	78.88	78.95
6984	76.64	77.22
6970	75.93	77.29
6955	75.92	76.14
6940	75.91	76.16
6910	75.49	75.71
6736	65.32	65.64
6450	64.23	64.48
6200	62.78	63.16
5895	60.10	60.10

5.0 Discussion

The results tend to corroborate observations [1] during flooding events along the Waterford River. In particular, the outward migration of the 20-year flood line suggests that some areas are being flooded "more often" than the previous 20-year flood line would indicate. As well, flow velocities would also be perceived to be higher.

Although the updated 20-year and 100-year flood magnitudes are higher than those used in the 1988 study, and a temporal trend towards higher flood flows seems be present in the flow record at the hydrometric station near Kilbride, this study has not addressed the question of whether the changes are related to land use changes in the watershed. Such a study should be undertaken to determine the causes of the trend and their implications for flood plain management of the Waterford River.

It should also be noted that the hydrometric station in Mount Pearl is no longer operational since 1996. It is clear that data from this station is crucial for determining flood extents and for managing the flood plain in the future, especially if there is indeed a trend as the flow record at Kilbride seems to indicate.

6.0 Recommendations

1. The Water Resources Management Division should revise the designated flood risk maps for Mount Pearl to reflect the new extents of the 20-year and 100-year flood lines. These lines should then be adopted by the City of Mount Pearl for planning purposes.

2. The Water Resources Management Division should investigate whether there is an increasing trend in flood flows in the Waterford River, the causes of the increase if any, and the implications for flood plain management of the river.

3. The City of Mount Pearl should consider cost-sharing the re-activation of the hydrometric station 02ZM010 in Mount Pearl under the Canada-Newfoundland Hydrometric Agreement.

7.0 References

[1] Letter dated July 31, 1997 from City of Mount Pearl to Robert Picco of Water Resources Division, Department of Environment and Labour.

[2] Fenco Newfoundland, June 1988, Hydrotechnical Study of the Waterford River Area (Main Report and Technical Appendices), Canada-Newfoundland Flood Damage Reduction Program, Environment Canada and Newfoundland Department of Environment and Lands.

[3] US Army Corps of Engineers, Hydrologic Engineering Center, April 1997, HEC-RAS River Analysis System, User's Manual, version 2.0.

Appendix A

HEC-RAS Simulation Results

Table A.1 Flood Levels Verification using HEC-RAS

Section	Reach	Z-Q20-1988	Z-Q20-1988	Difference	Z-Q100-1988	Z-Q100-1988	Difference
(Maps)	HEC-RAS	1988 Maps (m)	HEC-RAS (m)	(cm)	1988 Maps (m)	HEC-RAS (m)	(cm)
12570	209	136.75	138.06	131	137.77	138.08	31
12429	208	136.72	138.06	134	137.77	138.08	31
12418	207	136.71	138.06	135	137.75	138.08	33
12408	206	135.99	135.99	0	136.11	136.14	3
12384	205	135.91	135.95	4	136.19	136.23	4
12369	204	135.76	135.84	8	135.90	136.06	16
12365	202	135.76	135.80	4	135.89	135.94	5
12355	201	135.56	135.74	18	135.73	135.91	18
13720	199	156.24	156.24	0	156.29	156.29	0
13629	198	153.98	153.98	0	154.02	154.02	0
13607	197	153.26	153.26	0	153.31	153.31	0
13597	196	153.05	153.16	11	153.17	153.31	14
13579	195	153.03	153.05	2	153.14	153.16	2
13569	193	153.04	153.03	-1	153.16	153.14	-2
13550	192	152.93	153.05	12	153.09	153.16	7
13470	191	151.81	151.89	8	151.86	151.80	-6
13445	189	150.32	150.33	1	150.39	150.39	0
13330	188	147.31	147.31	0	147.35	147.35	0
13266	187	146.56	146.55	-1	146.73	146.77	4
13255	186	146.40	146.57	17	146.51	146.79	28
13244	185	146.16	146.16	0	146.22	146.22	0
13229	183	145.90	145.91	1	145.95	145.96	1
13200	182	145.36	145.35	-1	145.39	145.39	0
13146	181	144.86	144.86	0	144.90	144.90	0
13140	180	144.54	144.63	9	144.65	144.80	15
13117	179	144.22	144.29	7	144.27	144.36	9
13090	177	144.06	144.04	-2	144.13	144.12	-1
13002	176	143.32	143.38	6	143.37	143.39	2
12763	175	141.54	141.49	-5	141.63	141.61	-2
12747	174	141.46	141.54	8	141.51	141.65	14
12735	173	141.37	141.39	2	141.39	141.46	7
12717	171	141.29	141.19	-10	141.29	141.20	-9
12607	168	140.43	140.53	10	140.58	140.70	12
12593	166	139.88	139.92	4	139.91	139.97	6
12572	164	139.68	139.68	0	139.71	139.72	1
12458	163	137.72	137.72	0	137.78	137.78	0
12354	162	135.91	135.93	2	136.05	136.06	1
12338	161	135.79	135.81	2	135.91	135.93	2
12323	156	135.50	135.51	1	135.61	135.62	1
12312	155	135.48	135.50	2	135.63	135.64	1
12302	154	135.44	135.46	2	135.57	135.57	0
12244	153	135.31	135.34	3	135.43	135.42	-1
12235	152	135.28	135.32	4	135.41	135.39	-2
12233	150	135.15	135.13	-2	135.37	135.22	-15
12227	147	134.94	134.98	4	135.39	135.27	-12
12200	146	134.92	134.97	5	135.38	135.26	-12
12124	145	134.90	134.95	5	135.37	135.25	-12
12045	144	134.84	134.90	6	135.35	135.21	-14
11942	143	134.83	134.90	7	135.34	135.20	-14
11938	142	134.72	134.79	7	135.22	135.06	-16
11933	141	134.72	134.79	7	135.20	135.05	-15
11930	140	134.72	134.78	6	135.05	134.92	-13

Table A.1 (cont.) Flood Levels Verification using HEC-RAS

Section	Reach	Z-Q20-1988	Z-Q20-1988	Difference	Z-Q100-1988	Z-Q100-1988	Difference
(Maps)	HEC-RAS	1988 Maps (m)	HEC-RAS (m)	(cm)	1988 Maps (m)	HEC-RAS (m)	(cm)
11924	139	134.74	134.80	6	135.09	134.96	-13
11918	138	134.77	134.83	6	135.12	135.00	-12
11873	137	134.66	134.73	7	135.05	134.88	-17
11774	136	134.39	133.79	-60	134.92	134.06	-86
11767	135	134.34	133.34	-100	134.89	133.55	-134
11758	132	133.07	133.07	0	133.41	133.41	0
11650	131	132.46	132.47	1	132.93	132.92	-1
11480	130	130.38	130.42	4	130.51	130.56	5
11340	129	128.99	129.01	2	129.14	129.14	0
11050	128	125.90	125.93	3	126.03	126.04	1
10840	127	124.60	124.64	4	124.80	124.81	1
10582	126	122.57	122.60	3	122.77	122.80	3
10247	125	113.83	113.83	0	113.98	113.96	-2
10030	124	112.60	113.34	74	113.40	113.51	11
9885	123	112.66	113.36	70	113.43	113.54	11
9876	122	112.66	113.36	70	113.43	113.54	11
9870	121	111.68	113.36	168	111.95	113.53	158
9851	120	111.49	111.50	1	111.84	111.85	1
9836	119	110.61	110.61	0	110.81	110.81	0
9645	118	108.80	108.80	0	108.99	108.98	-1
9415	117	106.32	106.33	1	106.44	106.44	0
9260	116	105.38	105.38	0	105.47	105.46	-1
9048	115	104.57	104.58	1	104.66	104.67	1
8988	114	104.39	104.36	-3	104.43	104.46	3
8896	113	103.85	103.87	2	103.95	103.98	3
8842	112	103.63	103.66	3	103.75	103.77	2
8776	111	103.30	103.32	2	103.48	103.50	2
8629	110	103.02	103.03	1	103.22	103.24	2
8606	109	102.96	102.97	1	103.17	103.19	2
8508	108	102.87	102.88	1	103.08	103.10	2
8357	107	102.79	102.80	1	103.00	103.01	1
8232	106	102.73	102.74	1	102.95	102.95	0
8120	105	102.70	102.70	0	102.92	102.92	0
8022	104	102.69	102.69	0	102.91	102.91	0
7963	103	102.64	102.64	0	102.85	102.84	-1
7947	102	102.58	102.58	0	102.77	102.76	-1
7697	101	100.64	100.65	1	100.72	100.74	2
7585	100	94.99	95.01	2	95.61	95.61	0
7363	99	87.45	87.49	4	87.69	87.69	0
7193	98	85.29	85.32	3	85.56	85.55	-1
7070	97	78.82	78.83	1	78.91	78.91	0
6984	96	76.51	76.47	-4	76.73	76.72	-1
6970	95	75.79	75.83	4	75.97	76.05	8
6955	94	75.83	75.82	-1	76.04	76.04	0
6940	93	75.80	75.80	0	76.02	76.02	0
6910	92	75.40	75.40	0	75.60	75.60	0
6736	91	65.21	65.20	-1	65.50	65.49	-1
6450	90	64.06	64.09	3	64.29	64.32	3
6200	89	62.63	62.67	4	63.00	63.02	2
5895	88	59.88	59.95	7	59.96	59.96	0
5615	87	57.69	57.65	-4	58.05	58.88	83

Table A.2 Flood Levels using HEC-RAS with Updated Flood Flows

Section (Maps)	Reach HEC-RAS		Z-Q20-1988 1988 Maps (m)	Z-Q20-1998 HEC-RAS (m)	Difference (cm)		Z-Q100-1988 1988 Maps (m)	Z-Q100-1998 HEC-RAS (m)	Difference (cm)
12570	209		136.75	138.04	129		137.77	138.12	35
12429	208		136.72	138.04	132		137.77	138.12	35
12418	207		136.71	138.04	133		137.75	138.12	37
12408	206		135.99	136.06	7		136.11	136.39	28
12384	205		135.91	136.11	20		136.19	136.47	28
12369	204		135.76	135.97	21		135.90	136.24	34
12365	202		135.76	135.90	14		135.89	136.03	14
12355	201		135.56	135.87	31		135.73	136.05	32
13720	199		156.24	156.32	8		156.29	156.37	8
13629	198		153.98	154.04	6		154.02	154.09	7
13607	197		153.26	153.34	8		153.31	153.40	9
13597	196		153.05	153.35	30		153.17	153.45	28
13579	195		153.03	153.18	15		153.14	153.21	7
13569	193		153.04	153.17	13		153.16	153.21	5
13550	192		152.93	153.18	25		153.09	153.22	13
13470	191		151.81	151.82	1		151.86	151.86	0
13445	189		150.32	150.42	10		150.39	150.49	10
13330	188		147.31	147.37	6		147.35	147.41	6
13266	187		146.56	146.86	30		146.73	147.08	35
13255	186		146.40	146.88	48		146.51	147.10	59
13244	185		146.16	145.97	-19		146.22	146.01	-21
13229	183		145.90	146.00	10		145.95	146.00	5
13200	182		145.36	145.41	5		145.39	145.43	4
13146	181		144.86	144.92	6		144.90	145.06	16
13140	180		144.54	144.89	35		144.65	145.13	48
13117	179		144.22	144.39	17		144.27	144.47	20
13090	177		144.06	144.16	10		144.13	144.27	14
13002	176		143.32	143.40	8		143.37	143.35	-2
12763	175		141.54	141.67	13		141.63	141.83	20
12747	174		141.46	141.71	25		141.51	141.86	35
12735	173		141.37	141.50	13		141.39	141.57	18
12717	171		141.29	141.23	-6		141.29	141.42	13
12607	168		140.43	140.80	37		140.58	141.02	44
12593	166		139.88	140.00	12		139.91	140.06	15
12572	164		139.68	139.73	5		139.71	139.77	6
12458	163		137.72	137.83	11		137.78	137.92	14
12354	162		135.91	136.13	22		136.05	136.28	23
12338	161		135.79	135.99	20		135.91	136.13	22
12323	156		135.50	135.57	7		135.61	135.69	8
12312	155		135.48	135.59	11		135.63	135.78	15
12302	154		135.44	135.54	10		135.57	135.70	13
12244	153		135.31	135.40	9		135.43	135.57	14
12235	152		135.28	135.37	9		135.41	135.55	14
12233	150		135.15	135.22	7		135.37	135.52	15
12227	147		134.94	135.20	26		135.39	135.51	12
12200	146		134.92	135.19	27		135.38	135.51	13
12124	145		134.90	135.18	28		135.37	135.50	13
12045	144		134.84	135.14	30		135.35	135.47	12
11942	143		134.83	135.13	30		135.34	135.46	12
11938	142		134.72	135.00	28		135.22	135.29	7
11933	141		134.72	134.99	27		135.20	135.25	5
11930	140		134.72	134.89	17		135.05	135.02	-3

Table A.2 (cont.) Flood Levels using HEC-RAS with Updated Flood Flows

Section	Reach		Z-Q20-1988	Z-Q20-1998	Difference		Z-Q100-1988	Z-Q100-1998	Difference
(Maps)	HEC-RAS		1988 Maps (m)	HEC-RAS (m)	(cm)		1988 Maps (m)	HEC-RAS (m)	(cm)
11924	139		134.74	134.93	19		135.09	135.09	0
11918	138		134.77	134.96	19		135.12	135.14	2
11873	137		134.66	134.85	19		135.05	135.00	-5
11774	136		134.39	133.98	-41		134.92	134.30	-62
11767	135		134.34	133.49	-85		134.89	133.72	-117
11758	132		133.07	133.32	25		133.41	133.71	30
11650	131		132.46	132.81	35		132.93	133.29	36
11480	130		130.38	130.51	13		130.51	130.64	13
11340	129		128.99	129.10	11		129.14	129.25	11
11050	128		125.90	126.00	10		126.03	126.13	10
10840	127		124.60	124.75	15		124.80	124.96	16
10582	126		122.57	122.71	14		122.77	122.95	18
10247	125		113.83	113.93	10		113.98	114.08	10
10030	124		112.60	113.48	88		113.40	113.64	24
9885	123		112.66	113.51	85		113.43	113.68	25
9876	122		112.66	113.51	85		113.43	113.68	25
9870	121		111.68	113.50	182		111.95	113.66	171
9851	120		111.49	111.74	25		111.84	113.00	116
9836	119		110.61	110.75	14		110.81	110.98	17
9645	118		108.80	108.93	13		108.99	109.11	12
9415	117		106.32	106.41	9		106.44	106.53	9
9260	116		105.38	105.42	4		105.47	105.53	6
9048	115		104.57	104.64	7		104.66	104.73	7
8988	114		104.39	104.43	4		104.43	104.52	9
8896	113		103.85	103.94	9		103.95	104.06	11
8842	112		103.63	103.72	9		103.75	103.86	11
8776	111		103.30	103.44	14		103.48	103.61	13
8629	110		103.02	103.17	15		103.22	103.38	16
8606	109		102.96	103.12	16		103.17	103.34	17
8508	108		102.87	103.02	15		103.08	103.25	17
8357	107		102.79	102.94	15		103.00	103.16	16
8232	106		102.73	102.88	15		102.95	103.10	15
8120	105		102.70	102.85	15		102.92	103.06	14
8022	104		102.69	102.83	14		102.91	103.05	14
7963	103		102.64	102.77	13		102.85	102.98	13
7947	102		102.58	102.70	12		102.77	102.89	12
7697	101		100.64	100.70	6		100.72	100.81	9
7585	100		94.99	95.50	51		95.61	95.77	16
7363	99		87.45	87.63	18		87.69	87.65	-4
7193	98		85.29	85.44	15		85.56	85.85	29
7070	97		78.82	78.88	6		78.91	78.95	4
6984	96		76.51	76.64	13		76.73	77.22	49
6970	95		75.79	75.93	14		75.97	77.29	132
6955	94		75.83	75.92	9		76.04	76.14	10
6940	93		75.80	75.91	11		76.02	76.16	14
6910	92		75.40	75.49	9		75.60	75.71	11
6736	91		65.21	65.32	11		65.50	65.64	14
6450	90		64.06	64.23	17		64.29	64.48	19
6200	89		62.63	62.78	15		63.00	63.16	16
5895	88		59.88	60.10	22		59.96	60.10	14
5615	87		57.69	57.73	4		58.05	58.97	92