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1 INTRODUCTION

1.1 BACKGROUND

Marshall Macklin Monaghan Limited has been retained by the Toronto and Region Conservation Authority to update the hydrologic model for the Don River watershed. The model was originally formulated in the late 1970s and subsequently updated in the early 1990s. However, the TRCA felt the necessity to update the 1990s model due to the following reasons:

- The 1990s model was based on the HYMO computer program, which is slightly outdated at present, and seldom used for current watershed modelling. Hence, the previous model needed to be updated to Visual OTTHYMO (Version 2.0), which is the latest transformation of the HYMO model.

- There has been significant development in the Don watershed over the last 10 years. It was necessary to update the model to reflect the current development condition in the watershed. The City of Toronto recently completed their Wet Weather Flow Management study, during which, current land use data and statistics were collected for the Don River watershed. Hence this data can now be used to update the TRCA hydrologic model.

- In May 2000, there was a significant storm event, which resulted in a flood that ranged from a 5-year to 25-year event depending on the location in the Don watershed. This provided an ideal opportunity to calibrate and validate the updated model to this relatively rare event.

1.2 SCOPE OF WORK

The following tasks were identified in the Scope of Work for the Don hydrologic update:

- Conversion of the HYMO model from the previous update to Visual OTTHYMO Version 2.0 (VO2);

- Model update based on the current development condition in the watershed from the information available on existing land use from the City of Toronto Wet Weather

Flow Management Plan information south of Steeles, and 2002 orthophotography north of Steeles. All existing SWM ponds in the watershed should be incorporated in the updated watershed model using a "lumped" catchment approach;

- Calibration and verification of the model based mainly on the May 2000 storm event;
- Update of future conditions model based on areas of land use intensification identified south of Steeles Avenue in the Toronto WWFMP, and municipal and Regional OP's and OPA's for the north of Steeles areas;
- Simulation of appropriate 25mm, 2, 5, 10, 25, 50 and 100 year design events, and the Regional Storm using the updated and verified models, and documentation of results;
- Identifying areas affected by significant changes in flow conditions, including flood vulnerable areas and sites, active valley land use, and any other critical areas identified by the TRCA;
- Review of unit flow methodologies for the Humber and Don watersheds, and comparison of methodologies to confirm applicability of current method used in the Don watershed. Catchment flows should be updated if required based on the updated hydrologic model;
- Providing a summary of SWM quantity control recommendations as outlined in the Toronto WWFMP. Identifying opportunities in the City of Toronto where additional quantity controls may be beneficial, and simulating an additional scenario which incorporates these controls;
- Preparation of a report documenting the results of the hydrologic update, including all supporting calculations, conclusions and recommendations;
- Preparing a "user's guide" and a detailed protocol for future updates of the model.

1.3 RELEVANT PREVIOUS STUDIES

An extensive review of relevant studies was conducted for the present hydrologic update. The reviewed documents are summarized below:

- *Hydrologic Model Study, Humber, Don and Rouge Rivers, Highland, Duffin, Petticoat and Curruther's Creeks, James F. MacLaren Limited (October 1979);*

- *Regional Storm Hydrology Update, Lower Don River, Marshall Macklin Monaghan Limited (October 1990);*
- *Don River Hydrology and Hydraulic Update, Marshall Macklin Monaghan Limited (August 1992);*
- *Unit Flow Rates for Stormwater Control, Upper Don River Watershed, Marshall Macklin Monaghan Limited (November 1994);*
- *Hydrology/Hydraulics and Stormwater Management Study, Humber River Watershed;*
- *City of Toronto Wet Weather Flow Master Plan – Stage 2, Marshall Macklin Monaghan Limited (July 2003);*
- *Rouge River Hydrology Update, Marshall Macklin Monaghan Limited (2002).*

1.4 ORGANIZATION OF REPORT

Briefly, the layout of the present report is as follows:

Section 2 describes the methodology adopted for the development of the VO2 model for the Don River watershed. Section 2.1 focuses on the conversion, update, calibration and validation of the existing conditions hydrologic model. Section 2.2 provides relevant background information used for the development of the future conditions model.

Section 3 discusses the selection of appropriate 2 to 100-year design storms for the watershed, and the results obtained from the design storm and Regional Storm simulations performed using the validated models.

Section 4 discusses the stormwater management issues in the Don River watershed related to the present update. Section 4.1 compares the unit flow methodologies adopted for the Don and Humber watersheds, and ensures applicability of current method used in the Don watershed (developed during the 1990's hydrologic update). Section 4.2 correlates the stormwater management recommendations of the *City of Toronto Wet Weather Flow Management Master Plan (July 2003)* with the stormwater management issues identified in the present study. Stormwater controls in addition to those recommended in the City of Toronto Wet Weather Flow Management Master Plan, are also discussed briefly.

Section 5 summarizes the conclusions and recommendations of the present hydrologic update.

The "user's guide" and technical memorandum prepared to provide assistance for future updates of the watershed model are included as Appendix A.

2 MODEL UPDATE

The existing conditions HYMO models for the Don River watershed were converted to VO2 and modified to reflect the current land use in the watershed. Future conditions models were also developed based on the future land use as indicated in the official development plans of the municipalities. The following sections provide a brief discussion on the methodology used for completing the update.

2.1 EXISTING CONDITIONS MODEL

2.1.1 Model Conversion and Update

In accordance with the tasks identified in the scope of work for the present hydrologic update, the existing conditions HYMO based model from the previous update was initially converted to VO2 without changing the hydrologic parameters. It should be noted that during the development of the previous model, hydrographs from all catchments were generated using the COMPUTE HYD command in HYMO, which corresponds to the NASHYD command in OTTHYMO89 and VO2. The effect of the imperviousness was incorporated into the HYMO model by increasing the CN value estimated based on soil characteristics by a proportional amount, and by reducing K and T_p based on a formula developed in the *Hydrologic Model Study, James F. MacLaren Limited (October 1979)*. While converting the model to VO2, hydrographs from catchments with greater than 20% imperviousness, i.e. “urban” catchments, were generated using the STANDHYD command in VO2, consistent with standard practices. The original CN value estimated from soil characteristics was used as the pervious area CN. As noted in other studies, this change in subroutines yielded considerably “peakier” hydrographs for the urban catchments. Since the Don watershed is a predominantly urban watershed with more than 75% of the area already developed, the conversion of the COMPUTE HYD subroutine to the STANDHYD subroutine resulted in significant increase in peak flows throughout the watershed.

The converted VO2 model was then updated as follows:

- Hydrologic parameters for some of the catchments located north of Steeles Avenue were modified to account for the recent developments in these areas, according to the land use information collected during the preparation of the *City of Toronto Wet*

Weather Flow Master Plan, and the 2002 orthophotography provided by the TRCA. The existing land use in the Don watershed has been shown on Figure 2.1;

- SWM ponds constructed to implement the required SWM controls in the watershed and identified in the *City of Toronto Wet Weather Flow Master Plan*, were included in the model following a "lumped" pond approach. A more detailed discussion of the "lumped" SWM pond modelling has been included in Appendix A;

- In the original HYMO model, the area south of Steeles Avenue had been subdivided into 24 catchments. In the previous update underaken in the early 1990s, these 24 catchments south of Steeles Avenue remained unchanged. For the present update, a finer catchment discretization scheme was adopted in the area south of Steeles Avenue. This scheme is in better agreement with the discretization scheme adopted for the *City of Toronto Wet Weather Flow Master Plan*. Consequently the 24 catchments south of Steeles Avenue from the original model have now been subdivided into 40 catchments. The catchment boundaries from the present update are shown on Figure 2.2. The existing conditions model schematic is shown on Figure 2.3.

As evident from Figures 2.2 and 2.3, the overall modelling schematic, catchment delineation and numbering system from the original model were largely preserved during the present update. However, the above modifications made it necessary to recalibrate and validate the updated VO2 model.

2.1.2 Calibration and Validation

2.1.2.1 May 12/13 2000

As mentioned earlier, the May12/13 2000 rainstorm was selected as the main calibration event. Since the characteristics of this storm varied considerably according to its location in the watershed, the calibration was performed using rainfall data from five different rain gauges throughout the watershed. The locations of these gauges are shown on Figure 2.2. The peak intensities and rainfall amounts recorded at these eight stations during the May12/13 2000 event are summarized in Table 2.1.

TABLE 2.1: ANALYSIS OF MAY 12/13 2000 RAINSTORM

Raingauge #	Rainfall Volume (mm)	Peak Intensity (mm/hr)
1	61	17.6
2	68	15.4
4	68	17.8
5	77	16.8
6	52	16.1

The calibration was performed by comparing simulated flows to flow data recorded during the May 12/13 2000 event at the following streamflow gauge stations:

- WSC flow gauge on the Main Don at Todmorden near Pottery Road (02HC024),
- West Don gauge located near the intersection of Yonge and York Mills (02HC005).

Locations of both streamflow gauges are shown on Figure 2.2. The flow gauge on the Little Don (East Don) at Don Mills (02HC029), used for the previous calibration, was not operational during the May 2000 storm, and hence could not be used for the present update.

The calibration was completed by adjusting model parameters such as CN values, imperviousness, slope, etc., initially estimated from soil charateristics, land use data and topography. Further details of the calibration procedure are included in Appendix A. The simulated hydrographs from the final calibrated model and observed hydrographs at the flow gauge stations during the May 2000 storm are compared in Figures 2.4 and 2.5. The characteristics of the flow hydrographs are also summarized in Table 2.2.

TABLE 2.2: CALIBRATION RESULTS FOR MAY 12/13 2000 RAINSTORM

Gauge Location	Peak Flows (m3/s)			Volume (mm)			Time to peak (hrs)	
	Observed	Simulated	Difference (%)	Observed	Simulated	Difference (%)	Observed	Simulated
Todmorden	208.99	202.28	3.21	32.73	36.14	-10.42	5:00	3:30
W. Don	52.9	42.96	18.79	40.67	26.98	33.66	6:00	9:00

The above comparison indicates that the peak flows, runoff volumes and time to peak(s) between the observed and simulated hydrographs at Todmorden are in very good agreement. The runoff volumes and time to peak(s) for the simulated and observed flow hydrographs at the West Don gauge deviate considerably more from each other. These discrepancies may be attributed to the G. Ross Lord Dam, which is located immediately upstream of the gauge and has a significant influence on the flows at this location. The performance of the dam was simulated using the ROUTE RESERVOIR subroutine and a general rating curve developed during the Toronto Wet Weather Flow study based on previous operational levels of the dam. However, it was established from discussions with the TRCA that the gates of the G. Ross Lord Dam were kept closed throughout the night during the May12/13 2000 event, when the storm was at its peak, and were not opened until the next morning. Hence, the model was not capable of reproducing the actual performance of the G. Ross Lord Dam during the storm. Considering these uncertainties involved in simulating the performance of the dam during real events, and the good calibration results obtained further downstream at the gauge at Todmorden, the above calibration results are acceptable.

2.1.2.2 August 26 1986

The calibrated Don watershed model was further validated against the August 26, 1986 rainstorm event. The August 26, 1986 was one of the events used for model calibration during the previous update. Hence rainfall data with 15-minute time intervals from the *Regional Storm Hydrology Update – Lower Don River, MMM (October 1990)* were used for this simulation. The peak intensities and rainfall amounts recorded during this event at different locations throughout the watershed are summarized in Table 2.3.

TABLE 2.3: ANALYSIS OF AUGUST 26 1986 RAINSTORM

Rain Gauge	Rainfall Volume (mm)	Peak Intensity (mm/hr)
North Toronto	69	32.5
Leslie-Eglington	65	36.6
York Mills-Bayview	64	27.4
Leslie-Eglington	53	23.4
Buttonville	75	31.5
Keele-Finch	84	36.6
Kimberley	70	38.6

Please note that the August 26, 1986 storm event was comparable in intensities and rainfall amounts to the May 12/13 2000 storm event. The peak intensities in Table 2.3 are considerably higher than the peak intensities in Table 2.1 due to the difference in the time interval in the two sets of information. The results of the simulation August 26, 1986 are summarized in Table 2.4.

TABLE 2.4:
COMPARISON OF OBSERVED AND SIMULATED FLOWS – AUGUST 26, 1986 RAINSTORM

Gauge Location	Peak Flows (m3/s)		Volume (mm)		Time to peak (hrs)	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
Todmorden	207	268.22	23	33	3:00	3:00
L. Don (East Don)	153	199.5	35	35	3:00	3:00
W. Don	55.2	51.7	44	33	1:00	2:45

The comparison of observed and simulated flows show that the simulated flows at the East Don gauge are significantly greater (approximately 30%) than the observed flows during this event. However, this was anticipated since the updated model reflects existing conditions (2002) in the watershed, and the majority of the urban developments in the watershed since 1986 have occurred in this area. There has been a 20% increase in the imperviousness of the area contributing to the gauge. Moreover, major developments in some of the individual catchments in the upper reaches (eg: catchments 20, 22, 23) have resulted in the their changing from "rural" to "urban" catchments making greater contributions to the peak flows. The above results also indicate that the model tends to overestimate the peak flows and runoff volumes at the flow gauges on the Little Don at Don Mills, and the Main Don at Todmorden. This should be considered acceptable since the updated model is based on current land use in the Don watershed, and there have been considerable developments in the watershed since 1986, which account for the higher imperviousness in the model, and consequently higher runoffs yielded during the August 26, 1986 storm. The flows at the West Don streamflow gauge during the August 26 1986 event are underestimated by the model. This can be attributed to the uncertainty involved in simulating the actual performance of the G. Ross Lord Dam during the event, as in the case of the May 12/13 2000 storm. However, the differences are still within acceptable limits (less than 25% difference).

It can be concluded from the above results that the updated VO2 model performs reasonably well against real events recorded in the watershed when the noted uncertainties are accounted for. Hence, it is regarded as an appropriately calibrated and validated hydrologic model representing the existing conditions in the Don watershed. The hydrologic parameters from the calibrated and validated model are summarized in Table A-1 in Appendix A. Please note that the CN values used during calibration and for the design storm simulations are for AMC II antecedent conditions, which are regarded as the average soil moisture conditions.

2.2 FUTURE CONDITIONS MODEL UPDATE

The future conditions scenario was developed by modifying the existing conditions model to account for the following changes in land use:

- It was established from the Regional and Municipal OP's and OPA's that the areas committed for future developments north of Steeles Avenue within the Don River watershed are mainly in the Blocks 8, 9, 10, 11, 12, 18, 19, 20 and 33 of the official development plans for the City of Vaughan (updated June 2003). The primary land use categories in the proposed subdivisions will be residential and commercial. The future land use in the area is shown on Figure 2.6. As evident from the figure, the majority of the committed future developments will occur in catchments 1, 2, 4, 8A, 8B, 17, 18, 19, 20, 23 and 24 of the Don River watershed model. The appropriate hydrologic parameters, most significantly the imperviousness, of these catchments were adjusted for the future conditions scenario to account for the developments. The lumped SWM ponds for these catchments were also revised to include the additional ponds that will be constructed to provide the required quantity controls for the new subdivisions. The revised lumped SWM ponds are listed in Table A-3. The hydrologic parameters for the affected catchments in the future conditions model are summarized in Table A-5 in Appendix A.

- The areas of land use intensification in the catchments located south of Steeles Avenue identified during the preparation of the Toronto Wet Weather Flow Master Plan are shown on Figure 2.6. The effective imperviousness of the affected catchments in the future conditions model was increased to account for the land use intensification. The erosion control ponds recommended within the City of Toronto were incorporated in the model following the "lumped" pond modelling approach. A summary of these erosion control ponds has been provided in Table A-4. However, the recommended source controls and conveyance controls from the Toronto WWFMP cannot be modelled directly using VO2. They were therefore represented in the future conditions scenario by decreasing the imperviousness of the affected catchments to yield the reductions in runoff that are expected to follow from the implementation of the above controls. The estimated reductions were based on the results of the HSPF models developed during the WWF study. The modified catchments and their respective imperviousness are summarized in Table A-5 in Appendix A.

3 DESIGN STORM AND REGIONAL STORM SIMULATIONS

The 2 to 100 year design storms, and Regional Storm peak flows were simulated using the updated and validated model described in the previous sections for both the existing conditions and future conditions scenarios. The following sections provide a brief discussion of the modelling procedure and the results obtained from the 2 to 100 year design storms and Regional Storm simulations.

3.1 DESIGN STORM SIMULATIONS

3.1.1 Selection of Appropriate Distribution

It was established during the previous modelling exercises for the Don watershed that among the available design storm distributions available, the 12-hour SCS storm distributions produce the most conservative peak flows for the 2 to 100-year design events for the Don watershed. In order to verify the validity of the above conclusion for the updated model, 2 to 100-year design storm simulations were performed using 4-hour Chicago, 12-hour SCS and 12-hour AES distributions for the existing conditions model. Table 3.1 compares the peak flows from these simulations for certain selected flow nodes in the watershed. The locations of the flow nodes are shown on Figure 2.2.

As evident from the peak flows reported in Table 3.1, the most conservative peak flows on a watershed basis are obtained using the 12-hour SCS design storm distributions, although higher peak flows are probably obtained locally for significantly smaller catchment areas using one of the other distributions. Hence, the design storm simulations for the existing and future conditions models were performed using the 12-hour SCS distribution. Rainfall depths based on the IDF data recorded at the Toronto Bloor Street gauge and 15-minute time steps were used for the simulations, to be consistent with the previous updates. In accordance with the Scope of Work outlined for the study, an additional simulation using the 25mm storm was also performed.

3.1.2 Discussion of Results

The peak flows from the 25mm storm, and 2 to 100-year design storm simulations at various flow nodes throughout the watershed (see Figure 2.2) for the existing conditions scenario are summarized in Table 3.2. In general, the existing conditions peak flows show a consistent increase over the existing conditions peak flows simulated during the 1992 update, at the flow nodes affected by the recent developments in the watershed. The peak flows near the mouth of the Don have increased by approximately 3-6% for the 2 to 100-year design storms, although a more significant increase in peak flows is observed in the upper regions of the watershed.

The 100-year peak flows in the catchments north of Steeles Avenue with future developments show some marginal increases, and sometimes marginal decreases, compared to the existing conditions flows, indicating that the SWM ponds proposed for the future developments are sufficient to provide the required stormwater controls for the watershed. The flow nodes immediately downstream of the areas of future land use intensification within the City show more significant increases in peak flows (approximately 7-8%), although the effect of the increase dissipates further downstream. This indicates that the SWM controls recommeded by the WWF Master Plan perform well in providing watershed wide controls. 100-year design peak flows at the mouth of the Don (flow node 48.1) show a slight decrease over existing flows.

3.2 REGIONAL STORM SIMULATIONS

3.2.1 Methodology

To be consistent with the approach adopted in the previous updates, the Regional Storm simulations were performed using the 15-minute rainfall distribution for Hurricane Hazel. The following differences between the Regional Storm simulations and the 2- to 100-year design storm simulations should also be noted:

- In accordance with standard practices, AMC III antecedent conditions, which correspond to saturated ground conditions due to heavy rainfall during the previous 36 hours, were assumed for the simulation. Hence the CN values for AMC III conditions from Table A-1 were used for the existing and future conditions Regional Storm models;
- As recommended in the *Technical Guidelines for Flood Plain Management in Ontario*, a reduction factor was applied to the total rainfall depth at each flow node based on the "equivalent circular area" upstream of the flow node. The equivalent circular area upstream of a flow node is defined as the area of the circle drawn with its centre at the centroid of the upstream drainage area, and its radius equal to the

distance from the centroid to the flow node. The centroids of the upstream drainage areas for all flow nodes were calculated using the "script" writing capabilities of ARCVIEW. The applicable reduction factor for each flow node was then determined from Table D-3 in the *Technical Guidelines for Flood Plain Management in Ontario*. For example, an areal reduction factor of 82.4% was used for flow node 48.1, based on the equivalent circular upstream drainage area of 804 sq.km.;

- All SWM ponds were eliminated from the existing and future conditions Regional Storm simulations since these facilities were not designed to control a Regional Storm, and hence cannot be considered based on TRCA and MNR policy.

3.2.2 Discussion of Results

3.2.2.1 General

The existing and future conditions Regional Storm flows at flow nodes throughout the watershed and the applicable reduction factors are summarized in Table 3.3. The future conditions flows from the present update have been compared to the future conditions (Future 1) flows from the previous update in Table 3.3, since the Regional floodlines are updated based on these flows. The peak flows recorded in Table 3.3 indicate that the future conditions Regional Storm peak flow at the mouth of the Don has increased from 1548 m^3/s to 1694 m^3/s, which constitutes an increase of approximately 9%. However, the Regional Storm peak flows at some locations (for example, flow nodes 12.0, 19.0 and 29.0) show a more significant increase from the previous to the present update. This increase in peak flows may be attributed to the following factors:

- The imperviousness of some catchments has increased significantly due to the proposed developments in the north of Steeles areas, and land use intensification proposed within the City of Toronto. Since associated SWM quantity controls are not effective during the Regional Storm, a corresponding increase in Regional flows occurs at the affected downstream locations. Moreover, major developments in some of the individual catchments in the upper reaches have caused these former "rural" catchments to start behaving as "urban" catchments with hydrographs peaking in phase with downstream catchments, and thus making greater contributions to peak flows at downstream locations. The increase in Regional flows observed at node 48.1 is due to these reasons.

- The reduction factor of 82.4%, derived based on the "equivalent circular area" upstream of flow node 48.1 at the mouth of the Don River, was used throughout the watershed during the previous update. During the present update, an individual reduction factor for each flow node was calculated based on the recommendations of the *Technical Guidelines for Flood Plain Management in Ontario*. Consequently the input rainfall depths at flow nodes with smaller upstream drainage areas are greater than the input rainfall at these nodes during the previous update. This results in a proportional increase in peak flows at these nodes. For example, approximately 35% of the increase in Regional flows at node 12.0, and 37% of the increase in Regional flows at node 19.0 may be attributed to these higher reduction factors.

- As mentioned previously in Section 2.1, the change from the use of the COMPUTE HYD subroutine to the STANDHYD subroutine to generate runoff hydrographs from the urban catchments result in considerably "peakier" hydrographs for the urban catchments. This difference is responsible for significant increase in Regional flows at certain locations. For example, the Regional flows at node 12.0 increase by approximately 15%, and the flows at node 29.0 to increase by 26% due to this factor.

- There has been a shift in the boundaries of certain catchments due to the rediscretization of catchments located south of Steeles Avenue, leading to changes in areas of the relevant catchments, including adjacent catchments located north of Steeles Avenue in certain cases. Consequently the drainage areas at certain flow nodes have increased significantly from the previous update. For example, increase in the drainage area accounts for approximately 30% increase in Regional flows at node 12.0.

- For certain catchments, future developments have not occurred at the growth rates predicted during the previous study. Consequently the imperviousness of certain catchments deviate considerably from those considered for the "Future 1" scenario during the previous study. This has resulted in some apparent inconsistencies in the increase in flows for catchments with similar characteristics from the previous to the present update. For example, even though catchments 6 and 12 have very similar catchment areas and imperviousness, the increase in flows from the previous to the present update at flow nodes 6.0 and 12.0 are not consistent, due to this factor. A more detailed explanation is provided in the following section.

- As discussed in detail in Appendix A, the imperviousness of catchments draining to the East Don were adjusted more than the imperviousness of catchments draining to the West Don, during the calibration procedure. This has also led to some variations in the percentage increase in flows at nodes along the West Don and East Don from the previous to the present update. The effect of this difference is demonstrated more clearly by the analysis presented in the following section.

3.2.2.2 Analysis of Selected Catchments

To further understand the variations in flow increases between subcatchments, an additional analysis has been performed to investigate further the all apparent inconsistencies in the increase in peak flows during the Regional Storm from the previous to the present update. The objective of the analysis was to conduct a more detailed evaluation of the increase in peak flows of certain catchments to estimate the extent to which each of the factors summarized in Section 3.2.2.1 contributes to the increase of Regional Storm peak flows for each of these catchments. The analysis provides explanations for the apparent inconsistencies, to provide more confidence in the flows produced from the present update.

Please note that all catchments selected for the analysis are urban, since the increase in peak flows is generally more significant for the urban catchments. Catchments 6, 12, 31 and 36 were selected as appropriate for the present analysis, since they have similar characteristics with respect to drainage area, imperviousness, etc. for the future conditions scenario, but show wide variations in the increase in the peak flows during the Regional Storm from the previous to the present update, as apparent from the flows summarized in Table 3.3. Please note that even though the ultimate imperviousness and drainage areas of these four catchments in the future conditions VO2 model are similar, there are significant differences in the initial estimates of the impervious percentages, the adjustments made during calibration to the May 12 2000 storm event, the changes in imperviousness from the existing to the future conditions VO2 model, etc. The drainage areas, and impervious percentages of the catchments for the different scenarios are summarized in Table 3.4.

TABLE 3.4: CHARACTERISTICS OF SELECTED CATCHMENTS FOR ANALYSIS OF REGIONAL STORM FLOWS

	Catchment 6	Catchment 12	Catchment 31	Catchment 36
Drainage Area for Previous Update (sq. km.)	8.18	6.2	13.8	7.7
Drainage Area for Present Update (sq. km.)	8.18	7.81[1]	13.8	8.2[2]
Existing Conditions Imperviousness for Previous Update (%)	35	41	25	42
Future I Imperviousness for Previous Update (%)	**62**	**41**	**28**	**46**
Initial Existing Conditions Imperviousness for Present Update (%)	41	41	40	33
Effective Existing Conditions Imperviousness for Present Update (%)	39	39	36	30
Effective Future Conditions Imperviousness for Present Update (%)	**40**	**39**	**36**	**35**[3]

Table 3.4 indicates that there are significant differences between future conditions impervious percentages of catchments 6, 31 and 36 for the previous and present updates. These differences exist since for the catchments where significant developments have occurred since the previous update, impervious percentages in the existing conditions VO2 model were established independent of the information from the previous update. As mentioned previously in Section 2, the existing conditions land use update is based on the information obtained from the *City of Toronto Wet Weather Flow Master Plan –Don River*

[1] 27% increase in drainage area

[2] Combined drainage areas of 36A and 36B; 7% increase in drainage area

[3] Net Imperviousness from 36A and 36B

Watershed: Study Area 4, and the 2002 ortho-photography provided by the TRCA. The future conditions land use update is based on the latest Regional and Municipal OP's and OPA's provided by the TRCA. It appears that the changes in land use in the watershed according to this latest information varies significantly from what was projected in 1991 during the previous update for catchments 6, 31 and 36. Moreover, note that the "effective" future impervious percentages for these catchments summarized in Table 3.4 are less than the initially estimated values based on land use (5% less for catchment 6, and 10% less for catchments 31 and 36 – see Appendix A for further details).

The methodology adopted for the analysis is in accordance with the approach recommended by the TRCA in their comments regarding the draft report, with some modifications proposed by Marshall Macklin Monaghan in the communication dated June 7, 2004. The procedure finally adopted for the analysis is outlined below:

- A direct conversion of the characteristics of the above catchments from the 1991 existing conditions Regional Storm HYMO model to VO2 was undertaken. This procedure also involved the conversion of the COMPUTE HYD subroutine used in the previous subroutine for all catchments to the STANDHYD subroutine currently used for the modelling of urban catchments. The changes in the Regional Storm peak flows due to this conversion for all four catchments are summarized in Table 3.5.

- Changes in drainage areas, catchment discretization, etc. from the previous to the present update were included as appropriate. The changes in the Regional Storm peak flows due to this conversion are also summarized in Table 3.5.

- The adjustments to catchment imperviousness, slopes, etc., that were made during the calibration of the VO2 model were then included, and the changes in the peak flows were noted (see Table 3.5).

- Changes in "imperviousness" in the VO2 model from the existing to the future conditions scenario due to future developments, were included, and the changes in peak flows were noted and compared to the previous changes in peak flows (see Table 3.5).

- Finally, the reduction factor was increased from 82.4%, which was used throughout the watershed during the previous update to the appropriate reduction factor used during the present update, and calculated based on the "equivalent circular area" upstream of each individual flow node. The observed changes in peak flows due to this increase in reduction factors were also noted and are summarized in Table 3.5.

TABLE 3.5:
SUMMARY OF RESULTS -- ANALYSIS OF REGIONAL STORM FLOWS OF SELECTED CATCHMENTS

Procedure	Future Conditions Regional Storm Flows							
	Catchment 6		Catchment 12		Catchment 31		Catchment 36	
	Flow (cms)	Increase (%)	Flow (cms)	Increase (%)	Flow (cms)	Increase (%)	Flow (cms)	Increase (%)
Future I Flows from Previous Update	74.5	-	51.5	-	118.1	-	65.6	-
Conversion from Existing conditions HYMO to VO2	87.5	18	66.6	28	138.96	18	82.9	26
Increase and Re-discretization of Drainage Area	-	-	83.5[4]	33	-	-	83.0	0.2
Adjustments during Update and Calibration	78.9	-12	74.7	-16	124.9	-12	76.4	-10
Increase in Imperviousness from Existing to Future Conditions	79.7	1	-	-	-	-	76.5	0.14
Increase in Reduction Factor	97.8	24[5]	92.9	35[6]	154.98	25[7]	92.2	24[8]
TOTAL	97.8	31	92.9	80	154.98	31	92.2	40

[4] Increase in area only

[5] From 82.4% to 100%

[6] From 82.4% to 100%

[7] From 82.4% to 100%

[8] From 82.4% to 99.2%

Note that the maximum decrease in flows due to "adjustments in update and calibration" are observed at catchment 12 since this catchment shows the minimum change in conditions from the previous update, whereas block reductions in impervious percentages were applied during the model calibration procedure. Finer adjustments were not possible due to the lack of flow monitoring information in the upper regions of the watershed. Catchment 12 also shows the "peakiest" response to the model conversion and the change in reduction factor, since it has the smallest drainage area among the four selected catchments. Catchment 36 does not show a significant response to the increase and split in drainage area, due to the routing of the flows from catchment 36A.

Hence, the results of the analysis indicate that the variations in the increase in Regional Storm peak flows throughout the watershed can be logically explained by considering the effects of the appropriate factors among those summarized in Section 3.2.1 at the individual locations in the watershed.

4 STORMWATER MANAGEMENT

4.1 UNIT FLOW METHODOLOGY

The unit flow methodology developed for the upper regions of Don River watershed (north of Steeles areas) developed during the early 1990s was reviewed in order to confirm applicability of the method under current development conditions in the watershed. In accordance with the Scope of Work, the unit flow methodology for the upper Don watershed was also compared to the unit flow methodology later developed for the Humber River watershed,

Detailed descriptions of the unit flow methodologies for the Don and the Humber watershed have been provided in the *Unit Flow Rates for Stormwater Control-Upper Don River Watershed (November, 1994)* and *Hydrology/Hydraulics* and *Stormwaters Management Study-Humber River Watershed* respectively. As noted in these reports, watershed studies typically deal with catchments several square kilometres in area, and provide target flows for future developments at a number of reference points in the watershed based on these macro-level estimates. In the present Don Hydrologic Update, design storm and Regional Storm peak flows are estimated based on 66 catchments ranging from 1.5 to 14 sq.km. However, proposed urban developments are generally smaller in size, of the order of 10 to 100 ha, and implement stormwater management facilities based on site specific criteria. It is necessary to correlate the on-site target flows used for designing these facilities to the macro-level target flows established throughout the watershed, in order to ensure that the designed facilities achieve watershed-wide benefits. After experiencing consistent difficulties in this regard, TRCA introduced the unit flow concept, which ensures local target flows for developers consistent with the watershed wide target flows. The unit flow methodology can be used to develop generic unit flow rate targets for each return period. These unit flow targets can then be applied directly to proposed developments in the watershed.

The unit flow methodology developed for the Don watershed was restricted to the north of Steeles area, since the area within the City of Toronto is almost fully developed and has a limited possibility of significant future developments. A single regression equation was developed for the entire area, with a single set of regression coefficients for the 2 to 100-year design storms. The coefficients are summarized in Table C-1 in Appendix C. The pre-development unit flows for the catchments located north of Steeles Avenue for the 2- to 100-year design events are summarized in Appendix C-2.

The unit flow equations for the Humber watershed were developed to estimate the 100-year unit flows only from different regions of the watershed. It was determined that the same set of equations could not be used to estimate unit flows from different regions of the watershed accurately. Hence, a set of five equations was developed to estimate unit flows from catchments in different regions of the watershed. These equations are summarized in Table C-3 in Appendix C.

It was established during the analyses of unit flows for both the above watersheds that unit flow rate equations are not affected by the imperviousness of catchments resulting from later developments since they are derived based on pre-development conditions and peak flows. As expected, the unit flows are influenced most strongly by the CN values, which are estimated based on soil characteristics. Please note that any differences observed in the CN values of rural catchments, from the previous to the present update, are due to differences in development conditions, and calibration adjustments. The original estimates of CN values based on the soil characteristics of the subwatersheds, remain unaffected. Hence, the unit flows and the regression equations for estimating unit flows provided in the *Unit Flow Rates for Stormwater Control-Upper Don River Watershed (November, 1994)* (included in Tables C-1 and C-2 in Appendix C) are still valid for the upper Don watershed. These flows and regression equations can therefore be used to estimate local target flows for implementing site specific stormwater quantity controls for future developments north of Steeles Avenue.

4.2 SWM QUANTITY CONTROLS IN THE CITY OF TORONTO

4.2.1 Toronto Wet Weather Flow Master Plan Recommendations

The SWM quantity control recommendations in the *Toronto Wet Weather Flow Master Plan* were developed based on continuous hydrologic modelling using continuous rainfall data from the area, rather than the event based approach used for the current study. The largest storm events in the modelling period considered for the WWF study are in the range of 2-year design storms in the area. As such, the SWM recommendations in the *Wet Weather Flow Master Plan* were developed based on providing effective stormwater controls for more frequent storm events. The final "preferred" long-term (100-year) stormwater management strategy for the Don watershed was selected after evaluating several strategies against the City's hydrologic, water quality and geomorphic objectives. A detailed 25-year plan, which would be implemented as the first phase of the 100-year plan, was also developed. The stormwater quantity control measures in either of these strategies can be broadly subdivided into three categories:

- **Source Control Measures**-The full range of source control measures considered for various land uses in the above strategies have been listed in Table C-4 in Appendix C (Table 6.1.2 from the *Toronto Wet Weather Flow Master Plan -Area 4: Don River*). The 25-year plan includes the "voluntary" level of "uptake" of source controls, and the preferred strategy includes the "enhanced" level of "uptake" of source controls in Table C-4. These levels of uptake represent the best estimate of the public's willing to implement source control based upon current City programs and additional incentives. The "enhanced" level of source controls will be enforced by the city in areas of land use intensification.

- **Conveyance Controls**-These consist of exfiltration pipe systems in the areas with suitable soils, and filtration systems in all other areas. At the opportunistic level for the 25-year plan, the conveyance controls will be implemented over 25% of the area. At the enhanced level (for the long-term strategy), exfiltration methods were assumed to be implemented in all areas with suitable soils and filtration systems were assumed to be implemented in all other areas. The areas within the City with suitable soils for implementing exfiltration systems are shown on Figure 4.1;

- **End-of-Pipe Controls-**These consist of "opportunistic" or "green" end-of-pipe facilities above ground to provide erosion and water quality controls for the 25-year plan. Additional underground facilities to provide water quality controls were also included in the "aggressive" approach for the preferred long-term strategy. Quantity control storage for end-of-pipe facilities is not recommended in the WWF Master Plan. The locations of these erosion control facilities are shown on Figure 4.1;

The methodology adopted for modelling the quantity and erosion controls recommended in the 25-year plan has been described in Section 2.2. As discussed in Section 3.2, these controls appear to perform well in achieving watershed wide reductions in design flows.

4.2.2. Additional Opportunities for Quantity Controls

An additional modelling scenario was developed to explore whether further peak flow reductions can be achieved in the watershed by constructing SWM facilities within the City which provide attenuation of post-development flows to pre-development levels. This should be regarded as a conceptual analysis, which attempts to determine where such additional controls may prove to be beneficial. Therefore, actual space constraints in the catchments south of Steeles Avenue (which may make it impossible to construct these facilities) were not considered for this analysis.

4.2.2.1 Methodology

Quantity control ponds providing required storage during a 100-year event for the entire catchment area of all 40 catchments south of Steeles Avenue were included in the future conditions model used for the simulation of design storms. Table 4.1 provides a summary of the storage and outlet characteristics of these hypothetical SWM ponds designed according to the following criteria:

- During the *Rouge River Urban Drainage Study (MMM, 1988)*, it was established that approximately 500 m^3 of storage per impervious hectare is required to control 100-year post-development flows to pre-development levels. The maximum quantity control storage in the ponds was calculated based on this estimate.
- The outlet structures were designed based on 100-year outflows equal to pre-development flows from the catchments. The 100-year pre-development flows were calculated using the Modified Rational Method.

The 100-year design event was then simulated using this model.

4.2.2.2 Discussion of Results

The 100-year peak flows obtained at the flow nodes are summarized and compared to the 100-year peak flows obtained from the 100-year future conditions model in Table 4.2. The results indicate that significant reduction in peak flows may be achieved locally at a number of catchments south of Steeles Avenue by implementing quantity control SWM ponds, though the reductions achieved at instream flow nodes further downstream are considerably less. This is probably because even though the SWM ponds reduce the peak flows from the catchments, they also cause the hydrographs to peak later, and more in phase with the hydrographs in the upper regions of the watershed. Hence, due to the substantial land requirements associated with these facilities, they may not prove to be cost effective considering the marginal quantity controls they provide at the watershed level. Moreover, only 14 of these catchments were identified as having opportunities for "green" end-of-pipe facilities during the Toronto WWF study (see Sections 2.2 and 4.2). Underground tanks, which will have to be applied at the remaining catchments, are even more expensive with extremely high maintenance costs. Consequently such facilities are generally not considered as cost effective quantity controls measures.

5 CONCLUSIONS AND RECOMMENDATIONS

The main conclusions and recommendations of this study may be summarized as follows:

- The HYMO based hydrologic model for the Don watershed was converted to a Visual Otthymo Version 2.0 (VO2) based model and then updated to reflect the current development conditions in the watershed. The updated model was then calibrated to the May 12/13 2000 storm, and validated against the August 26, 1986 event. It was concluded that the updated and validated VO2 model is an accurate representation of the current hydrologic conditions in the Don watershed;

- Based on the 2 to 100-year design event simulations performed using the updated and validated model, the existing 100-year peak flows near the mouth of the Don have increased by approximately 3% over the existing flows from the previous update. This indicates that the SWM controls implemented in the new developments (in the north of Steeles area) based on the recommendations of the previous studies, are effective in providing watershed wide quantity controls;

- The Regional Storm simulation was performed without any of the stormwater quantity controls implemented in the watershed, since TRCA and MNR policy does not account for storage not ópecificálly designed to control Regional Storm flows. The future conditions Regional Storm flows at several locations throughout the watershed show significant increases. As discussed in Section 3.2, the main reasons for these increases are:

    ◊ Runoff hydrographs from recently urbanized catchments in the upper regions of the watershed peak in time with the catchments in the lower regions, thus making greater contributions to the peak flows at downstream nodes;

    ◊ Areal Reduction factors used at a number of locations in the watershed during the present update deviate significantly from the reduction factors applied during the previous update;

- The results of the 2 to 100-year design storm simulations using the existing and future conditions models indicate that

    ◊ The SWM quantity controls proposed for developments north of Steeles Avenue are effective in providing watershed wide benefits;

- ◊ The SWM quantity controls recommended in the Toronto Wet Weather Flow Master Plan are effective in providing quantity controls for frequent storm events, but cannot achieve significant peak flow attenuation during design events;

- It was confirmed that the unit flow regression equations developed to estimate target flows for quantity controls in the upper Don watershed (area north of Steeles Avenue) are still applicable, since the estimated pre-development unit flows do not depend on the current development conditions in the catchments;

- The benefits of SWM quantity control facilities south of Steeles Avenue were analyzed by simulating an additional scenario, which included these facilities at the outlet of all catchments south of Steeles Avenue. Based on the results of this simulation, it was concluded that such facilities can achieve significant reduction of local peak flows, but only small reductions on a watershed level. Because of space restrictions and cost considerations, it may not be feasible to implement the hypothetical storages simulated in this study.

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A1 INTRODUCTION

The User's Guide has been prepared in accordance with the Terms of Reference to provide supplementary information regarding the modelling procedures adopted during the update and validation of the Don River hydrologic model to assist in future updates of the model. The User's Guide contains detailed discussions on:

- Initial estimates of model parameters for the existing conditions models, including the more detailed discretization introduced for the catchments south of Steeles Avenue;
- Calibration and validation procedure for the existing conditions model, and the parameters mainly used for this purpose;
- Methodology adopted for the modelling of "lumped" SWM ponds;
- Update of model parameters for the future conditions model.

Tables summarizing final model parameters, characteristics of the lumped SWM ponds, etc., and recommendations for adjustments required during future updates, have also been included in the Appendix.

A2. EXISTING CONDITIONS MODEL

A2.1 "LUMPED" SWM POND MODELLING

As discussed in Section 2.1 in the main report, SWM ponds constructed in the watershed since 1986 were included in the updated Don hydrologic model based on a "lumped" SWM pond modelling procedure. This involved combining all SWM ponds located in a particular subcatchment into one "lumped" pond modelled using a single ROUTE RESERVOIR subroutine. The storage volumes in these "lumped" ponds can be determined by adding the storage volumes in each of the ponds in the catchment, for the 2 to the 100-year design storms. Please note that where the storage-discharge curve for the individual pond was not available, the discharges were derived from the unit flows, which can be regarded as the predevelopment flows for the upstream drainage areas. The discharges from the lumped ponds were estimated following the same approach as that adopted in previous studies (e.g.: the *Rouge Watershed Study*, *MMM*). Following this approach, the discharges from the lumped ponds are calculated as the sum of the discharges from the individual ponds scales up by a "scaling factor". The discharges of smaller off-line ponds were not considered to contribute significantly to the discharges from the lumped ponds, if larger on-line ponds were present. The scaling factor represents the ratio of the controlled upstream drainage area to the entire catchment, and is calculated based on the Rational Method. It is calculated by equation:

$$\alpha = \left\{A_c\left[0.9 * i_c + 0.2 * \left(1 - i_c\right)\right]\right\} \Big/ \left\{A_p \left[0.9 * i_p + 0.2 * \left(1 - i_p\right)\right]\right\}$$

where

$\alpha =$ scaling factor;

$i =$ imperviousness; and

subscripts 'p' and 'c' denote pond and catchment respectively

It has been established from previous studies that the design flows obtained from these "lumped" ponds at the outlets of the respective catchments are very similar to the flows obtained from the catchments when the SWM ponds are modelled individually. The "lumped" ponds have the added advantage of reducing the size of the hydrologic model. Hence, the "lumped" SWM pond approach is considered be a more efficient approach to SWM pond modelling on a watershed scale, especially when there are a significant number of ponds in a watershed. The "lumped" SWM ponds, and their respective storage-discharge curves, included in the existing conditions model of the Don River watershed, are summarized in Table A-1.

Please note that the storage-discharge relations in Table A-1 include "caps" to avoid unrealistic reductions of post-development flows when the storages are exceeded. Moreover, it was necessary to provide storage-discharge pairs in addition to those in Table A-1 during application, to avoid increase (rather than attenuation) of post-development flows due to instabilities arising from the abrupt increase in discharges in the "caps".

A2.2 DISCRETIZATION SCHEME FOR AREA SOUTH OF STEELES AVENUE

The existing conditions model update also involved introducing a more detailed discretization scheme than that adopted for the original model (and maintained in the previous update) for the area south of Steeles Avenue. During the present update, the 24 catchments in the south of Steeles area within the City of Toronto were further subdivided into 40 catchments broadly based on the discretization scheme followed in the hydrologic model developed for the *City of Toronto Wet Weather Flow Master Plan*. The HSPF model developed for the above mentioned study includes 69 catchments south of Steeles in the separated storm sewer area. Three or four of these catchments were lumped together in the VO2 hydrologic model, based on a common downstream channel reach or tributary to which they drain. The resultant catchments in the area south of Steeles Avenue are shown on Figure 2.2 in the main report. It should be noted that the new catchments south of Steeles Avenue were numbered according to the "parent" catchment from the original model. For example, combined area of catchments 11A, 11B, and 11C is approximately equal to the area of catchment 11 of the existing HYMO model.

A2.3 CALIBRATION AND VALIDATION

The updated VO2 model reflecting existing conditions in the Don watershed was calibrated and validated against the May 12/13 2000 and August 26 1986 events, as discussed in Section 2.1 of the main report. The May 12/13 2000 event was initially simulated using the updated model, and the rainfall distributions from five rain gauges distributed evenly throughout the watershed. As mentioned in the main report, the calibration was performed by comparing simulated and observed flows at the flow gauges at Todmorden on the Main Don, and at Yonge and York Mills on the West Don downstream of the G. Ross Lord dam. However, due to the uncertainties associated with reproducing the outflows from the dam during a real event, the calibration was performed based mainly on the comparison of observed and simulated flows at Todmorden. It was found that the initial conversion of the model overestimated the peak flows produced during the May 2000 rainstorm by a significant amount, and also peaked earlier than the observed hydrograph. Hence, the hydrologic model was re-calibrated until better agreement was obtained with the observed flows during the May 12/13 2000 storm.

The model was calibrated mainly by adjusting the CN value and the time-to-peak for the rural catchments, modelled using NASHYD, and the imperviousness for the urban catchments, modelled using STANDHYD. Initially, it was observed that the recorded flow hydrographs at Todmorden and York Mills were peaking considerably earlier than the simulated flow hydrographs. Hence, the following adjustments were introduced in the model:

- The CN values for the rural catchments were decreased by 5%, and the time-to-peaks were decreased by 5%.

- The slopes for all the urban catchments were also reduced from 2% (default value in the STANDHYD subroutine in VO2) to 0.5%.

- Based on the response of the model to changes in hydrologic parameters, it was concluded that the flow hydrographs in the lower reaches were more sensitive to the parameters of the catchments draining to the East Don than those draining to the West Don, due to the presence of the G. Ross Lord dam on the West Don. Hence, the imperviousness for the urban catchments draining to the East Don and the Lower Don was decreased by approximately 10% of their initial estimated values based on land use. The imperviousness for the catchments draining to the West Don was decreased by approximately 5%.

This reduced the peak flows from the model sufficiently to obtain good agreement with the observed flows during the May 12/13 2000 rainstorm. However, the flow hydrographs produced by the model were now found to peak earlier than the observed hydrographs. Hence, the roughness parameters in the ROUTE CHANNEL subroutines were increased by approximately 10% to delay the peaks of the simulated hydrographs.

The final calibration results for the May 12/13 2000 storm, as well as the August 26 1986 storm simulation results have been discussed in the main report. The model parameters from the final calibrated and validated model have been listed in Table A-2. The imperviousness of urban catchments in the model is referred to as the "effective" imperviousness since these percentages represent the adjusted imperviousness obtained during the recalibration of the model.

A3. FUTURE CONDITIONS MODEL UPDATE

A3.1 LUMPED SWM PONDS

As shown on Figure 2.5 in the main report, the official plans for the north of Steeles municipalities indicate that the committed future developments in the area will mainly occur in catchments 1, 2, 4, 8A, 8B, 17, 18, 19, 20, 23 and 24 of the Don River hydrologic model. Stormwater management ponds have been proposed in these subdivisions to apply the required quality, erosion and quantity controls in the area. These ponds were included in the future conditions model by revising the storage volumes of the lumped ponds in the existing conditions model to include the additional storage volumes provided in these proposed ponds. Please note that since these are quantity control facilities providing post- to pre-development controls, the discharges from the existing conditions lumped ponds were not increased. Storage-discharge relations for lumped ponds in catchments 18, 23 and 24 (where there were no existing lumped ponds) were estimated using the same methodology as used for the existing conditions model. The future conditions lumped ponds and the associated storage-discharge pairs are listed in Table A-3.

As discussed in the main report, the erosion control facilities within the City of Toronto recommended in the Wet Weather Flow study were also incorporated in the future conditions model, following the lumped modelling approach. The opportunities identified in the Wet Weather Flow study for providing these green end-of-pipe facilities are shown on Figure 4.1. The erosion control storage volumes for these individual facilities were estimated during the Wet Weather Flow study as the runoff from the upstream catchment areas for a 25mm storm. The storage volumes from all of the individual ponds located in a particular catchment in the Don hydrologic model were added to provide the erosion control storage of the lumped SWM pond modelled at the outlet of the catchment. The outflows from these lumped erosion control ponds were derived based on providing 24-hour detention for the erosion control storage. The lumped erosion control facilities in the catchments south of Steeles Avenue, included in the future conditions scenario are summarized in Table A-4.

TABLE A-4:
PROPOSED "LUMPED" EROSION CONTROL PONDS
SOUTH OF STEELES AVENUE

Catchment #	Storage Volume (ha-m)
9A	1.61
9B	0.12
10B	0.08
11A	2.35
11B	4.70
15	0.69
28	0.67
33	0.04
34	0.37
35	1.68
37	0.20
41B	0.41
41C	0.87
41D	3.37

A3.2 MODIFIED PARAMETERS FOR AFFECTED CATCHMENTS

The imperviousness of the catchments north of Steeles Avenue affected by future developments was increased to reflect future development conditions in the area. The estimated increase in imperviousness for each of these catchments was reduced by an appropriate amount to be consistent with the adjusted imperviousness values in the calibrated model. As evident from Figure 2.5, the imperviousness of catchments 2, 17 and 24 will increase significantly due to future developments due to the proposed developments. However, since the overall imperviousness for the catchments were still estimated to less than 20%, they were modelled using the NASHYD subroutine in the future conditions scenario. The CN values for the catchments were increased by proportional amounts to reflect the increase in imperviousness.

Catchments 18, 19 and 23 will start behaving as urban catchments due to their increase in imperviousness resulting from future developments. Hence, the runoff hydrographs from these catchments were simulated using the STANDHYD subroutine in the future conditions model.

The imperviousness of catchments south of Steeles Avenue with significant areas of land use intensification was also increased by proportional amounts. The increase in imperviousness was scaled down to be consistent with the effective imperviousness values in the calibrated model. The reductions in runoff achieved by the source controls and conveyance controls recommended in the Wet Weather Flow study were also included in the model. Since these cannot be modelled directly in VO2, the effect of the recommended controls was modelled by introducing proportional reductions in the effective imperviousness of catchments based on the reductions in runoff achieved by the controls for the Wet Weather Flow study. These reductions are estimated to be very low, in the range of 1-3%.

Model parameters for all catchments modified to reflect the future conditions in the Don River watershed are summarized in Table A-5.

TABLE A-5:
MODIFIED PARAMETERS FOR AFFECTED CATCHMENTS IN FUTURE CONDITIONS MODEL

Catchment #	Area (sq. km.)	Effective Imperviousness (%)	CN (AMC II)	CN (AMC III)	Modelling Subroutine
1	13.70	42	64	82	STANDHYD
2	9.17	N/A	70	87	NASHYD
4	4.27	50	73	88	STANDHYD
6	8.18	40	80	93	STANDHYD
8A	5.05	56	80	92	STANDHYD
8B	6.53	33	80	92	STANDHYD
14A	6.21	41	80	90	STANDHYD
15	4.97	28	80	92	STANDHYD
17	6.73	N/A	70	86	NASHYD
18	8.37	47	72	91	STANDHYD
19	5.26	25	62	88	STANDHYD
23	4.64	38	75	90	STANDHYD
24	3.13	N/A	84	93	NASHYD
33	6.32	25	80	94	STANDHYD
36B	4.15	38	81	92	STANDHYD
38	3.03	27	80	90	STANDHYD
39A	3.31	31	80	92	STANDHYD
41A	5.80	37	80	92	STANDHYD
41D	6.90	43	80	92	STANDHYD
42B	4.10	40	80	93	STANDHYD
46A	4.60	46	80	93	STANDHYD
47A	3.17	57	80	94	STANDHYD

A4 RECOMMENDATIONS FOR FUTURE UPDATES

The following modelling procedures are recommended for future updates of the VO2 model for the Don River watershed:

- Future developments in the watershed can be incorporated in the model by increasing the effective imperviousness of the relevant catchments. Until re-calibration and validation of the model is undertaken, the effective imperviousness can be calculated as approximately 90% of the imperviousness estimated from land use for catchments draining to the East Don, and as approximately 95% of the initially estimated imperviousness for the remaining catchments.

- All future SWM ponds can be included in the model according to the "lumped" modelling procedure adopted for the present study. For catchments with existing (or proposed) "lumped" SWM ponds, the future ponds can be included simply by increasing the storage volumes of the existing ponds modelled using the ROUTE RESERVOIR subroutine, to account for the additional storage. For catchments without any "lumped" ponds the future SWM facilities can be included as "lumped" facilities at the outlet of the relevant catchments with storage volumes equal to the combined storage of all individual facilities proposed within the catchments. The discharges for the ponds can be estimated either from the available information from the pond design/inventory or as the predevelopment "unit" flows from the catchments. The discharges from the lumped ponds can then be estimated as the sum of these discharges, scaled up according to the scaling factors calculated using the Rational Method.

Marshall Macklin Monaghan

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B1 INTRODUCTION

The TRCA requested Marshall Macklin Monaghan to undertake an additional analysis in the Scope of Work for the Don hydrologic update to provide an understanding of the potential impacts of climate change on the hydrology of the Don watershed. Meteorologists and climatologists generally work with a significantly larger scale than that required to evaluate the response of the Don watershed to changes in climactic variables such as rainfall, temperature, etc. Hence, the present analysis constitutes a preliminary study to provide an initial understanding of the sensitivity of the hydrologic processes in the Don watershed to changes in rainfall patterns.

It should be mentioned that the actual interplay between the various climactic phenomena and the hydrologic processes occurring in the watershed cannot be reflected through the present analysis. The objective of the present study is limited to producing preliminary estimates on the changes in peak flows and water levels due to changes in the rainfall during the Regional Storm and 2 to 100-year design events.

In accordance with the Scope of Work, the impact of climate change on the hydrology of the Don watershed was analyzed by undertaking the following tasks:

- Sensitivity analysis of the Regional Storm flows at the mouth of the Don to increasing rainfall, which can be used to study the potential impact upon the design of flood protection in the Lower Don flood plain.
- Sensitivity analysis of the flow frequency curves at selected locations in the watershed due to changes in the rainfall frequency curve.
- Changes in the thresholds of flooding at flood prone areas and flood vulnerable roads due to shifts in the rainfall frequency curve.

B2 SENSITIVITY ANALYSIS

B2.1 REGIONAL STORM FLOWS AT THE MOUTH OF THE DON

The sensitivity analysis for Regional flows at the mouth of the Don (flow node 48.1) to increasing rainfall during the Regional Storm was performed by comparing the Regional flows and runoff volumes obtained at the mouth using varying amounts of rainfall, for both the existing conditions and future conditions scenarios. As mentioned in Section 3.2, the Regional flows at node 48.1 listed in Tables 3.2 and 3.3, were obtained for a total rainfall volume of 211mm, applying a reduction factor of 82.4%. The increase in peak flows and runoff volumes obtained by increasing the volume of rainfall in small increments are summarized in Tables B-1 and B-2. Please note that the rainfall volumes recorded in Tables B-1 and B-2 represent the total volume of rain during the Regional Storm (i.e., for a reduction factor of 100%).

TABLE B-1:
SENSITIVITY ANALYSIS FOR EXISTING CONDITIONS
REGIONAL STORM FLOWS AT THE MOUTH OF THE DON

Rainfall (mm)	Increase over Original Rainfall (%)	Peak Flow (cms)	Increase over Original Peak Flow (%)	Runoff Volume (mm)	Increase over Original Runoff (%)
211	0	1610.42	0	151.55	0
215	2	1651.13	3	154.80	2
229	9	1849.97	15	165.80	9
235	11	1921.27	19	171.11	13
244	16	1963.46	22	178.91	18
251	19	2012.78	25	182.78	21
256	21	2059.89	28	186.44	23

TABLE B-2:
SENSITIVITY ANALYSIS FOR FUTURE CONDITIONS
REGIONAL STORM FLOWS AT THE MOUTH OF THE DON

Rainfall (mm)	Increase over Original Rainfall (%)	Peak Flow (cms)	Increase over Original Peak Flow (%)	Runoff Volume (mm)	Increase over Original Runoff (%)
211	0	1640.13	0	152.16	0
215	2	1682.08	4	155.42	3
229	9	1883.91	17	166.42	10
235	11	1955.31	21	171.72	13
244	16	2069.11	28	180.50	19
251	19	2120.87	32	184.38	22
256	21	2171.52	35	188.06	24

In the recent update undertaken for the DHM model for the mouth of the Don River, it was established that the Regional water levels at the mouth were not very sensitive to increase in peak flows. For example, when the future conditions Regional Storm flow at the mouth was increased from 1461 m^3/s from the previous hydrologic update to 1640 m^3/s in the present update (12% increase in flows), the water levels at the downstream sections remain unchanged. Hence, the increase in flows due to a 21% increase in rainfall volume during the Regional Storm will probably result in marginal changes in the water levels at the mouth.

B2.2 DESIGN STORMS

B2.2.1 Changes in Design Storm Flows

The effect of a shift in the rainfall frequency curve on the design storm peak flows was analyzed by comparing the peak flows at selected locations in the watershed obtained from the 2 to 100-year design storm simulations. The flow nodes were selected based on their proximity to flood prone locations. It was also ensured that the nodes were evenly distributed throughout the watershed. The results of this analysis for the existing and future conditions scenarios are summarized in Tables B-3 and B-4 respectively.

The tabulated results provide estimates for the shifts in the flow frequency curves resulting from a shift in the rainfall frequency curve, i.e., the increase in peak flows that will result if a 1 in 100 year rainfall becomes a 1 in 50 year rainfall, a 1 in 50 year rainfall becomes a 1 in 25 year rainfall, and so on. The increase in peak flows during the 100-year event will depend on the increase in rainfall during the 100-year storm, which cannot be estimated based on this approach.

B2.3 Effect on Thresholds of Flooding at Flood Vulnerable Areas

A shift in the rainfall frequency curve will also affect the thresholds of flooding in the flood vulnerable areas and roads in the Don watershed. The flood vulnerable areas and roads according to the TRCA's existing database (see Figure B-1) have been used for this analysis. This database was developed based on the results on the previous update of the Don River hydraulic model, and may change if there are any significant changes in water levels from the current hydraulic model update.

The existing thresholds of flooding were derived from the information in the TRCA's existing database and have been reported in Tables B-5 and B-6. They represent the most frequent design storm event for which a particular stretch of road or structures in a particular area will be flooded. The reference section numbers in these tables are consistent with the section numbers in the TRCA's database. As evident from the information summarized in these tables, the thresholds of flooding at the flood vulnerable areas and roads will be lowered if there is a shift in the rainfall frequency curve. Moreover, there may be some additional areas and roads, which will now be flooded during the 1 in 50 year event. It was not possible to update the database to include these additional locations from the available information.

B3 CONCLUSIONS

The main conclusions of the present study may be summarized as follows:

- An increase in rainfall during the Regional Storm due to climate change will result in a proportional increase in the Regional Storm flows at the mouth of the Don River. However this will probably lead to only a marginal increase in water levels at the mouth of the Don since the Regional Storm water levels at the mouth are not very sensitive to changes in peak flows;

- The percent increase in peak flows due to a shift in the rainfall frequency curve were calculated at selected locations in the watershed. These results provide some preliminary estimates, which can assist in understanding the potential impact of climate change on the hydrology of the Don River watershed.

- The thresholds of flooding in the flood vulnerable areas and roads in TRCA's existing database will be lowered as a result of a shift in the rainfall frequency curve due to climate change. Additional flood vulnerable areas may also result if the 1 in 100 year event increases.

It should be noted that the above conclusions are based upon a sensitivity analysis of rainfall amounts but are not directly related to specific predictions of future rainfalls resulting from climate change. With the current state-of-the-art, climatologists are not yet able to provide such predictions at a local scale.