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- 20 years practice as Water Resources Engineer (Hydrologic and Hydraulic modelling, Watershed and Subwatershed Studies, Stormwater Management Planning and Design)

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A Contemporary Approach to Establishing Watershed-Scale Criteria for Flood Control Using PCSWMM

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Presentation Outline

1. Introduction and Study Context
2. Hydrologic Model Development
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   2.2 Model Discretization and Parameterization
   2.3 Model Calibration and Design Storm Selection
3. Impact Assessment
   3.1 Future Land Use Conditions
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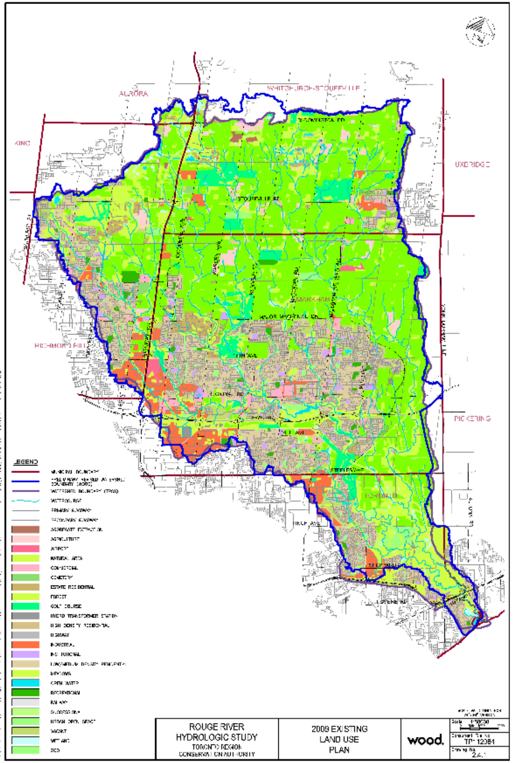
4. Stormwater Management Plan
   4.1 End-of-Pipe Only
   4.2 End-of-Pipe with LID BMPs
5. Conclusions

1. Introduction and Study Context

- The Rouge River Watershed lies in Toronto and Region Conservation Authority jurisdiction and measures some 336 km^2
- The majority of the Watershed (i.e. 65% +/-) is currently in a non-urban condition



1. Introduction and Study Context

- In 2012 TRCA initiated the Rouge River Watershed Hydrology Study (previously completed in 2000) to:
  - *Update the watershed hydrologic modelling;*
  - *Calibrate and validate the updated model;*
  - *Estimate peak flows for 2 to 350-year design storms and the Regional storm; and*
  - *Develop flood (quantity) control criteria for proposed future development lands (approved Official Plans).*

2. Hydrologic Model Development

2.1 Model Selection

- PCSWMM was selected as the modelling platform for the hydrology study
  - Fully compatible with GIS software.
  - Widely used across North America for watershed and subwatershed scale studies.
  - The analytical core of the PCSWMM platform (EPA SWMM) is fully supported by the US EPA and freely available.
  - The EPA SWMM hydrologic model is supported by the MNRF for Regulatory Floodline Mapping.
  - The EPA SWMM hydrologic model applies the Green & Ampt methodology, which is applied by other accepted hydrologic models for modelling non-urban subwatersheds.

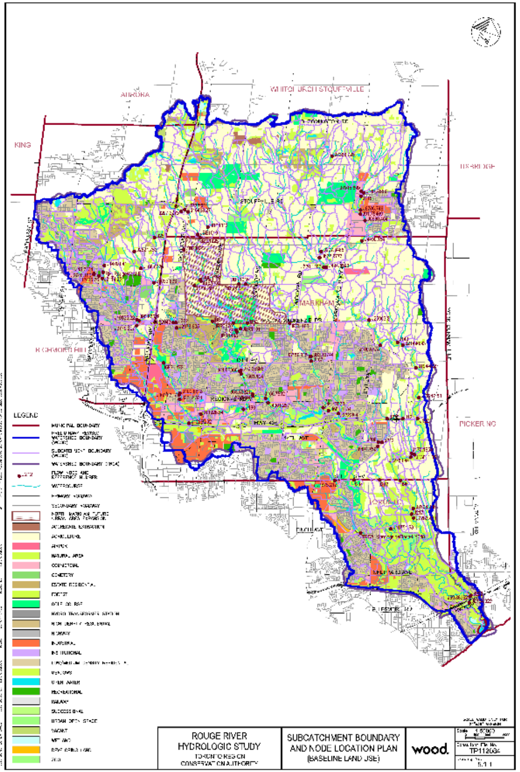
2. Hydrologic Model Development

2.2 Model Discretization and Parameterization

- Subcatchment boundaries were delineated using 2002 DEM and analysis tools within ArcGIS™ and refined based upon background information
- Hydraulic elements representing the open watercourses generated from 2002 DEM
- Storage-discharge relationships representing stormwater management facilities incorporated into the model based upon design reports

2. Hydrologic Model Development

- PCSWMM model includes:
  - 840 subcatchments (average size 40 ha)
  - 1,336 hydraulic elements for open watercourses
  - 151 elements representing stormwater management facilities



2. Hydrologic Model Development

2.2 Model Discretization and Parameterization

- Dominant soils type, based on surficial geology, consists of diamicton
- Uniform parameterization of diamicton soils failed to yield acceptable calibration results
- TRCA database included an attribute which characterized diamicton soils texture, however no literature data is available for these textures
- Base soils parameterization was established by determining generic parameterization for loamy soils, corresponding to texture data for diamicton soils

2. Hydrologic Model Development

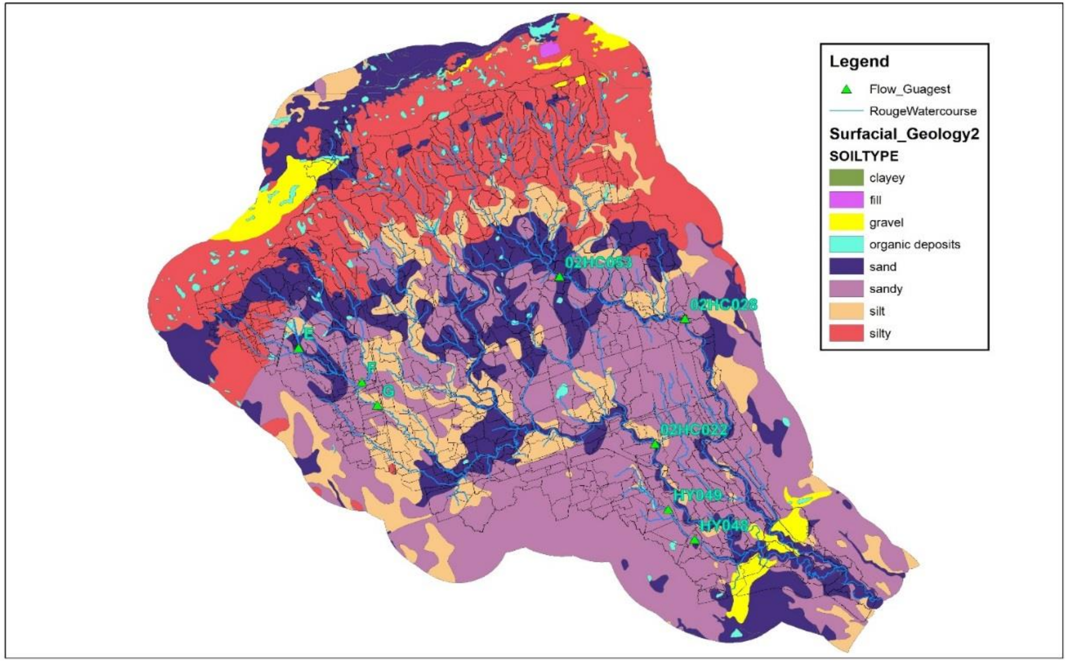


Table 2.4.2 Green and Ampt Infiltration Parameters

Soil Type	Conductivity (mm/hr)	Suction Head (mm)	Initial Moisture Deficit (fraction)
Recommended Green-Ampt Parameters as per CHI, 2010			
Sand	120.4	49.02	0.024
Loamy Sand	29.97	60.96	0.047
Sandy Loam	10.92	109.98	0.085
Loam	3.3	88.9	0.116
Silt Loam	6.6	169.93	0.135
Sandy Clay Loam	1.52	219.96	0.136
Clay Loam	1.02	210.06	0.187
Silty Clay Loam	1.02	270	0.21
Sandy Clay	0.51	240.03	0.221
Silty Clay	0.51	290.07	0.251
Clay	0.25	320.04	0.265
Initial Green-Ampt Parameters for Soils As Identified in TRCA Database			
clayey	1.02	270	0.21
gravel	120.4	49.02	0.024
organic deposits	6.6	169.93	0.135
sand	29.97	60.96	0.047
sandy	1.52	219.96	0.136
silt	6.6	169.93	0.135
silty	6.6	169.93	0.135

2. Hydrologic Model Development

2.2 Model Discretization and Parameterization

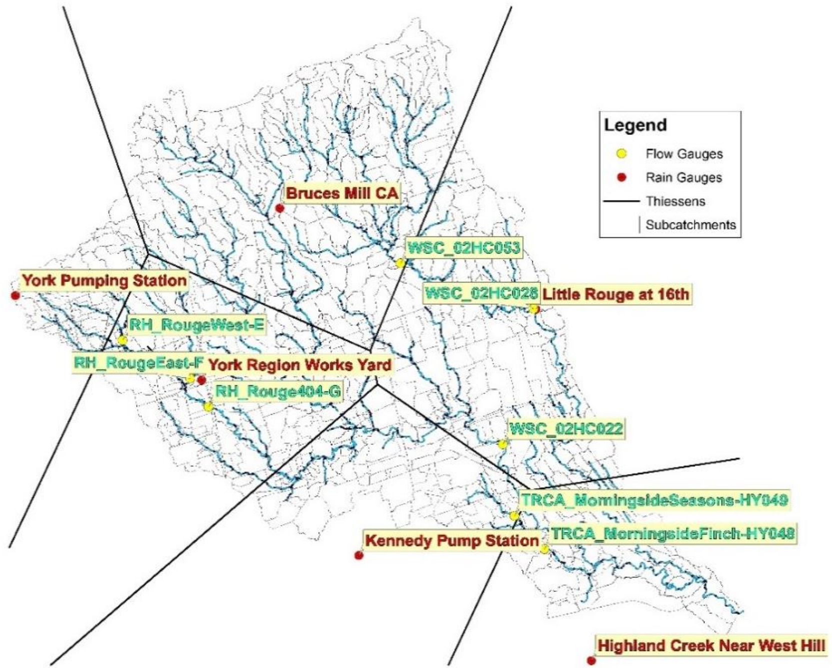
- Initial parameterization of rural subcatchments generated zero or near-zero runoff response for formative storm events (i.e. 100 year and Regional Storm event) for certain subcatchments
- Subcatchment imperviousness and overland flow length/width were identified as key parameters influencing runoff response for rural subcatchments
- Rural subcatchment imperviousness was established as 10% for Little Rouge Subwatershed and 5% for remainder of watershed
- Overland flow length was determined assuming a 3:1 length:width ratio for rural subcatchments

2. Hydrologic Model Development

2.3 Model Calibration and Design Storm Selection

- The base PCSWMM model has been calibrated using rainfall and flow data local to the Rouge River Watershed
  - 6 rainfall gauges
  - 4 flow gauges
- Local calibration and parameterization used to establish soil parameters:
  - West Rouge River Watershed
  - Little Rouge River Watershed

2. Hydrologic Model Development



2. Hydrologic Model Development

2.3 Model Calibration and Design Storm Selection

- Model calibration applied the criteria provided in the Wastewater Planning Users Group (WaPUG) Modelling Code of Practice (2002) for calibrating closed conduit models:
  - Simulated volume is within +20% to -10% of the measured volume
  - Simulated peak flow is within +25% to -15% of the measured value
  - The observed and modelled hydrographs meet the criteria for two (2) out of three (3) events
- Visual inspection of simulated and observed hydrographs also completed for shape and timing

2. Hydrologic Model Development

2.3 Model Calibration and Design Storm Selection

- Hydrologic analyses applied synthetic design storm methodology, consistent with legacy practice in TRCA jurisdiction
- Design storms used as a surrogate for continuous simulation and frequency analysis
- Frequency analyses of historic flow data indicated sensitivity to inclusion/exclusion of snow accumulation and melt
- Design storm selection considered storm distribution and duration which best reproduced frequency flows for storm events (i.e. non-snowmelt conditions)

2. Hydrologic Model Development

Table 4.2.1 Comparison of Simulated Return Period Peak Flow and Calculated Frequency Flows at WSC Gauge 02HC022 (m^3/s)

Return Period	Frequency Analyses	
	Annual Peak Flow	May to October
2	37.3	17.7
5	56.4	30.5
10	68.7	41.2
25 (20)	80.2	53.3
50	94.4	72.1
100	104.8	88.6

Table 4.2.2: Comparison of Simulated Return Period Peak Flow and Calculated Frequency Flows at WSC Gauge 02HC028 (m^3/s)

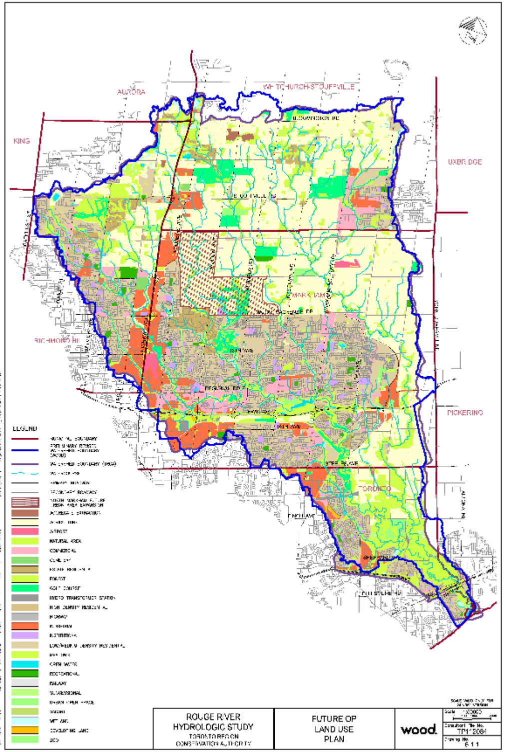
Return Period	Frequency Analyses	
	Annual Peak Flow	May to October
2	20.3	9.1
5	27.4	16.4
10	31.3	21.9
25 (20)	34.6	27.6
50	38.4	35.6
100	40.9	41.9

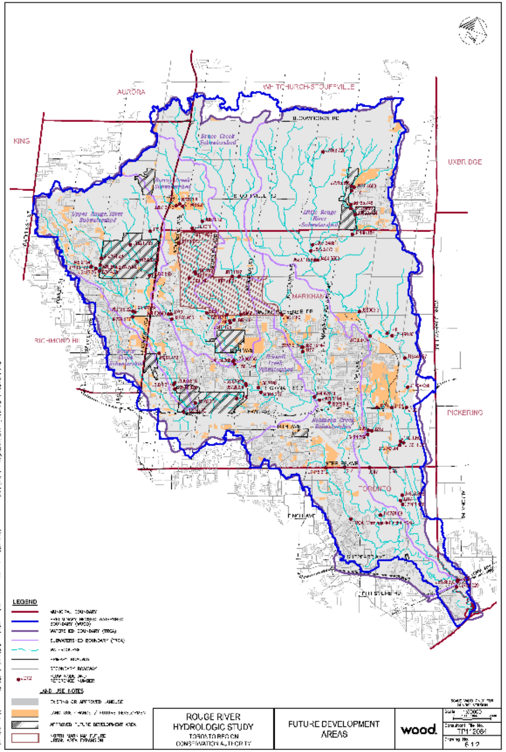
3. Impact Assessment

3.1 Future Land Use Conditions

- Future land use conditions have been established for the Rouge River Watershed, based upon the Municipal Official Plans for the member municipalities within the Watershed
- Subcatchment impervious coverages have been adjusted to represent areas of future development
- Subcatchment boundaries were not refined to separate existing development from future development
- PCSWMM model executed to assess change in return period and Regional Storm event peak flows resulting from future development

3. Impact Assessment





3. Impact Assessment

3.2 Impact Assessment

- In the absence of quantity controls, return period and Regional Storm event peak flows would be anticipated to increase throughout the Watershed primarily within, and proximate to, the future development areas
- Results show increases in peak flows during more frequent events at all locations downstream of future development areas, with some reductions in peak flows during less frequent events due to shifts in hydrograph timing

4. Stormwater Management Plan

4.1 End-of-Pipe Only

- Historic practice within Ontario uses end-of-pipe facilities to control post-development flows to pre-development levels for flood protection
- Storage elements representing end-of-pipe facilities have been incorporated into the PCSWMM model to assess sizing criteria for peak flow control
- Drainage areas to storage elements included existing and future development
- Unit release rates were established for each development area, to account for pervious and impervious elements of the contributing drainage area under baseline conditions

4. Stormwater Management Plan

Table 7.2.1: Storm Water Management Facility Sizing Criteria –Unitary Discharge for Impervious and Pervious Areas ($m^3/s/ha$)

Subwatershed Basin	Return Period (Years)											
	2 Year		5 Year		10 Year		25 Year		50 Year		Regional / 100 Year	
	Impervious	Pervious	Impervious	Pervious	Impervious	Pervious	Impervious	Pervious	Impervious	Pervious	Impervious	Pervious
Eckardt Creek - Upper East Basin	0.089	0.009	0.122	0.020	0.155	0.037	0.171	0.037	0.191	0.047	0.212	0.060
Beaver Creek - Upper West Basin	0.084	0.010	0.115	0.021	0.148	0.042	0.163	0.042	0.183	0.051	0.202	0.061
Berczy Creek - Upper Basin	0.093	0.009	0.126	0.025	0.162	0.052	0.176	0.052	0.196	0.067	0.216	0.081
Berczy Creek - Central Basin	0.088	0.008	0.120	0.019	0.154	0.039	0.169	0.039	0.190	0.048	0.210	0.058
Berczy Creek - Lower Basin	0.097	0.032	0.129	0.059	0.175	0.103	0.176	0.103	0.196	0.122	0.214	0.141
Bruce Creek - Lower Basin	0.092	0.006	0.125	0.017	0.163	0.044	0.175	0.044	0.195	0.058	0.215	0.072
Little Rouge - Upper Basin	0.075	0.003	0.105	0.005	0.129	0.009	0.152	0.009	0.172	0.011	0.191	0.014
Little Rouge - Lower Basin	0.072	0.011	0.102	0.017	0.129	0.028	0.148	0.028	0.168	0.033	0.187	0.039
Robinson Creek - Lower West Basin	0.089	0.012	0.121	0.024	0.156	0.048	0.170	0.048	0.190	0.059	0.210	0.070
Robinson Creek - Upper Basin	0.089	0.012	0.121	0.024	0.156	0.048	0.170	0.048	0.190	0.059	0.210	0.070
Upper Rouge River - Upper Basin	0.090	0.005	0.122	0.016	0.161	0.042	0.172	0.042	0.192	0.056	0.212	0.070

4. Stormwater Management Plan

4.1 End-of-Pipe Only

- Unitary Storage Volumes were tested for each SWM facility specific to each Subwatershed Basin
- Storage for each SWM facility was calculated using the respective Subwatershed Basin unitary storage rate, multiplied by the *increase* in impervious coverage (baseline to future) for the contributing drainage area

4. Stormwater Management Plan

4.1 End-of-Pipe Only

- After numerous iterations, it was concluded that peak flows could not be controlled solely by the application of end-of-pipe facilities
- Greatest relative (i.e. percent) residual increases occurred during more frequent events (i.e. 2 year and 5 year)
- Results were consistent with findings from other studies (i.e. Credit River Flow Management Study; North Markham FUA Subwatershed Study) which demonstrated that residual increases were due to timing of peak flows and increase in runoff volume from future development

4. Stormwater Management Plan

4.2 End-of-Pipe with LID BMPs

- The stormwater management criteria were modified to incorporate Low Impact Development Best Management Practices (LID BMPs) in addition to end-of-pipe facilities
- The use of LID BMPs is consistent with contemporary stormwater management practices which incorporate technologies and practices to promote infiltration and/or intercept storm runoff for reuse

4. Stormwater Management Plan

4.2 End-of-Pipe with LID BMPs

- The LID BMPs have been represented in the model by the depression storage within the pervious portion of the subcatchment
- Adjustment in depression storage for the pervious portion of the subcatchment was weighted according to the proportion of future development in the subcatchment
- Subcatchment routing was modified to route the subcatchment runoff from future impervious surfaces across the pervious portion of the subcatchment, proportionate to the future development in the subcatchment
- The depression storage of the impervious area has been adjusted by increments of 5 mm to account for the capture from LID BMPs for infiltration and/or interception and reuse on-site.

4. Stormwater Management Plan

4.2 End-of-Pipe with LID BMPs

- Release rates from the end-of-pipe facilities were determined using the unitary rates previously determined for the pervious and impervious areas
- Release rates for the operating stages of the facilities were determined by multiplying the unitary release rate by the area of the pervious and impervious components of the subcatchment under baseline conditions

4. Stormwater Management Plan

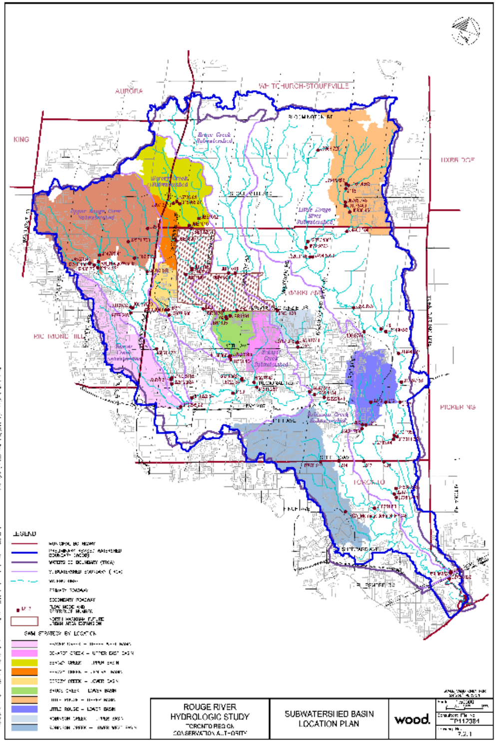
4.2 End-of-Pipe with LID BMPs

- Unitary Storage Volumes within the end-of-pipe facility were adjusted by increments of 25 m^3/imp. ha
- Storage for each SWM facility was calculated using the respective Subwatershed Basin unitary storage rate, multiplied by the *increase* in impervious coverage (baseline to future) for the contributing drainage area
- Unitary storage volumes were determined for each Subwatershed Basin

4. Stormwater Management Plan

4.2 End-of-Pipe with LID BMPs

- Unitary storage volumes were determined for each Subwatershed Basin



4. Stormwater Management Plan

Table 7.2.2: Storm Water Management Facility Sizing Criteria – Unitary Storage (m^3/impervious ha)						
Subwatershed Basin	Return Period (Years)					
	2 Year	5 Year	10 Year	25 Year	50 Year	Regional/ 100 Year
Eckardt Creek - Upper East Basin	250	350	450	550	650	750
Beaver Creek - Upper West Basin	750	800	850	900	950	1000
Berczy Creek - Upper Basin	1000	1050	1100	1200	1600	1800
Berczy Creek - Central Basin	1000	1050	1100	1200	1600	1800
Berczy Creek - Lower Basin	1000	1050	1100	1200	1600	1800
Bruce Creek - Lower Basin	750	800	850	900	950	1200
Little Rouge - Upper Basin	750	800	850	900	950	1000
Little Rouge - Lower Basin	100	150	200	750	850	1200
Robinson Creek - Lower West Basin	350	400	500	600	900	1000
Robinson Creek - Upper Basin	1000	1050	1600	1700	1800	1900
Upper Rouge - Upper Basin	350	400	475	1200	1300	1400

4. Stormwater Management Plan

4.2 End-of-Pipe with LID BMPs

- The unitary sizing criteria for end-of-pipe facilities are comparable to criteria developed in Subwatershed Studies in other jurisdictions and areas
- Recommended stormwater management plan includes applying a LID BMP capture of 20 mm/impervious hectare for future development within the Robinson Creek Subwatershed and 15 mm/impervious hectare for future development within the remainder of the Rouge River Watershed

5. Conclusions

- The PCSWMM hydrologic model for the Rouge River Watershed is representative of existing predominantly rural land use conditions within the watershed and is considered suitable for conducting event-based analyses within the watershed
- The calibrated PCSWMM hydrologic model is suitable for generating instantaneous peak flows for use in developing Regulatory Floodline mapping within the Rouge River Watershed
- Diamicton soils may be parameterized using literature values for loamy soils

5. Conclusions

- Frequency flows in rural watersheds are sensitive to inclusion/exclusion of snowmelt conditions
- End-of-pipe facilities alone would be insufficient to control post-development peak flows resulting from future development in the Rouge River Watershed per the current Official Plans
- LID BMPs, combined with end-of-pipe facilities, would be required for flood protection for all events, particularly the more frequent events

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