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Runoff Volume Control Targets for Ontario

Final Report

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Disclaimer: The following report and recommendations contained herein are technical recommendations based on expert input, stakeholder consultation and professional judgement and are not endorsed by the Ministry of the Environment and Climate Change (MOECC) and have been prepared for consideration only.

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Runoff Volume Control Targets (RCV_T) for Ontario

1 INTRODUCTION

The following report describes the Minimum Runoff Volume Control Target (RCV_T) for Ontario and has been undertaken to inform the development of the Ministry of the Environment & Climate Change (MOECC) Low Impact Development Stormwater Management Guidance Manual.

1.1 Background

Following the completion of the **Jurisdictional Scan of Canadian, US and International Stormwater Management Volume Control Criteria** Report, the MOECC selected five (5) jurisdictions for further study in regards to:

- The volume target for the specific jurisdiction including the type of criteria (e.g. Volume Retention/ Reduction Criteria etc.)
- The methodology and rationale for selecting the specific volume target
- Depth (mm) or event types that are excluded from the analysis of the volume target
- The definition of what constitutes a 'rainfall event'
- The definition or method for determining the Minimum Interevent Time (MIT)

The study of the selected five (5) jurisdictions is intended to inform and provide the basis for the development of the Runoff Volume Control Target (RVC_T) for Ontario. In several cases, multiple jurisdictions were studied due to their inherent similarities or connections between jurisdictions and the development of the relevant stormwater criteria. The five (5) recommended jurisdictions include:

1. Province of British Columbia and the City of Chilliwack
2. State of Minnesota & the Lake Simcoe Region Conservation Authority
3. Great Lake States: New York State & the State of Michigan
4. District of Columbia, Washington, D.C.
5. New Zealand – National & Christchurch

The study of the selected five (5) jurisdictions is detailed in **Section 2.0**.

Subsequently, it was proposed through discussions with the MOECC, that a rigorous analysis with supporting rationale be undertaken using Ontario rainfall data to support the selection of Runoff Volume Control Target. As such hourly and daily rainfall data was collected for 393 and 1,464 active and historical climate stations respectively across the province. After screening the hourly and daily rainfall data, ninety-nine (99) and two hundred and twenty-three (223) climate stations respectively were selected for detailed analysis. Note: 15-minute rainfall series were also obtained but were not be utilized due to the small quantity of available data and poor station density.

In addition, to the above, five (5) 'locations of interest' were selected in consultation with the MOECC in order to represent and provide comparison of the geographically significant climactic variation and trends within the province. The five (5) 'locations of interest' included:

1. Toronto
2. Ottawa
3. Windsor

4. Sudbury and
5. Thunder Bay

The following report describes the study for the five (5) selected jurisdictions, summarizes the results of the analysis of hourly and daily rainfall data, with supporting rationale, for various locations across the Province, and recommends a Runoff Volume Control Target (RVC_T) for Ontario.

The rainfall analysis for Ontario is detailed in **Section 3.0**.

1.2 Report Purpose

The purpose of this report is to provide analysis and recommendations for a Runoff Volume Control Target for Ontario for new development, redevelopment, infill-developments, reurbanization and linear infrastructure and retrofits to inform the development of the Ministry of the Environment & Climate Change (MOECC) Low Impact Development Stormwater Management Guidance Manual.

1.3 Report Structure

This report contains four (4) sections relating to the following:

- **Section 1 –** Introduces the document, provides the study background, and outlines the report purpose.

- **Section 2 –** provides a summary of the five (5) jurisdictions selected for further study, including the Province of British Columbia and the City of Chilliwack, State of Minnesota & the Lake Simcoe Region Conservation Authority, Great Lake States (New York State & the State of Michigan), the District of Columbia and New Zealand.

- **Section 3 –** provides a summary of the rationale and background supporting the use of the 90th and 95th percentile approaches, presents the results of the rainfall analysis completed for the province of Ontario using hourly and daily rainfall data and provides the recommended Rainfall Frequency Spectrum (RFS) for Ontario for use as the Runoff Volume Control Target for Ontario.

- **Section 4 –** Presents key terminologies and the recommended Runoff Volume Control Targets for Ontario (RVC_T).

- **Section 5 –** Discusses potential future considerations.

2 FIVE (5) SELECTED JURISDICTIONS

The following section provides a summary of the five (5) jurisdictions selected for further study following the completion of the **Jurisdictional Scan of Canadian, US and International Stormwater Management Volume Control Criteria** Report. The five (5) jurisdictions include:

1. Province of British Columbia and the City of Chilliwack
2. State of Minnesota & the Lake Simcoe Region Conservation Authority
3. Great Lake States: New York State & the State of Michigan
4. District of Columbia, Washington, D.C.
5. New Zealand – National & Christchurch

2.1 Introduction

The purpose of this section of the report is to summarize the sources, methods, and research that were used to determine the runoff volume treatment target used by the five (5) selected jurisdictions. Several items were examined in-depth, including how the jurisdictions calculated their treatment volumes, if they excluded precipitation events below a certain threshold, how they defined a rainfall event, or the specified inter-event period. In several cases, multiple jurisdictions were studied due to their inherent similarities or connections between jurisdictions and the development of the relevant stormwater criteria.

Table 2.1 summarizes the five (5) recommended Canadian Jurisdictions, American and International Jurisdictions in regards to:

- The respective jurisdiction current volume control targets;
- Method by which the control target is achieved;
- Volume control criteria type and the method for achieving the volume control;
- Mean annual rainfall depth for each location and division between rainfall and snowfall where relevant (as available);
- Additional information relating to volume control targets or criteria, other stormwater criteria specified by the individual jurisdiction (for information purposes only) and identification if Low Impact Development (LID) techniques are recommended, required or supported with the jurisdiction.

Table 2.1 – Summary of the Selected Jurisdictions: Stormwater Control Targets and Criteria

Location	Volume Target	Volume Control Criteria & Method for Achieving Control	Mean Annual Rainfall (snow)	Notes
Prov. of British Columbia	90% of mean annual rainfall event volume	**Volume Retention** (Infiltration & ET) or **Volume Detention**	2,000 mm (250 to 3,000 mm)	Runoff Volume – 90% of mean annual rainfall volume Runoff Rate – Natural Mean Annual Flow[1] (MAF) occur no more than once per year.
Chilliwack, B.C	First 30 mm	**Volume Retention** - Infiltration, ET & reuse	1,650 mm	Runoff Volume = 50% Mean Annual Rainfall (MAR of 63 mm, 24 hr) - corresponds to what some jurisdictions describe as the '6-month storm
	Next 30 mm	**Volume Detention**		Runoff Rate – Natural Mean Annual Flow (MAF) occur no more than once per year, on average.
State of Minnesota	28 mm (1.1 in)	**Volume Retention** - Infiltration, ET & reuse	800 mm	Minimal Impact Design Standards (MIDS) - Post retained to pre-development levels Also, designs must meet water quality removal standards for Total P and TSS via infiltration.
Lake Simcoe Region Conservation Authority (LSRCA)	90th percentile storm thresholds of 25 mm (1 in)	**Volume Retention –** Infiltration & ET; **Volume Capture and Treatment; & Volume Detention**	890 mm	New non-linear & redevelopment – retain the first 25 mm from impervious surfaces Linear Development, greater of: • The first 12.5 mm of runoff from new a fully reconstructed • The first 25 mm of runoff from the net increase in impervious area Flexible (restricted sites): 1. Min 12.5 mm & 75% annual TP load reduction 2. Maximum extent practical of vol. reduction & 60% annual TP load reduction 3. Off-site treatment Requires the use of LIDs

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[1] Mean annual flow is the average flow for the individual year or multi-year period of interest. When working with hydrologic data it is customary to view the data by water years (October-September) rather than by calendar years (January-December).

Location	Volume Target	Volume Control Criteria & Method for Achieving Control	Mean Annual Rainfall (snow)	Notes
State of Michigan	(0.5 in) 12.5 mm to (1 in) 25 mm	**Volume Capture and Treatment**	815 mm (120 mm snow)	One inch of runoff generated from the entire project site. Uses the 90th percentile storm.
State of New York	23 mm (0.8 in) to 34 mm (1.2 in)	**Volume Retention**	1,200 mm	Maintain pre-development infiltration, runoff, and volume. Achieve 80% TSS reduction and 40% Phosphorus reduction.
District of Columbia, Washington DC	30 mm (1.2 in)	**Volume Retention**	980 mm	Unified Sizing Criteria - New Developments
	20 mm (0.8 in)	**Volume Retention**		Unified Sizing Criteria - Re-development
New Zealand-national	16.7 - 43 mm	**Volume Capture and Treatment**	600-1600 mm	Storage volume or design storm approach
New-Zealand-Christchurch	25 mm	**Volume Capture and Treatment**	600 mm	Storage volume equates to corresponding runoff depth

2.2 British Columbia

The following section describes the development of the stormwater volume targets including supporting rationale and methodology for the Province of British Columbia, the City of Chilliwack and the B.C. Department of Fisheries and Oceans (DFO), which has been added for completeness, as the governing volume retention target in the province.

For additional information and context in regards to the Province of British Columbia and the City of Chilliwack, refer to the **Jurisdictional Scan of Canadian, US and International Stormwater Management Volume Control Criteria**.

2.2.1 Background

British Columbia (B.C.) is the western most province in Canada and is a component of the Pacific Northwest. B.C. is home to the Cities of Victoria and Vancouver, the 15th largest and 3rd largest metropolitan regions in Canada respectively. B.C. drains to many interior lakes and rivers as well as the Pacific Ocean.

Prior to 2002, site design practices were not clearly laid out in stormwater policy objectives. The British Columbia (B.C.) Stormwater Planning Guidebook pioneered the use of “adaptive management” in stormwater management. The goal of Adaptive Management is to learn from experience and constantly improve land development and rainwater management practices over time. Implicit in an adaptive management approach is recognition of the need to both accept and manage risk if the state-of-the-practice is to be advanced.

In British Columbia, the term Integrated Stormwater Management Plan (ISMP) has gained widespread acceptance by local governments and the environmental agencies to describe a comprehensive approach to stormwater planning. The purpose of an ISMP is to provide a clear picture of how to be proactive in applying land use planning tools to protect property and aquatic habitat, while at the same time accommodating land development and population growth. The Guidebook also introduced the concept of Performance Targets to facilitate implementation of the Integrated Strategy for managing the complete rainfall spectrum. The Stormwater Guidebook established the framework for making integrated and adaptive management of stormwater and land development a reality.

The City of Chilliwack Policy and Design Criteria Manual for Surface Water Management (May 2002) was developed as a case study application of the British Columbia (B.C.) Stormwater Planning Guidebook a collaborative effort of an inter-governmental partnership that was initiated by local government.

The Department of Fisheries and Oceans (DFO), since 1993, has been promoting the protection of fish and fish habitat through detention of stormwater flows from urban development areas[1] and have established volume retention targets for fish bearing creeks which generally supersede other provincial and municipal requirements in B.C. This is discussed in **Section 2.2.4.**

2.2.2 Determination of the B.C. Stormwater Target

Runoff volume-based performance targets are not only quantifiable, but also synthesizes complex information into a single number that is simple to understand and achieve, yet is comprehensive in scope. The B.C. Stormwater Design Guidebook recommends 90% of *rainfall volume* as the target best able to achieve the biophysical target conditions for the watershed.

2.2.2.1 B.C. Stormwater Targets

Both the runoff volume target and runoff rate targets are derived from a thorough understanding of the rainfall spectrum. A key parameter for describing the rainfall spectrum is the Mean Annual Rainfall (MAR) which is roughly equivalent to the 2-year, 24-hour duration storm event.

To simplify performance targets, the Guidebook organized rainfall volumes into three (3) Tiers: Tier A, Tier B and Tier C. **Table 2.2.2.1** summarizes the three (3) tiers.

1. **Tier A Events**[2] – The small rainfall events that are less than half the size of a MAR. About 90% of all rainfall events are Tier A events.
2. **Tier B Events**[3] – The large rainfall events that are greater than half the size of a MAR, but smaller than a MAR. About 10% of all rainfall events are Tier B events.
3. **Tier C Events**[3] – The extreme rainfall events exceeding a MAR. An extreme event may or may not occur in any given year.

Table 2.2.2.1 - Summary Tiers A, B and C Events

Location	Tier A Events (less than 50% of MAR)	Tier B Events (between 50% of MAR and MAR)	Tier C Events (greater than MAR)
Vancouver (North Shore)	< 40 mm	40 to 80 mm	> 80 mm
Chilliwack	< 30 mm	30 to 60 mm	> 60 mm
Nanaimo	< 20 mm	20 to 40 mm	> 40 mm
Kelowna	< 10 mm	10 to 20 mm	> 20 mm

Roughly 90% of all rainfall events are Tier A events; about 10% of rainfall events are in Tier B, and Tier C events may or may not occur in a given year.

Each tier corresponds to a component of the ISMP.

- Rainfall capture (source control) is designed to manage smaller Tier A rainfall events. On-lot and on-street BMPs, such as rain gardens and infiltration pits, keep rain on site.

- Runoff control (detention) is able to manage large Tier B rainfall events. BMPs deployed for these events address runoff rate targets by delaying overflow runoff, thereby eliminating spikes in stormwater runoff. Typical BMPs include ponds and other detention storage.

- Flood risk management (contain and convey) reduces the threats to public safety and damage to property from extreme Tier C events. These practices reduce flooding by providing sufficient hydraulic capacity to contain and convey runoff from large storms. The Guidebook provides a very useful example to explain how the integrated stormwater planning process moves from defining the rainfall spectrum to setting performance targets for each tier of rainfall events to establishing design criteria for specific practices.’

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[2] For the purpose of setting performance targets, a rainfall event is defined as total daily rainfall (i.e. mm of rainfall accumulated over 24 hours). This assumption results in conservative site design criteria, which can be optimized over time through continuous simulation modeling, and by monitoring the performance of demonstration projects

2.2.2.2 B.C. Analysis and Rationale

When the impervious area of watersheds with traditional ditch and pipe systems reaches the 10% threshold, about 10% of the total rainfall volume becomes runoff that enters receiving waters; this runoff volume is the root cause of aquatic habitat degradation.

The B.C. Stormwater Design Guidebook notes that there is virtually no surface runoff from the naturally vegetated portion of a watershed, but nearly all rain that falls on directly connected impervious surfaces becomes runoff.

An appropriate performance target for managing runoff volume is to limit total runoff volume to 10% (or less) of total rainfall volume. This means that 90% of rainfall volume must be returned to natural hydrologic pathways, through infiltration, evapotranspiration or re-use on the development site. Managing 90% of the rainfall volume throughout a watershed should achieve the biophysical target condition for the watershed. Managing 90% of rainfall volume therefore becomes the volume-based performance target.

No detailed analysis is referenced in the development of the above noted targets within the B.C. Stormwater Design Guidebook.

2.2.3 Determination of the City of Chilliwack Stormwater Target

At its core, the City of Chilliwack aims to manage the *Complete Spectrum of Rainfall Events*. The City's approach to stormwater management evolved, from a reactive approach that only dealt with the consequences of extreme events, to one that is proactive in managing all 170 rainfall events that occur in a year. The regional MAR for Chilliwack is 63 mm. This value was obtained by analyzing 100 years of peak annual daily rainfall values and graphing it using a logarithmic distribution (**Figure 2.2.3.1**).

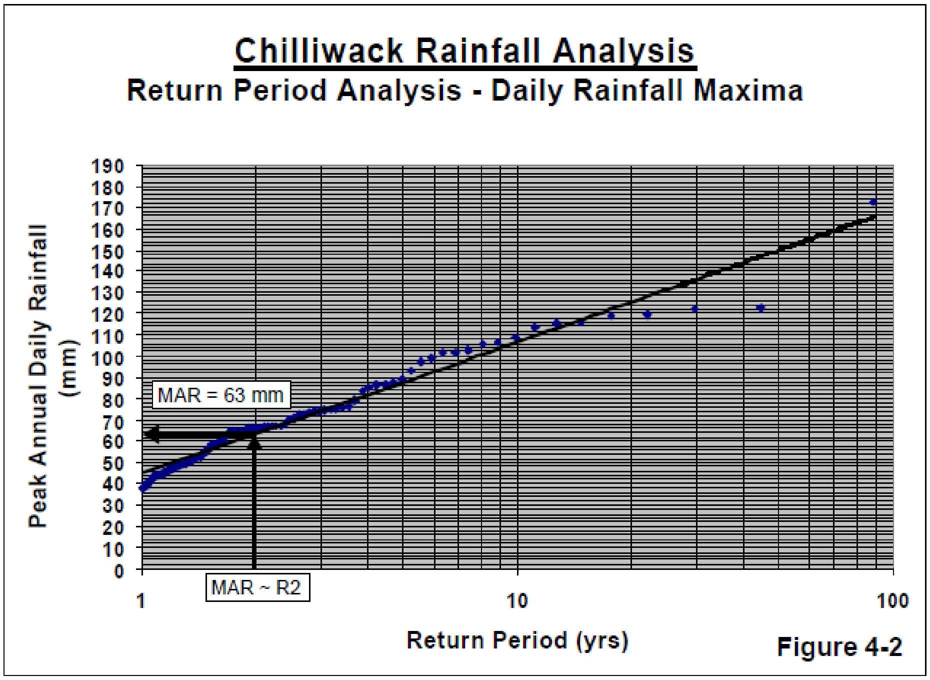


Figure 2.2.3.1 - Regional MAR for Chilliwack

2.2.3.1 City of Chilliwack Stormwater Targets

Chilliwack's stormwater management approach is to manage the complete spectrum of rainfall events, from the very small to the extreme. The operative words offered within the Manual are retain, detain, and convey: The City of Chilliwack requires that new development projects meet the following performance targets:

1. **Rainfall Capture (retention)**
    a. Capture less than 50 percent of the MAR for a 24-hour duration, which equates to the first 30 mm of rainfall per day and restore it to natural hydrologic pathways by promoting infiltration, evapotranspiration or rainwater reuse. These are known as Tier A/B storms. For Chilliwack, capture of the first 30 mm equates to 89% of the annual rainfall volume.

    b. This becomes a design criterion of capturing 300 cu. m of rainfall per hectare of impervious area, as well as incorporating infiltration at the natural percolation rate of local soils, and/or reuse stormwater within the development site.

2. **Runoff Control (detention)**
    a. Detain 50 percent of the MAR which equates to 30-60 mm per day and release to drainage system or water courses at natural interflow rate. These are known as Tier C storms.
    b. This becomes a design criterion of providing an additional 300 cu. m of detention storage per hectare of impervious area, and releasing stormwater to storm sewers or streams at a rate of 1 liter per second per hectare.

3. **Flood Risk Management (conveyance)**
    a. Ensure that the stormwater plan can safely convey storms greater than 60 mm up to the 100-year rainfall. These are known as Tier D storms.
    b. This becomes a design criterion of providing emergency spillways based on extreme storm events, and ensuring that these routes are both hydraulically adequate and physically adequate.

2.2.3.2 City of Chilliwack Rationale

Following the B.C. Stormwater Design Guidebook (2002), the objective is to control runoff volume so that watersheds behave as though they have less than 10% impervious area. The manual states – that "reducing runoff volume at the source – where the rain falls - is the key to protecting property, habitat and water quality". The City of Chilliwack is addressing the root cause of drainage related problems – "that is, land development alters the Natural Water Balance." Thus, Chilliwack's approach to stormwater management is evolving from a reactive approach that only 'deals with the consequences' of land use change, often at great public expense to a proactive approach that also 'eliminates the root cause of problems' by reducing the volume and rate of runoff at the source.

2.2.4 Department of Fisheries and Oceans

Upon review of SWM Criteria and Guidelines as part of the detailed review and speaking to practitioners in B.C. it was noted that the volume reduction targets specified in the Department of Fisheries and Oceans (DFO) Urban Stormwater Guidelines and Management Practices for the Protection of Fish and Fish Habitat (2001), are more stringent and as such supersedes the

B.C. Stormwater Design Guidebook (2002), as detailed in the Template for Integrated Stormwater Management Planning (Greater Vancouver Regional District, 2005).

The Template for Integrated Stormwater Management Planning (2005) notes that the criteria detailed in both documents stipulate volumetric reductions, however "the DFO criteria outline a more stringent 6-month storm (72% of the 2-year storm) whereas the guidebook refers to a mean annual rainfall amount which is roughly 50% of the 2-year storm. Since the DFO criterion commonly is dependent upon approvals for instream works, it is recommended that the more stringent 6-month storm be used to facilitate timely approvals by federal agencies."

Comparisons of the DFO requirements and the City of Chilliwack as an example, the DFO target would require the capture of approximately 72 mm of rainfall per day versus the capture of 30 mm.

2.2.5 Summary

Table 2.2.5 presents a summary of the British Columbia included as part of the selected jurisdictions in regards to the respective volume target, the rationale for selecting the target, the rainfall events considered as part of the target development and the Minimum Inter Event (MIT) used in the analysis.

Table 2.2.5 – Summary of the British Columbia Jurisdiction

Jurisdiction/ Agency	Volume Target	Rationale	Rainfall Event	Minimum Interevent Time (MIT)
Province of B.C & Chilliwack, B.C.	**Volume Retention** (Infiltration & ET) 0-50% MAR (Tier A/B rainfall Events) MAR = 2 yr, 24-hour event	Capture 90% of mean annual rainfall volume and either infiltrate or evaporate at source. To achieving the biophysically-based target condition (a healthy watershed) requires that 90% of total rainfall volume must be captured at the source to reduce total runoff volume to 10% or less of total rainfall volume.	**Type:** Daily rainfall (24 hr duration) **Exclusions:** n/a	**N/A** (Daily rainfall analysis, MIT not required)
DFO	6-month, 24-hour	Infiltrate, evaporate, transpire or re-use all rainfall up to the 6-month storm. Only applicable to fish bearing creeks. Note: Recommended by the GRVD as the governing target.	**Type:** Calculated as 72% of the 2 year, 24 hour storm **Exclusions:** n/a	**N/A** (Daily rainfall analysis, MIT not required)

2.3 State of Minnesota & the Lake Simcoe Region Conservation Authority

The following section describes the development of the stormwater volume targets including supporting rationale and methodology for the State of Minnesota and the Lake Simcoe Region Conservation Authority.

For additional information and context in regards to the State of Minnesota and the Lake Simcoe Region Conservation Authority, refer to the **Jurisdictional Scan of Canadian, US and International Stormwater Management Volume Control Criteria**.

2.3.1 Background

Minnesota is the 12th largest state by area and 21st most populous state of the U.S. It borders Wisconsin to the east, North Dakota and South Dakota to the west, Iowa to the south, and Manitoba and Ontario to the north. Minnesota is a National Pollutant Discharge Elimination System (NPDES) delegated state. Its Stormwater Regulatory Program has been developed based on the NPDES stormwater program to address polluted stormwater runoff across the state. It is administered by the Minnesota Pollution Control Agency (MPCA) with oversight from the EPA. To address a need for improved SWM control, the Minnesota Legislature directed state agencies to “develop performance standards, design standards or other tools to enable and promote the implementation of Low Impact Development and other stormwater management techniques.”[2] The Minimal Impact Design Standards (MIDS) scheme was developed in response to this direction. It is based on Low Impact Development (LID) - an approach to storm water management that mimics a site’s natural hydrology as the landscape is developed

The Lake Simcoe Region Conservation Authority (LSRCA) recently released the Lake Simcoe Watershed LID SWM Guidelines for Municipalities (April, 2015) which was based on the MIDS approach. The LSRCA LID SWM Guidelines were developed in response to the Lake Simcoe Protection Plan. The plan is based on the Lake Simcoe Protection Act (2008) which intends to restore and protect the ecological health of the watershed. The act allows policies in relation to research and monitoring of activities that impact ecological health within the watershed.

2.3.2 Determination of the State of Minnesota Target

The State of Minnesota requires that stormwater runoff volumes be controlled and the post-construction runoff volume shall be retained on-site for 1.1 inches (28 mm) of runoff from impervious surfaces statewide which equates to the 90% of the runoff producing events annually. This is translated into specific performance goals for new development, non-linear development, linear development and the three (3) flexible treatment options.

2.3.2.1 Minnesota Stormwater Management Targets

The stakeholder input, working group discussions, and expert recommendations resulted in several innovative and strict performance goals for new development, non-linear development, linear development and the three (3) flexible treatment options. Additional detail is provided below.

1. New, nonlinear developments that create more than one acre of new impervious surface on sites without restrictions, stormwater runoff volumes will be controlled and the post-construction runoff volume shall be retained on-site for 1.1 inches (28 mm) of runoff from impervious surfaces statewide.

2. Nonlinear redevelopment projects on sites without restrictions, that create one or more acres of new and/or fully reconstructed impervious surfaces shall capture and retain on-site 1.1 inches (28 mm) of runoff from the new and/or fully reconstructed impervious surfaces.

3. Linear projects on sites without restrictions that create one acre or more of new and/or fully reconstructed impervious surfaces, shall capture and retain the larger of either:
    1. 0.55 inches (14 mm) of runoff from the new and fully reconstructed impervious surfaces; or
    2. 1.1 inches (28 mm) of runoff from the net increase in impervious area. Mill and overlay and other resurfacing activities in linear projects are not considered fully reconstructed.

The MIDS approach further requires that all projects must first attempt to meet the volume reduction Performance Goal on site. However, if an applicant is unable to achieve the full Performance Goal due to site restrictions as attested by the local authority and documented by the applicant, the development project must follow one of three (3) Flexible Treatment Options.

1. Flexible Treatment Option 1: Applicant attempts to comply with the following conditions:
    i. Achieve at least 0.55 (14 mm) inch volume reduction goal, and
    ii. Remove 75 percent of the annual total phosphorus load, and
    iii. Options considered and presented shall examine the merits of relocating project elements to address varying soil conditions and other constraints across the site

2. Flexible Treatment Option 2: Applicant attempts to comply with the following conditions:
    i. Achieve volume reduction to the maximum extent practicable (as determined by the Local Authority), and
    ii. Remove 60 percent of the annual total phosphorus load, and
    iii. Options considered and presented shall examine the merits of relocating project elements to address varying soil conditions and other constraints across the site.

3. Flexible Treatment Option 3: Off-site mitigation (including banking or cash or treatment on another project, as determined by the local authority) equivalent to the volume reduction performance goal can be used in areas selected in the following order of preference:
    i. Locations that yield benefits to the same receiving water that receives runoff from the original construction activity.
    ii. Locations within the same Department of Natural Resources (DNR) catchment area as the original construction activity.
    iii. Locations in the next adjacent DNR catchment area up-stream.
    iv. Locations anywhere within the local authority's jurisdiction.

2.3.2.2 Minnesota Analysis and Rationale

Minnesota bases its volume targets on what it calls “Integrated Stormwater Design Principles”. In regards to stormwater practices that are to be integrated into urban landscapes to improve function and performance, these principles include the following:

1. Provide reliable pollutant removal performance
2. Mimic pre-development hydrology

Small storms are often the focus of water quality analysis because research has shown that pollution migration associated with frequently occurring events accounts for a large percentage of the annual load. This is because of the “first flush” phenomenon of early storm wash-off and the large number of events with frequent return intervals. Rain events between 0.5 inches (13 mm) and 1.5 inches (38 mm) are responsible for about 75% of runoff pollutant discharges (MPCA, 2000).

Precipitation Frequency Analysis

In 2005, as part of the development of MIDS, the rainfall depth corresponding to 90% and 95% total annual rainfall depth were analyzed at six (6) locations in the state (Map inset). The six (6) stations represent east-central, central, southeast, northwest, north east and southwest regions of the state with daily precipitation records with a minimum of 30 years of data (1970 to 2000-04). Rainfall less the 0.1 inches (2 mm) were not included in the analysis, per the U.S. EPA[3,4 & 5] recommendations which suggests that small rainfall events that are 0.1 of an inch (2 mm) or less be excluded from the percentile analysis because this rainfall generally does not result in any measurable runoff due to absorption, interception and evaporation by permeable, impermeable and vegetated surfaces, as well as since most rain gauges only record values to the nearest 0.1 inch (2.5 mm). Note: initial abstractions are commonly estimated to be between 0.10 and 0.15 inches in urban areas (0.1 and 3.8 mm).

Minnesota Precipitation Frequency Analysis Locations

The six stations analyzed were:

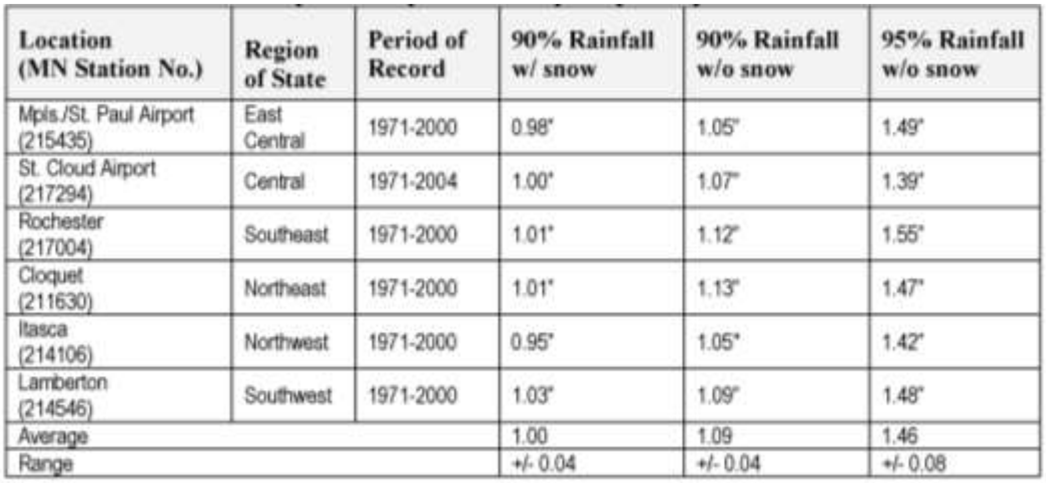
1. Minneapolis/St. Paul International Airport,
2. St. Cloud Airport,
3. Rochester Airport,
4. Cloquet,
5. Itasca, and
6. Lamberton SW Experiment Station.

The analysis was conducted under two scenarios: (1) evaluating the total precipitation (rain and snow) record and (2) evaluating the rainfall record only. The report states that “the second analysis was performed because, while snowfall is a part of the precipitation record, it does not produce runoff immediately. Thus, the 90th percentile storm event can be calculated by eliminating snowfall from the precipitation record. A simplified assumption was used for the second analysis (rainfall only) whereby any day that had recorded snowfall was discarded from the analysis. This analysis reduces the total number of records from which the frequency analysis was developed”[6]

The results of the analysis are reproduced as **Table 2.3.2.2** and demonstrate:

- A 0.09 inch (2.3 mm) difference from Scenarios (1) and (2), total precipitation vs. rainfall record only, which provides justification for the simplified assumption of applying scenario (2) rainfall only in determining the 90th percentile rainfall depth.
- The rainfall depth corresponding to 90th percentile and 95th percentile of the annual total rainfall depth shows surprising consistency among six (6) stations chosen to represent regional precipitation across the State. The rainfall depth which represents 90% and 95% of runoff producing events was 1.09 inches (28 mm) (+/- 0.04 inches (1 mm)) and 1.46 inches (37 mm) (+/- 0.08 inches (2 mm)), respectively. This rainfall depth can be used for water quality analysis throughout the state.
- The percent of total cumulative rainfall depth treated by a theoretical BMP at each of the six (6) locations applying Scenario (1) for the 90% rainfall ranges from 87 to 89%.

Table 2.3.2.2 – Summary of Precipitation Frequency Analysis for Minnesota



Location (MN Station No.)	Region of State	Period of Record	90% Rainfall w/ snow	90% Rainfall w/o snow	95% Rainfall w/o snow
Mpls./St. Paul Airport (215435)	East Central	1971-2000	0.98"	1.05"	1.49"
St. Cloud Airport (217294)	Central	1971-2004	1.00"	1.07"	1.39"
Rochester (217004)	Southeast	1971-2000	1.01"	1.12"	1.55"
Cloquet (211630)	Northeast	1971-2000	1.01"	1.13"	1.47"
Itasca (214106)	Northwest	1971-2000	0.95"	1.05"	1.42"
Lamberton (214546)	Southwest	1971-2000	1.03"	1.09"	1.48"
Average			1.00	1.09	1.46
Range			+/- 0.04	+/- 0.04	+/- 0.08

Performance Goal Assessment

A subsequent analysis completed for the Minnesota Pollution Control Agency (MPCA) in 2011, assessed the MIDS performance goal alternatives[7]. Three (3) runoff volume control options were assessed:

(1) Retention of the runoff volume of 1 inch (25 mm) of runoff from impervious surfaces;

(2) Retention of the post-construction runoff volume for the 95th percentile 24-hour rainfall event, which at the time was being considered by the U.S. Environmental Protection Agency (EPA) as a national standard;

(3) Limitation of the post-construction runoff volume equal or less than the native soils and native vegetation conditions for: a) the 1 year, 24-hour storm event, b) the 2-year, 24-hour storm event.

This analysis used long-term, continuous simulation, XP-SWMM models, for three regions of Minnesota (Twin Cities Metropolitan area, Southeast, and North-Central). The models used between twenty-six (26) and thirty-five (25) years of measured precipitation data with a time increment of 15 minutes.

Larger events such as the spring snowmelt, however, can be the single largest water and pollutant loading event in the year. In Minnesota, this spring snowmelt occurs over a comparatively short period of time (i.e., approximately two weeks) in March or April of each year – depending on the region of the state. The large flow volume during this event may be the critical water quality design event in much of the state. As such precipitation in the form of rain and snow on frozen and unfrozen ground conditions was also used to determine the effectiveness of common volume control performance goals on annual runoff.[8] Performance goals were assessed based on estimated total phosphorus (TP) and total suspended solids (TSS) removal efficiency on an average annual basis.

This study concluded that:

- Both rate and volume control Best Management Practices (BMPs) are needed to mimic native hydrology from developed conditions
- Developed sites without volume control BMPs produce approximately two (2) to four (4) times the average annual runoff volume of native conditions
- All of the volume control performance goals evaluated do well at matching native conditions on an average annual basis
- All of the performance goals evaluated do worse at matching native conditions during non-frozen ground conditions (some yield up to two times more runoff than runoff form native conditions)
- Volume control BMPs controlled the 1-year, 24-hour peak rates to flows less than or equal to native conditions for most scenarios evaluated
- Volume control performance goals result in significant pollutant loading reduction from developed sites
- All volume control performance goals evaluated have similar removal efficiencies for TP and TSS
- The BMP size required to match native runoff volumes on an average annual basis varied with soil type, impervious percentage, and region of the state

The report also notes that despite the assumptions of the ‘frozen ground’ conditions where no infiltration occurred and which assumed that all snowmelt and precipitation in excess of the volume which could fill the surface storage of the BMP would become runoff, “all of the developed conditions scenarios have a lower average annual runoff than native conditions during this time period’ (from snowmelt or rain on frozen ground) for all scenarios evaluated. Indicating that depression storage within the BMP is a significant benefit and a potential design recommendation to address snowmelt and spring freshets conditions.

Selection of the Volume Target

The MIDS process was a collaborative approach which involved industry, agencies, municipalities, and consultants. As such from stakeholder input, working group discussions, and expert recommendations, ultimately the 90th percentile event (rainfall record only) of 1.1 inches (28 mm) was selected as the preferred option. This is modified version of Option 2 from the Performance Goal Assessment. No further analysis was conducted to provide justification for this recommendation.

2.3.3 Determination of the LSRCA Target

Following the MIDS approach, the LSRCA requires stormwater runoff volumes to be controlled and the post-construction runoff volume to be retained on site from runoff of the first 25 mm of rainfall from all impervious surfaces on the site. This equates to the 90% of the runoff producing events annually for the LSRCA watershed.

For detail in regards to the application of the specific performance goals for new development, non-linear development, linear development and the three (3) flexible treatment options, see **Section 4.2.2.2** of the **Jurisdictional Scan of Canadian, US and International Stormwater Management Volume Control Criteria Report**.

2.3.3.1 LSRCA Stormwater Target

Similar to the MIDS approach, the LSRCA LID SWM Guidelines include provisions and targets for:

- New Development
- Redevelopment
- Linear Development
- Flexible Treatment Options for Sites with Restrictions

The specifics of each are detailed below.

New Development
For new, nonlinear developments that create more than 0.5 hectares of new impervious surface on sites without restrictions, stormwater runoff volumes will be controlled and the post-construction runoff volume shall be retained on site from runoff of the first 25 mm of rainfall from all impervious surfaces on the site.

Redevelopment
Nonlinear redevelopment projects on sites without restrictions that create 0.5 or more hectares of new and/or fully reconstructed impervious surfaces shall capture and retain on site the first 25 mm of runoff from the new and/or fully reconstructed impervious surfaces.

Linear Development

a) Linear projects on sites without restrictions that create 0.5 or greater hectares of new and/or fully reconstructed impervious surfaces, shall capture and retain the larger of the following:
    I. The first 12.5 mm of runoff from the new and fully reconstructed impervious surfaces on the site
    II. The first 25 mm of runoff from the net increase in impervious area on the site
b) Mill and overlay and other resurfacing activities are not considered fully reconstructed.

2.3.3.2 Flexible Treatment Options for Sites with Restrictions

Proponent shall fully attempt to comply with the appropriate performance goals described above. Options considered and presented shall examine the merits of relocating project elements to address, varying soil conditions and other constraints across the site such as:

i. Karst geology,
ii. Shallow bedrock,
iii. High groundwater,
iv. Hotspots or contaminated soils,
v. Areas with high salt concentrations,
vi. Significant Groundwater Recharge Area and Wellhead Protection Areas or Intake Protection Zones or within 200 feet of drinking water well,
vii. Zoning, setbacks or other land use requirements,
viii. Excessive cost, and
ix. Poor soils (infiltration rates that are too low or too high, problematic urban soils, such as soils that are highly compacted or altered)

The proponent shall document the flexible treatment options sequence starting with Alternative #1 in a hierarchical approach ending with Alternative #3.

Alternative #1: Proponent attempts to comply with the following conditions:

I. Achieve at least 12.5 mm volume reduction from all impervious surfaces if the site is new development or from the new and/or fully reconstructed impervious surfaces for a redevelopment site.
II. Remove 75% of the annual Total Phosphorus (TP) load from all impervious surfaces if the site is new development or from the new and/or fully reconstructed impervious surfaces for a redevelopment site.
III. Options considered and presented shall examine the merits of relocating project elements to address, varying soil conditions and other constraints across the site.

Alternative #2: Proponent attempts to comply with the following conditions:

I. Achieve volume reduction to the maximum extent practicable.
II. Remove 60% of the annual TP load from all impervious surfaces if the site is new development or from the new and/or fully reconstructed impervious surfaces for a redevelopment site.
III. Options considered and presented shall examine the merits of relocating project elements to address, varying soil conditions and other constraints across the site.

Alternative #3: Off-site Treatment.

Mitigation equivalent to the performance of 25 mm of volume reduction for new development or redevelopment as described above in this section can be performed off-site to protect the receiving water body. Off-site treatment shall be achieved in areas selected in the following order of preference:

I. Locations within the same LSRCA catchment area as the original construction activity.
II. Locations within the next adjacent catchment area upstream.
III. Locations that yield benefits to the same receiving water that receives runoff from the original construction activity.
IV. Locations anywhere within the Lake Simcoe Watershed within the municipal boundary jurisdiction.

2.3.3.3 LSRCA Analysis and Rationale

The LSRCA developed rainfall frequency curves for nine (9) stations within and around the Lake Simcoe Watershed. The methodology was separated into several steps:

Step 1 – Three (3) local gauges with approximately 30 years of daily precipitation data (1980 – 2010) for were selected around Lake Simcoe itself, specifically 1) Lindsay Frost, 2) Shanty Bay and 3) Coldwater Warminster.

Step 2 - Precipitation values less than 5.1 mm (daily values) were removed because these “storms” based on local watershed monitoring do not typically generate run-off. Due to changing climates and warmer winters, large rainfall events between the typical snowy seasons (Dec-Feb) were included

LSRCA Precipitation Frequency Analysis Locations

Step 3 – Frequency curves were developed, and subsequently separated into two (2) periods 1980-2000 and 2001-2013 to identify if changes in precipitation could be identified over the “recent” time period. Results indicated that the two (2) time periods showed little to no variation; as such the analysis was repeated for six (6) additional gauges in the watershed to cover a better geographic distribution. They included:

1. Orillia Brain,
2. Udora,
3. Egbert CS,
4. Sonya Sundance Meadows,
5. Lagoon City and
6. Toronto Buttonville

Results are summarized in **Table 2.3.3.3** and **Figure 2.3.3.3** below

Table 2.3.3.3 - LRSCA Rainfall Frequency Analysis

Location	90th Percentile Rainfall Depth (mm)	95th Percentile Rainfall Depth (mm)
Shanty Bay	24.1	30.8
Coldwater Warminster	22.2	28.9
Lindsay Frost	23.3	28.7
Orillia Brain	25.8	35.0
Udora	22.9	27.1
Egbert CS	23.5	30.4
Sonya Sundance Meadows	22.2	26.6
Lagoon City	22.2	30.3
Toronto Buttonville	23.9	29.1
Average (90th percentile)	**23.3**	**29.7**
Minimum (90th percentile)	**22.2**	**26.6**
Maximum (90th percentile)	**25.8**	**35.0**

Source: LSRCA (2016), via email

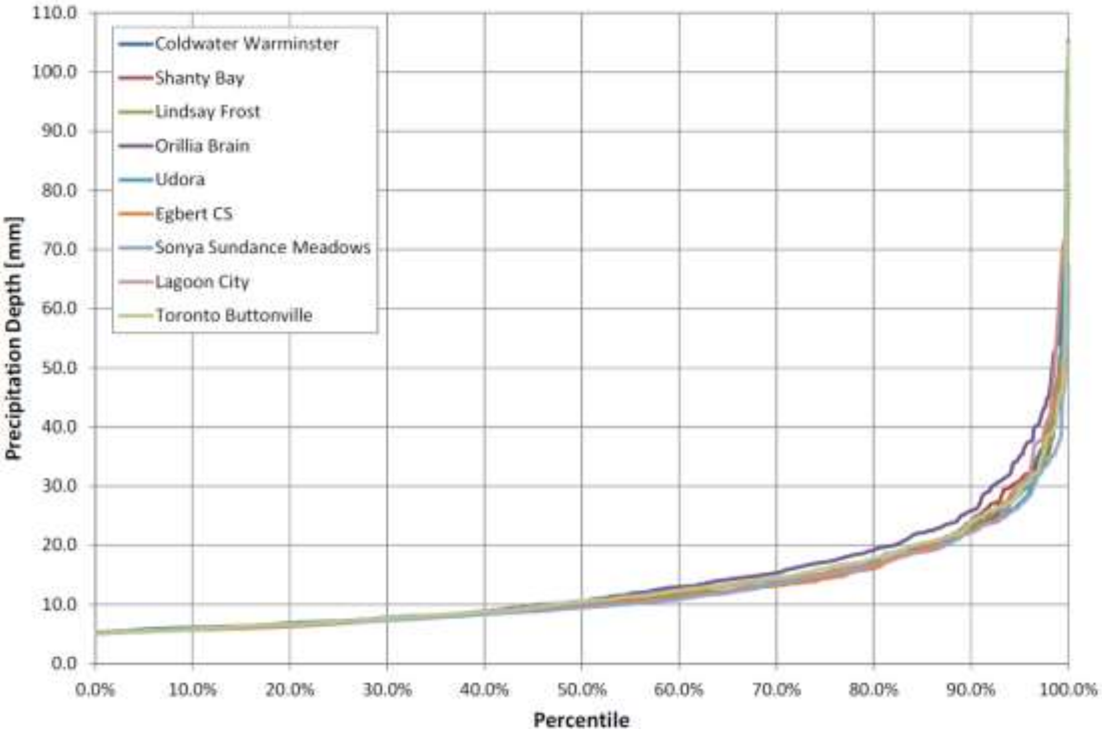


Figure 2.3.3.3 - Lake Simcoe Watershed Precipitation Frequency. **(Source: Longstaff, 2015).**

2.3.4 Summary

Table 2.3.4 presents a summary of the State of Minnesota and LSRCA included as part of the selected jurisdictions in regards to the respective volume target, the rationale for selecting the target, the rainfall events considered as part of the target development and the Minimum Inter Event (MIT) used in the analysis.

Table 2.3.4 – Summary of the State of Minnesota and LSRCA Jurisdictions

Jurisdiction/ Agency	Volume Target	Rationale	Rainfall Event	Minimum Interevent Time (MIT)
State of Minnesota	**Volume Retention** 1.1 inches (28 mm)	Runoff volumes will be controlled and the post-construction runoff volume shall be retained on-site for 1.1 inches (28 mm) of runoff from impervious surfaces statewide which equates to the 90% of the runoff producing events annually.	**Type:** Daily rainfall (24hr duration) **Exclusions:** <2.5 mm	**N/A** (Daily rainfall analysis, MIT not required)
LSRCA	**Volume Retention** 25 mm	Runoff volumes to be controlled and the post-construction runoff volume to be retained on site from runoff of the first 25 mm of rainfall from all impervious surfaces on the site. Equates to the 90th percentile storm event.	**Type:** Daily rainfall (24hr duration) **Exclusions:** <5.1 mm	**N/A** (Daily rainfall analysis, MIT not required)

2.4 Great Lake States: New York and Michigan

The following section describes the development of the stormwater volume targets including supporting rationale and methodology for the Grate Lake States of New York and Michigan.

For additional information and context in regards to the State of New York and the State of Michigan, refer to the **Jurisdictional Scan of Canadian, US and International Stormwater Management Volume Control Criteria Report**.

2.4.1 Background

New York State is the 4th most populous with an estimated 19.8 million residents and 7th most densely populated state. Portions of the state discharge to Lake Ontario and Lake Erie, as well as numerous interior lakes and the Atlantic Ocean. Pursuant to Section 402 of the Clean Water Act ("CWA"), operators of small municipal separate storm sewer systems ("small MS4s"), located in urbanized areas and those additionally designated by New York State are unlawful unless they are authorized by a National Pollutant Discharge Elimination System ("NPDES") permit or by a state permit program

The State of Michigan is the 10th most populous state and has the 11th most extensive total area. The state is bordered by three (3) of the Great Lakes: Lake Michigan, Lake Huron and Lake Erie. Michigan's National Pollutant Discharge Elimination System (NPDES) Permit Application for Discharge of Storm Water to Surface Waters from a Municipal Separate Storm Sewer System (MS4) requires the applicant to provide a description of the Best Management Practices (BMP) that will be implemented for each minimum control measure and the applicable water quality requirements. These BMPs build the applicant's Storm Water Management Program (SWMP).

2.4.2 Determination of the New York State Target

The State of New York requires the control of the Water Quality Volume (denoted as the WQv) to improve water quality by capturing and treating runoff from small, frequent storm events that tend to contain higher pollutant levels.

2.4.2.1 New York Stormwater Targets

New York has defined the WQv as 23 mm (0.8 in) to 34 mm (1.2 in) which equates to the volume of runoff generated from the entire 90th percentile rain event over a 24-hour period. The WQv is directly related to the amount of impervious cover constructed at a site.

However, where enhanced phosphorous removal is required for projects in phosphorus-limited watersheds, the WQv is defined by the 90% runoff from the entire catchment, as opposed to using the impervious fraction only. This is discussed further in the subsequent sections.

2.4.2.2 New York Analysis and Rationale

The New York State Design Manual requires the use of TR-55 method for calculating stormwater volume to meet water quantity objectives and the use of 90% rule for calculating water quality volume. The rainfall event used to size practices for water quality is based on the 90th percentile daily rainfall event, which is normally a small storm (0.8 inch-1.2 inch (20 mm – 34 mm) in NY). The WQv is directly related to the amount of impervious cover constructed at a site.

The 90% rainfall depths are derived from a rainfall frequency analysis of daily rainfall events performed for 152 locations throughout New York. The geographic distribution and number of stations analysed permitted the State of New York to generate geographically specific 90th Percentile Contours (isohyet) mapping (**Figure 2.4.2.2**) represent a design rainfall depth ranging between 0.8 and 1.2 inches. The use of regional mapping and volume targets is unique to the State of New York in the context of the jurisdictions presented in this report and represents an approach which recognizes the regional differences in rainfall patterns and depth across a varied landscape.

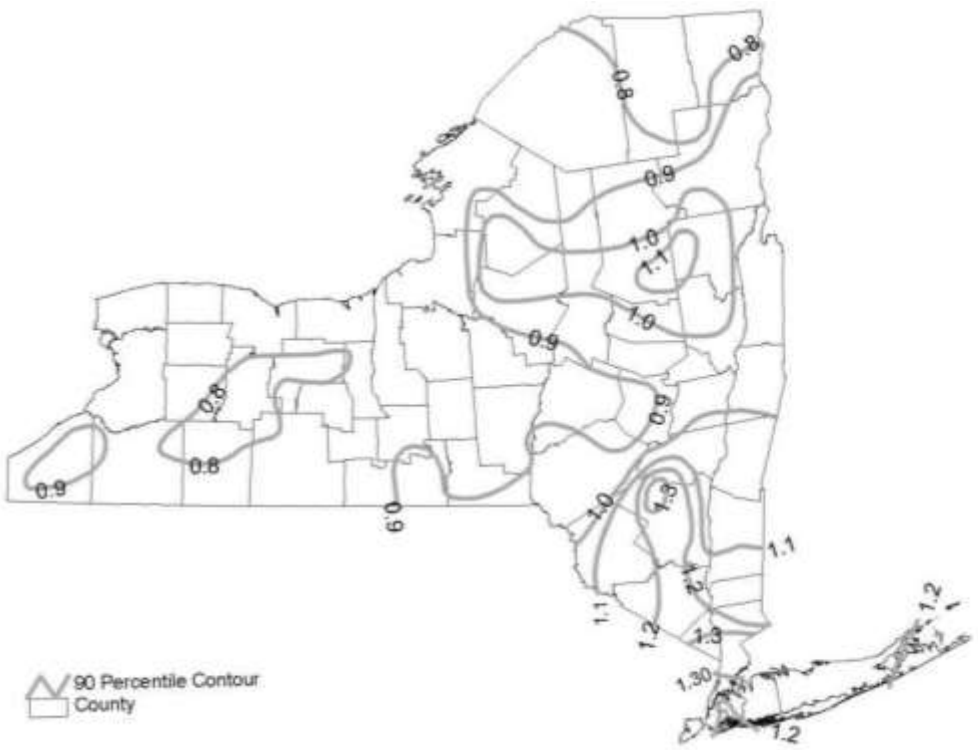


Figure 2.4.2.2 - 90th Percentile Rainfall in New York State (NYSDEC, 2013)

2.4.2.3 *WQv in Phosphorous-limited Watersheds*

The Enhanced Phosphorus Removal Supplement of the New York State Stormwater Management Design Manual addresses standards for projects in phosphorus-limited watersheds and presents additional treatment performance standards for enhanced phosphorus removal. Where enhanced phosphorous removal is required for projects in phosphorus-limited watersheds, the WQv is defined by the 90% runoff from the entire catchment, as opposed to using the impervious fraction only.

Enhanced phosphorus treatment is defined as “a measurable, significant improvement in phosphorus-treatment performance over the design methodology used for standard practices.” Phosphorous treatment performance goals (4) in this regard include:

1. Reduction in runoff volumes and runoff prevention through the use of “upstream controls” (source controls) as a primary means for reducing runoff volumes and their associated pollutant loads by maximizing evapotranspiration and infiltration.
2. Achieve less than 15% treatment bypass of the long-term runoff volume, assessed through continuous simulation.

3. Median effluent concentrations of particulate phosphorus shall be at or below 0.1 mg/L. (equivalent to a net removal of particulate phosphorus of 80%, given a median influent concentration of 0.5 mg/L).
4. Median effluent concentrations of dissolved phosphorus shall be at or below 0.06 mg/L. (equivalent to a net removal of dissolved phosphorus of 60%, given a median influent concentration of 0.15 mg/L).

Note: Effluent quality goals for particulate and dissolved phosphorus are based on analysis of available empirical influent and effluent water quality data for a variety of treatment systems and operational conditions (e.g., catchment characteristics, climate). (Pitt, 2004)

Analysis for phosphorus-limited watersheds

The analysis performed in the development of the enhanced phosphorus removal performance targets and design criteria is based on continuous simulation modeling of hydrology and hydraulics, as well as process-level analysis of the water quality performance of specific treatment systems when properly designed. Separate analyses were performed for storage (i.e. basins) and flow-through systems (filtration and infiltration practices) to help assess the relative difference in treatment performance between systems sized according to WQv defined by the 90% runoff using the impervious fraction only and WQv as defined by the 90% runoff from the entire catchment.

The results of this analysis indicated that the current method of sizing treatment systems using the WQv defined by the 90% runoff using the impervious fraction only is insufficient to meet the enhanced phosphorus treatment performance goals.

The alternate WQv calculation for enhanced phosphorus treatment is thus the estimated runoff volume resulting from the 1-year, 24-hour design storm over the post-development watershed. This is considered by the State of New York to be suitable for both storage and flow-through systems and applicable to catchments that range from highly impervious to highly pervious.

It is also noted that through the use of “green infrastructure practices, a site's contributing impervious area can be reduced and the hydrology of the pervious areas altered. These practices will result in lower curve number (CN) and lower WQv.”

2.4.3 Determination of the State of Michigan Target

The State of Michigan requires volume control for both the Channel Protection and Water Quality Protection.

2.4.3.1 Michigan Stormwater Targets

Channel Protection

The State of Michigan requires that without a specific study, the site must not increase the predevelopment runoff conditions for all storms up and including the 2-year, 24-hour return frequency storm. The 2-year event encompasses approximately 95% of the annual rainfall volume across the state and also equals or exceeds resettlement groundwater recharge volumes (See **Figure 2.4.3.1**).

Note: a separate groundwater recharge criterion does not exist, instead it is suggested that this can be accomplished "by implementing a volume control criterion and maximizing the use of infiltrating LIDs".

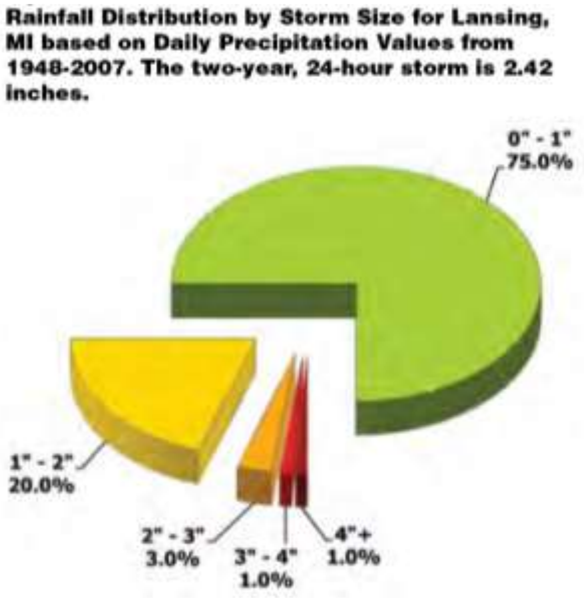


Figure 2.4.3.1 – Rainfall Distribution Lansing Michigan

Water Quality Protection Requirements

The State of Michigan has four (4) options for water quality protection.

1) 0.5 inch (12.5 mm) from a single impervious area
2) One (1) inch (25 mm) of runoff from all impervious areas and 0.25 inches (6.4 mm) of runoff from all disturbed pervious areas.
3) One (1) inch (25 mm) of runoff generated from all disturbed and impervious areas
4) The calculated site runoff for the entire project site from the 90 percent annual non-exceedance storm for the region or locality according to one of the following:
    a) The statewide analysis by region for the 90 Percent Annual Non-Exceedance Storms summarized in a memorandum dated March 24, 2006, and available on the Internet at http://www.michigan.gov/documents/deq/lwm-hsu-nps-ninety-percent_198401_7.pdf.
    b) The analysis of at least ten years of local published rain gauge data following the method in the memo "90 Percent Annual Non-Exceedance Storms" cited below.

Option 1 - 0.5 inch of runoff

This criterion was one of the first to define the "first flush" phenomenon resulting from a study of runoff from parking surfaces. Additional research has found that this only applies to runoff from a single impervious area (i.e. parking lot to a single development). It is assumed that this additional research is referring to the Michigan Department of Environmental Quality 2014 Post-Construction Storm Water Runoff Controls Program which states that "Research has shown that nearly all the pollutants washed off in the "first flush" of runoff from impervious surfaces are contained in the first 25 mm of runoff" (MDEQ, 2014). As such, the State of Michigan states that “although it may be applicable in some limited circumstances” it is not recommended that Option 1 be used.

Option 2 - One inch of runoff from all impervious areas and 0.25 inches of runoff from all disturbed pervious areas

This method provides a reasonable certainty that the runoff containing the majority of the pollutants from impervious areas is captures and treated. It assumes that distributed pervious areas contribute less runoff and pollutants to the specified BMP and can only be used when the percentage of impervious area on a site is small and both the pervious and impervious areas are treated by the same BMP.

Option 3 - One inch of runoff from disturbed pervious and impervious areas

Is the most conservative method and assures that the entire first flush from any site will be captured and treated. In the State of Michigan, this method often results in the water quality volume requirements exceeding the channel protection volumes. This method eliminates the need for detailed soil/land cover descriptions, choosing an appropriate storm and rainfall runoff calculations. The resulting volume will typically be less than the “one inch of runoff from disturbed pervious and impervious areas” and slightly more than Option 4.

Option 4 - 90 percent of runoff producing storms

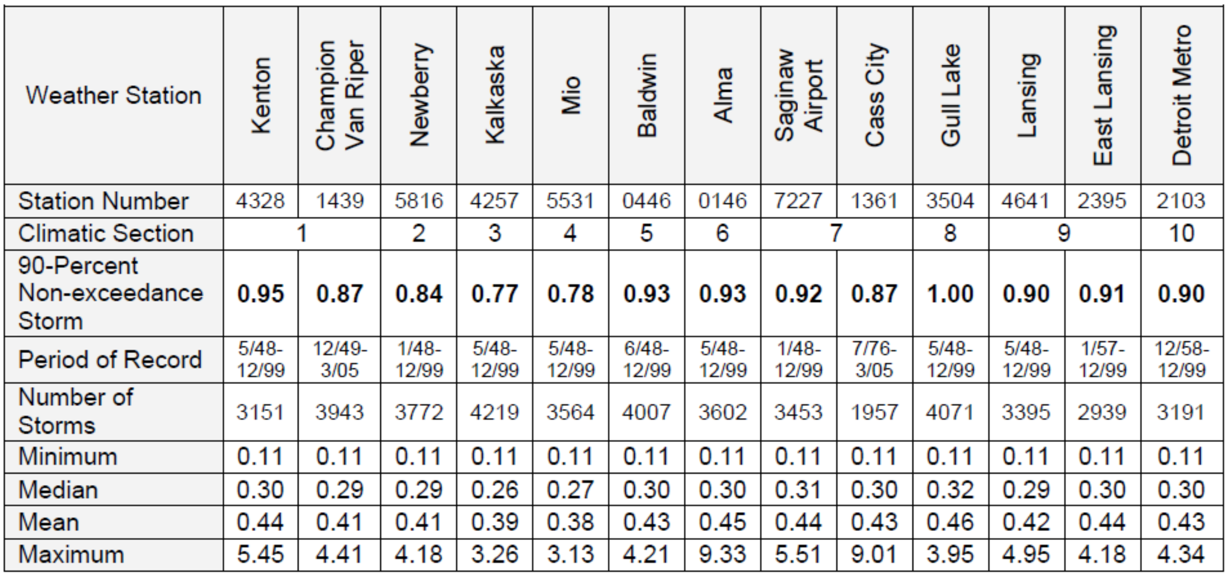
This method determines the water quality volume by calculating the runoff generated from the 10 percent exceedance rain event for the entire site which varies from 0.77 inches (19.6 mm) to 1 inch (25 mm). This method is a more rigorous analysis of the runoff generated from different land types for the entire project site for 90 percent of all the storms that generate runoff. It is a more accurate representation of the runoff from the project site and usually results in a smaller treatment volume than using 25 mm of runoff from the entire project site. The 10 percent exceedance storm values for thirteen (13) climatic regions of the state can be found in **Table 2.4.3.2** below.

2.4.3.2 Michigan Analysis and Rationale

The Michigan Department of Environmental Quality (MDEQ) in development of MDEQ’s BMP Guidebook, and to replace the previous 0.5 inch (12.5 mm) capture and treatment requirement for a single site (see Option 1) considered alternative volume criteria. The criteria considered runoff from “multiple or large sites which may exhibit elevated pollutants concentration longer, because the first flush runoff from some portions of the drainage area will take longer to reach the outlet” and as such recommended that it was “better to capture and treat 90% of the runoff producing storms” citing the “90 percent rule” as proposed by Claytor (1996).

In support of the application of the “90 percent rule”, in 2006 the Hydrologic Studies Unit of the Land and Water Management Division of the Michigan Department of Environmental Quality (MDEQ) completed a rainfall analysis for the period of January 1948 to March 2005 in order to statistically define 90-percent non-exceedance storms statewide. The MDEQ followed the recommendations of the Center for Watershed Protection (CWP) (2008), using a dataset of greater than 20-30 years and removing all rainfall events below 0.1 inches (2 mm). The analysis included some thirteen (13) climatic stations, with at least one (1) station within each of the ten (10) Michigan climatic regions, plus three (3) additional stations to improve coverage. The results of the MDEQ analysis are presented in **Table 2.4.3.2** which demonstrates the 90th percentile ranging from 19.6 mm to 25.4 mm (average 20.1 mm). Ultimately, it would appear that the State of Michigan selected the 25 mm as the default volume target for the state, although no rationale was provided.

Table 2.4.3.2 - Statistics for storms with more than 2.5 mm of rainfall at selected weather stations. (All values reported as inches Source: MDEQ, 2006)



Weather Station	Kenton	Champion Van Riper	Newberry	Kalkaska	Mio	Baldwin	Alma	Saginaw Airport	Cass City	Gull Lake	Lansing	East Lansing	Detroit Metro
Station Number	4328	1439	5816	4257	5531	0446	0146	7227	1361	3504	4641	2395	2103
Climatic Section	1		2	3	4	5	6	7		8	9		10
90-Percent Non-exceedance Storm	**0.95**	**0.87**	**0.84**	**0.77**	**0.78**	**0.93**	**0.93**	**0.92**	**0.87**	**1.00**	**0.90**	**0.91**	**0.90**
Period of Record	5/48-12/99	12/49-3/05	1/48-12/99	5/48-12/99	5/48-12/99	6/48-12/99	5/48-12/99	1/48-12/99	7/76-3/05	5/48-12/99	5/48-12/99	1/57-12/99	12/58-12/99
Number of Storms	3151	3943	3772	4219	3564	4007	3602	3453	1957	4071	3395	2939	3191
Minimum	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Median	0.30	0.29	0.29	0.26	0.27	0.30	0.30	0.31	0.30	0.32	0.29	0.30	0.30
Mean	0.44	0.41	0.41	0.39	0.38	0.43	0.45	0.44	0.43	0.46	0.42	0.44	0.43
Maximum	5.45	4.41	4.18	3.26	3.13	4.21	9.33	5.51	9.01	3.95	4.95	4.18	4.34

2.4.4 Summary

Table 2.4.4 presents a summary of the Great Lakes States (New York State and State of Michigan) included as part of the selected jurisdictions in regards to the respective volume target, the rationale for selecting the target, the rainfall events considered as part of the target development and the Minimum Inter Event (MIT) used in the analysis.

Table 2.4.4 – Summary of the Great Lake States

Jurisdiction/ Agency	Volume Target	Rationale	Rainfall Event	Minimum Interevent Time (MIT)
State of New York	Volume Capture and Treatment General: Runoff from 23 mm (0.8 in) to 34 mm (1.2 in) from imp. areas Phosphorous-limited Watershed: Runoff from 23 mm (0.8 in) to 34 mm (1.2 in) from entire catchment	General: Maintain pre-development infiltration, runoff, and volume. Achieve 80% TSS reduction and 40% Phosphorus reduction. Utilizes the 90% rule for calculating water quality volume using the impervious fraction. Phosphorus-limited watersheds: Four (4) performance goals. WQv is defined by the 90% runoff from the entire catchment. $90^{\%}$ = 1-year, 24-hour storm	**Type:** Daily rainfall (24 hr duration) **Exclusions:** unknown	**N/A** (Daily rainfall analysis, MIT not required)
State of Michigan	Volume Retention (0.5 in) 12.5 mm to (1 in) 25 mm	"multiple or large sites which may exhibit elevated pollutants concentration longer, because the first flush runoff from some portions of the drainage area will take longer to reach the outlet" and as such recommended that it was "better to capture and treat 90% of the runoff producing storms" citing the "90 percent rule" as proposed by Claytor (1996).	**Type:** Daily rainfall (24 hr duration) **Exclusions:** 0.1" (2 mm)	**N/A** (Daily rainfall analysis, MIT not required)

2.5 District of Columbia (Washington, D.C.)

The following section describes the development of the stormwater volume targets including supporting rationale and methodology for the District of Columbia (Washington, D.C.).

For additional information and context in regards to the District of Columbia (Washington, D.C.), refer to the **Jurisdictional Scan of Canadian, US and International Stormwater Management Volume Control Criteria Report**.

2.5.1 Background

The District of Columbia's (D.C.) Department of the Environment (DDOE) new stormwater rules are arguably the most comprehensive approach to stormwater management in the Chesapeake Bay watershed. The "2013 Rule on Stormwater Management and Soil Erosion and Sediment Control"[9] rule was published in July 2013.[10]

D.C.'s new framework includes stormwater retention performance standards designed to considerably reduce stormwater runoff's harmful impacts to the Anacostia and Potomac Rivers, Rock Creek, and their tributaries. Stormwater retention performance standards in the District of Columbia are based on the 90th percentile rainfall event, and the "unified sizing approach" and require the retention of the 1.2 in (30 mm) event for new developments and the 0.8 in (20 mm) event for redevelopment.

2.5.2 District of Columbia (Washington, D.C.) Stormwater Targets

All sites are subject to new development and redevelopment standards. For new development, any development that affects 5,000 square feet (0.05 ha) of land or greater, except in Public Right of Way (PROW)[11] areas, is subject to the specific stormwater requirements.

- First, the first 1.2 inches (30 mm) of rainfall from a 24-hour rainfall event with a 72-hour dry period must be retained on-site or through a combination of on-site and off-site retention methods.
- Second, a peak discharge rate for a 2-year frequency 24-hour storm to pre-development conditions must be maintained; and a peak discharge rate for a 15-year frequency, 24-hour storm to must be maintained to predevelopment conditions.
- Lastly, appropriate BMPs must be selected and implemented to achieve the retention standard. If PROW areas are affected by new development, stormwater retention must be achieved to its Maximum Extent Practicable[12].

For redevelopment, any improvement activity where the cost of the project is greater than or equal to 50% of its previous development cost and exceeds a land disturbance of 5,000 square feet (0.05 ha) must retain the first 0.8 inch (20 mm) of rainfall on-site through a combination of on-site and off-site retention methods. Any land disturbance within the PROW areas must achieve stormwater retention from PROW's Maximum Extent Practicable (MEP) standards.

Runoff reduction practices are triggered by two different categories of projects:

1. Major land-disturbing activity: Sites that disturb 5,000 square feet (0.05 ha) or more of land[13] will be required to retain the first 1.2 inches (30 mm) of rainfall, either on-site or through both on-site and off-site retention.

2. Major substantial improvement projects: Renovations of existing structures that have a 5,000 ft^2 (0.05 ha) footprint and project costs that exceed 50% of the pre-project value of

the structure, must retain the first 0.8 (20 mm) inches of rainfall on-site, or through a combination of on-site and off-site retention.

2.5.3 Determination of Washington D.C. Target

Stormwater retention performance standards in the District of Columbia are based on the 90th percentile rainfall event, and the "unified sizing approach" advocated by stormwater expert Tom Schueler. The goal of the unified framework is to develop a consistent approach for sizing stormwater practices that can perform efficiently and effectively, be administered simply, promote better site design, and be flexible in responding to special needs. A unified framework for sizing stormwater practices provides greater consistency and integration among the many city, county, watershed organization, regional and statewide stormwater requirements and ordinances adopted over the years. It also establishes a common framework to address all stormwater problems caused by development sites over the entire spectrum of rainfall events. Simply stated, the unified sizing approach seeks to manage the range and frequency of rainfall events that are anticipated at development sites, by setting the control threshold at the 90th percentile. The unified approach proposes to standardize the basic approach to stormwater design for regular waters of the state, while also defining certain site conditions or development scenarios where individual stormwater sizing criteria may be relaxed or waived. The unified framework also clearly indicates when sizing criteria need to be enhanced to provide a higher degree of water resource protection for special or sensitive waters.[14] **Table 2.5.3** outlines the Rain Frequency Spectrum (RFS) for the Washington, DC metropolitan area.

Schueler (1987 and 1992) conducted a detailed evaluation of 50 years of hourly rainfall data in the Washington, DC area. The recorded precipitation data from Washington National Airport consisted of all storm events separated by at least 3 hours from the next event. The base data collected at National Airport included minor storm events that normally do not produce measurable runoff. These minor events make up approximately 10% of all annual rainfall, are usually less than 2 mm and were therefore excluded from the RFS analysis. The analysis reported that, these small storms seldom produce measurable stormwater runoff, yet are numerically the most common rainfall event.

Table 2.5.3 Rain Frequency Spectrum Washington DC Area (USEPA, 2004)

Percent of All Storm Events*	Return Interval	Rainfall Volume (mm)
30	7 days	6.4
50	14 days	10.2
70	Monthly	19.1
85	Bi-monthly	26.7
90	Quarterly	31.8
95	Semi-annually	41.9
98	Annually	61.0
99	2-Yr	73.7
* Equal to or less than given rainfall volume		

A careful examination of **Table 2.5.3** suggests that a BMP which is sized to capture and treat the three-month storm frequency storm (or 32 mm) rainfall) will effectively treat 90% of the annual average rainfall. While this is true, such a practice will also capture and at least partially treat the first 32 mm of larger rainfall events. Therefore, treating the 32 mm rainfall will result in a capture efficiency of greater than 90%.

Citing Claytor (1996), the District of Columbia states that given the economic considerations of capturing and storing a reasonable large water quality volume, and the realization that stormwater filters tend to lose efficiency as pollutant load input concentrations decrease (Bell et al., 1995), a smaller storm event was investigated to evaluate the effectiveness of an alternative treatment criteria. Many jurisdictions require storage of the first one half inch (13 mm) of runoff from impervious surfaces. While this volume appears to have gained widespread acceptance, there has been little research on the cumulative pollutant load bypassing facilities sized on this principle. One notable exception, is a study conducted by Chang (1990) where the annual total solids load captured using the half inch (13 mm) rule showed significant decrease when imperviousness approached 70 percent (Claytor et al., 1996).

To balance the desire to capture and treat as much cumulative rainfall as possible while avoiding an overly burdensome sizing criteria, additional rainfall data was evaluated throughout Chesapeake Bay watershed. In addition to Washington D.C., three other locations were selected to evaluate longer term rainfall characteristics (Claytor et al., 1996).

Daily precipitation data was analyzed for an 11-year period (January 1980 through December 1990) at four locations within the Chesapeake Bay Watershed. Norfolk VA, Washington D.C., Frederick MD, and Harrisburg, PA were selected as representative of the bay-wide watershed where new development activity was occurring. In addition, locations are separated by 100 to 150 miles and represent a distribution from costal to inland, and south to north (Claytor et al., 1996).

The one-inch (25 mm) rainfall was evaluated to assess whether this value could be used to effectively capture 90% of the annual runoff. The average capture percentage using the one inch (25 mm) rainfall ranges from approximately 85% to 91% for the four locations. The analysis included the first one inch (25 mm) of larger rainfall events which will be captured, but probably not completely treated. It is recognized that during these large events treatment conditions may be less than ideal. But it is safe to say that approximately 90% of the annual average rainfall events will be captured and treated using a 1 inch (25 mm) rainfall criterion (Claytor et al., 1996).

The results presented in **Table 2.5.3.1** provide justification for using the one inch (25 mm) rainfall event for sizing stormwater filtering practices throughout the Chesapeake Bay Watershed.

Table 2.5.3.1 - Comparison of Precipitation Data for Four Locations within the Chesapeake Bay Watershed 1980-1991 (Daily Analysis). (Source: Claytor et al., 1996)

	Norfolk, VA	**Washington D.C.**	**Harrisburg, PA**	**Frederick, MD**
Annual average precipitation	1,102.4 mm	962.7 mm	1,005.8 mm	939.8 mm
Annual average snowfall	195.6 mm	436.9 mm	795.0 mm	Not Obtained
Annual average # of precipitation days*	76 days	67 days	71 days	68 days
Annual average # of precipitation days > 25 mm	10.5 days	9.5 days	9.5 days	7.7 days
Annual average # of precipitation days < 2.5 mm	39 days	45.4 days	55.1 days	Not Obtained
Percent of annual average rainfall ≤ 25 mm*	85.3%	91.4%	86.8%	89.9%
Percent of annual precipitation days ≤ 25 mm*	86.2%	85.9%	86.7%	88.6%
*Adjusted to exclude rainfall events ≤ 2.5 mm (assumed to produce no runoff)				

From this data, the target rainfall event for estimating the water quality volume for the Chesapeake Bay Watershed in general was based on the 90 percent rule, with a suggested rainfall capture value of 1 inch (25 mm). However, for Washington D.C. the 1 inch (25 mm) capture depth equates only to the 85th percent storm.

Subsequently, the ‘2013 SW Rule’ (stormwater rule) was adopted into the District of Columbia Municipal Regulations (DCMR) which per the MS4 permit required the District of Columbia “to implement a 1.2 inch stormwater retention standard for land-disturbing activities, a lesser retention standard for substantial improvement projects, and provisions for regulated sites to satisfy these standards off site.”[15] The 1.2 inch (30 mm) stormwater retention standard is the 90th percentile event for Washington D.C. area..

The Stormwater Management Guidebook (SWMG) provides technical guidance on the 2013 revisions to the previous regulations and notes that the “detention requirements have not changed significantly, but the focus on water-quality treatment has shifted to a standard for volume retention.” By keeping stormwater on site, retention practices effectively provide both treatment and additional volume control, significantly improving protection for District waterbodies. The new Stormwater Retention Volume (SWRv) can be managed through runoff prevention (e.g., conservation of pervious cover or reforestation), runoff reduction (e.g., infiltration or water reuse), and runoff treatment (e.g., plant/soil filter systems or permeable pavement).

2.5.4 Summary

Table 2.5.4 presents a summary of the District of Columbia (Washington, D.C.) included as part of the selected jurisdictions in regards to the respective volume target, the rationale for selecting the target, the rainfall events considered as part of the target development and the Minimum Inter Event (MIT) used in the analysis.

Table 2.3.4 – Summary of the District of Columbia (Washington, D.C.)

Jurisdiction/ Agency	Volume Target	Rationale	Rainfall Event	Minimum Interevent Time (MIT)
District of Columbia (Washington, D.C.).	30 mm (1.2 in) Stormwater Retention Volume (SWRv) for New Development (90th percentile) 20 mm (0.8 in) Stormwater Retention Volume (SWRv for Re-Development (80th percentile)	"90 percent rule" (unified sizing criteria) Retention performance standards designed to considerably reduce stormwater runoff's harmful impacts to the Anacostia and Potomac Rivers, Rock Creek, and their tributaries	**Type:** Daily and hourly rainfall (24 hour) **Exclusions:** 2.5 mm	**MIT:** 3 hours

2.6 New Zealand – National & Christchurch

The following section describes the development of the stormwater volume targets including supporting rationale and methodology for New Zealand and Christchurch

For additional information and context in regards to New Zealand refer to the **Jurisdictional Scan of Canadian, US and International Stormwater Management Volume Control Criteria Report**.

2.6.1 Background

In 2001, many respondents made unprompted suggestions that a guideline was needed for better stormwater management throughout New Zealand, while more than two-thirds of respondents agreed with the proposition that a New Zealand guideline on comprehensive stormwater management was necessary. Work on the project began in January 2004 and through the Minister for the Environment's Sustainable Management Fund and the other funding contributors listed earlier, NZWERF has produced the current guideline to meet the needs – and concerns – identified in that 2001 survey.

The Resource Management Act (RMA) sets up the statutory framework requiring stormwater discharge permits. Activities which do not meet the permitted activity criteria of the Transitional Regional Plan and the proposed Regional Plan: Air, Land, and Water (ALW) require resource consents.

2.6.2 Determination of the National Target

The national stormwater targets are based on either Auckland Regional Council (ARC) approach or the Christchurch City Council approach. The ARC method provides for using the water quality design storm together with catchment physical characteristics to calculate a 'water quality volume' for the catchment area contributing to a device. This method is calculated in TP108 (Auckland Regional Council, 1999, *Guidelines for stormwater runoff modelling in the Auckland region*, ARC Technical Publication No. 108) using the US Soil Conservation Service rainfall-runoff model, based largely on its Technical Release No. 55 (SCS 1986). The model takes into account rainfall losses based on ground cover and soil type. The Christchurch approach is discussed in **Section 2.6.2.2.**

2.6.2.1 National Stormwater Targets

In regards to the ARC approach, for the Auckland region the water quality design storm depths Range over the Auckland region from 16.7 mm to 43.3 mm and for most of the urbanised area is 26.7 mm.

2.6.2.2 National Analysis and Rationale

The water quality goal is to capture 75 percent of the total suspended sediment on a long-term average basis. This value was chosen because it is the water quality objective of ARC TP 10 and is also the treatment objective of a number of overseas agencies (Seyb, 2001).

The water quality design storm for the ARC method has been developed from detailed analysis of long term rainfall records at one rain gauge, which yielded a water quality design storm depth of 25 mm, equivalent to 1/3 of the 2-year average recurrence interval (ARI) daily rainfall at this location. The ARC method provides for the water quality design storm to be calculated for any location in the region by dividing the 2 year ARI daily rainfall at that location by a factor of 3.

An analysis of rainfall from the rain gauge at the Botanic Gardens at Manurewa arrived at a rainfall depth of 25 mm for the Stormwater Quality Design Storm (Sd). In order to make allowance for the differences in location, the rainfall depth corresponding to the site location is obtained from Figures in the TP-10 manual, the 2 Year average recurrence interval (ARI) Daily Rainfall Depth.

Sd = (2 year 24-hour rainfall depth at site) /3

This rainfall depth is to be applied on a 24-hour event. The Stormwater Quality Design Storm, Sd, is the rainfall depth chosen from hydrological analysis of a rain gauge located in the Auckland Region that enables 80% of the runoff volume of all storms to be captured and treated.

From the Botanic Gardens rain gauge record it has been determined that 25 mm first flush interception will achieve treatment of 78% of the rainfall depth falling on the recipient catchment in an average year and that 12.5 mm first flush interception will achieve treatment of 58% of annual rainfall depth (**Figure 2.6.2.1**).

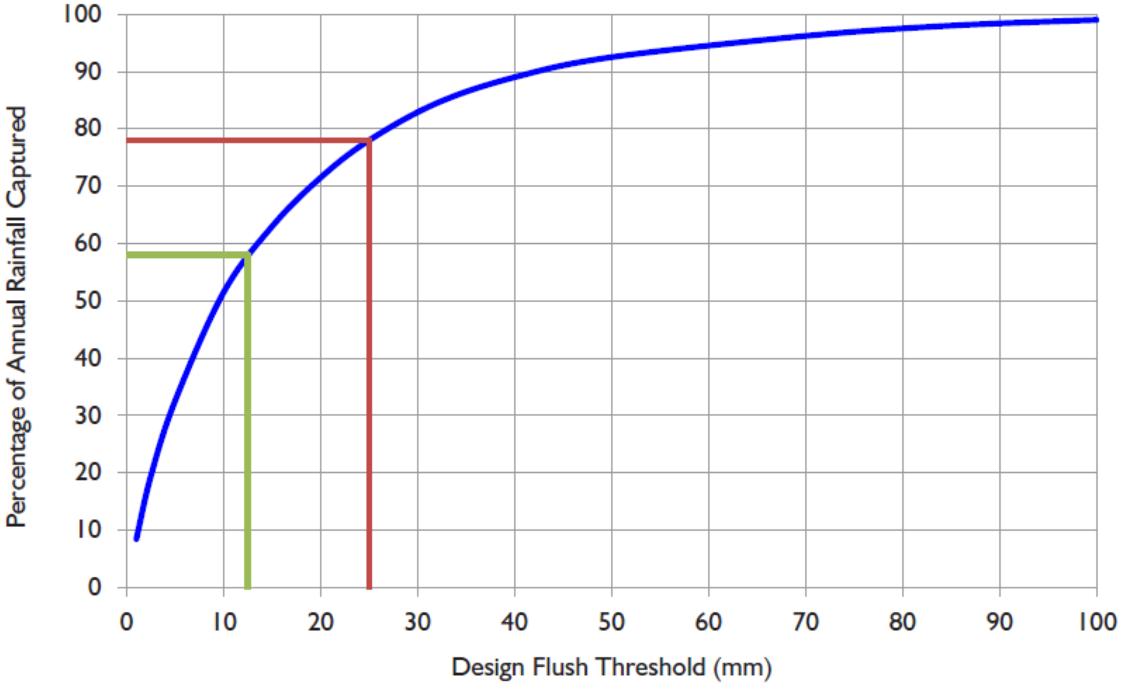


Figure 2.6.2.1 - Botanic Gardens rain gauge percentage of annual rainfall captured for design flush depth. The highlight lines show 58% capture for a rain depth threshold of 12.5 mm and 78% capture for a 25 mm threshold.

2.6.2.3 Christchurch Stormwater Targets

The Christchurch City Council recommends as best practice the capture of runoff from the first 25 mm of storm rainfall depth, but not less than 12.5 mm. The capture of runoff from at least the first 25 mm of storm rainfall depth is a requirement for ‘green fields development’. A ‘green field’ development is one that lacks constraints imposed by prior work. The analogy is to that of construction on greenfield land where there is no need to work within the constraints of existing buildings or infrastructure.

2.6.2.4 Christchurch Analysis and Rationale

The Christchurch approach is as follows. The Environment Canterbury consent CR C000315 (granted to the Christchurch City Council for green fields development in the Upper Heathcote / Wigram area) requires capture and treatment of the first 12.5 mm of all rainfall events prior to discharge to ground. This first flush interception will achieve treatment of 58% of the Christchurch average annual rainfall depth falling on the recipient catchment.

A suggested requirement within Environment Canterbury's Draft Canterbury Natural Resources Regional Plan (2002) is for first flush to be considered as the first 15 mm of all rainfall events followed by 72-hour detention prior to discharge to surface water. Christchurch City Council recommends as best practice the capture of runoff from the first 25 mm of storm rainfall depth, but not less than 15 mm. Average detention time prior to discharge to surface waters should be at least 24 hours. To be effective in treating dissolved pollutants, detention time in wetlands and wet ponds should be longer.

The CCC (2003) method uses average effective impervious area percentages based on land use zonings to calculate first flush volumes. The CCC (2003) first flush method is limited to the design of ponds and wetlands.

2.6.3 Summary

Table 2.6.3 presents a summary of the National and Christchurch, New Zealand jurisdiction, included as part of the selected jurisdictions in regards to the respective volume target, the rationale for selecting the target, the rainfall events considered as part of the target development and the Minimum Inter Event (MIT) used in the analysis.

Table 2.3.4 – Summary of the New Zealand

Jurisdiction/ Agency	Volume Target	Rationale	Rainfall Event	Minimum Interevent Time (MIT)
Auckland, New Zealand	16.7- 43 mm volume capture and treatment 25 mm water quality storm	Capture 75 percent of the total suspended sediment on a long-term average basis. Water quality design storm depth of 25 mm, equivalent to 1/3 of the 2-year average recurrence interval (ARI).	**Type:** Daily and hourly rainfall (24 hour) **Exclusions:** N/a	**MIT:** n/a
Christchurch, New-Zealand	25 mm Volume capture and treatment	First flush interception: achieve treatment of 58% of the Christchurch average annual rainfall depth falling on the recipient catchment.	**Type:** Daily and hourly rainfall (24 hour) **Exclusions:** N/a	**MIT:** n/a

2.7 Conclusions and Recommendations

From the review of the sources, methods, and research that were used to determine the runoff volume treatment target by the five (5) selected jurisdictions, the following conclusion and recommendations have been developed for:

- The proposed rainfall analysis for Ontario
- The development of Recommended Runoff Volume Control Targets (RVC_T) for Ontario.

Recommendations for the development of Runoff Volume Control Targets (RVC_T) for Ontario are discussed in **Section 4.0**.

2.7.1 Recommendations for the proposed rainfall analysis for Ontario

From the review of the sources, methods, and research that were used to determine the runoff volume treatment target by the five (5) selected jurisdictions, the following recommendations are proposed for the analysis of Ontario rainfall data.

- That the analysis of Ontario rainfall be conducted to determine the 50th, 75th, 80th, 90th, 95th and 99th percentile events and that respective Rainfall Frequency Spectrum (RFS) be developed.

- That the analysis of the Ontario rainfall be conducted under two scenarios:
    1. Evaluating the total precipitation (rain and snow) record, and
    2. Evaluating the rainfall record only using the simplified assumption whereby any day that had recorded snowfall was discarded from the analysis per the approach undertaken as part of the MIDS development.

- That the analysis of Ontario rainfall includes the assessment of both hourly and daily rainfall data. Furthermore, an investigation and assessment should be completed using the hourly rainfall data in regards to the effect of various Minimum Interevent Times (MITs) including a 3, 6, 12, 18, 24 and 36 hour MIT on the Rainfall Frequency Spectrum (RFS).

- That regional analyses be conducted using the daily and hourly rainfall data for Ontario in order to inform the development of the Recommended Runoff Volume Control Targets for Ontario

- That regional contours (isohyet) mapping be developed based on the regional rainfall data. This approach which recognizes the regional differences in rainfall patterns and depth across the varied landscape of Ontario and will inherently consider the effects of the Great Lakes and other significant bodies of water on regional rainfall patterns.

- That rainfall less than 0.1 inches (2 mm) not be included in the analysis, per the U.S. EPA[16,17 & 18] recommendations which suggests that small rainfall events that are 0.1 of an inch (2 mm) or less be excluded from the percentile analysis because this rainfall generally does not result in any measurable runoff due to absorption, interception and evaporation by permeable, impermeable and vegetated surfaces, as well as since most rain gauges only record values to the nearest 0.1 inch (2.5 mm). Note: initial abstractions are commonly estimated to be between 0.10 and 0.15 inches in urban areas (0.1 and 3.8 mm). Furthermore, it is recommended the exclusion of rainfall less the 5 mm also be evaluated per the LSRCA approach and a comparison made.

3 RAINFALL ANALYSIS FOR ONTARIO

The following section provides a summary of the rationale and background supporting the use of the 90th percentile approach including a discussion of the water balance, hydromodification, urbanization and the effects of watershed impervious from urbanization on the environment, people and infrastructure.

Subsequent sections present the results of the rainfall analysis completed for the province of Ontario using hourly and daily rainfall data and provides the recommended Rain Fall Spectrum (RFS) for Ontario for use as the Runoff Volume Control Target for Ontario.

3.1 Water Balance

Precipitation that falls onto the ground either flows over land as ***surface runoff*** which makes its way directly to a watercourse, soaks into the ground as ***infiltration*****,** or is retained on vegetation and other surface materials as ***interception storage***. Rainfall retained as interception storage is returned to the atmosphere through ***evaporation*** and never contributes to runoff. A portion of the waters infiltrating the soil recharges deep ***groundwater*** reserves and the remainder is stored near the ground surface where it is depleted through ***transpiration*** by plants. Some groundwater migrates laterally and is intercepted by valleys, ravines or the banks of watercourses where it emerges to become surface flow. This groundwater discharge, known as baseflow, maintains flow in the channel during periods between precipitation events and consequently it is a very significant factor in the determination of habitat value and the maintenance of ecological flows. These processes and pathways are all part of the hydrologic cycle for undeveloped and developed lands.

The proportion of precipitation occurring as surface runoff versus infiltration and how rapidly the surface runoff is delivered to the receiver determines the impacts to the natural environment, habitats, and people. The proportions of precipitation (P) which enter the hydrologic pathways of runoff (R), infiltration (I) and evapotranspiration (ET) is known as a water balance and is represented by the following simplified equation:

$$\boldsymbol{Precipitation\ (P) = Runoff\ (R) + Infiltration\ (I) + Evapotranspiration\ (ET)}$$

Or

$$\boldsymbol{P = R + I + ET}$$

A water balance is a way of accounting for what portion of precipitation occurs as runoff versus infiltration or interception, how much water is returned to the atmosphere through evaporation and transpiration or supplied to the watercourse through groundwater discharge. The portion of precipitation accounted for in each of these components of the water balance is determined by a number of factors which can be broadly classified as:

1. Climate,
2. Vegetation and
3. Geology.

Climate refers to long term trends in meteorological conditions typically measured in units of decades to thousands of years. Although there may be short-term changes to the water balance as a result of climate variations, over the long term the water balance is constant, providing vegetation and geology are not altered.

3.2 Urbanization and Hydromodification

Changes in land use from natural cover, such as clearing forests for cultivation or conversion of rural lands to urban development forms, alters the water balance as pervious surfaces are converted to impervious surfaces, infiltration characteristics of the soils are altered and vegetation is removed or altered. When rural lands are urbanized, porous soils are replaced with impervious materials such as concrete and asphalt which yield high runoff during precipitation events. Consequently, land use change can lead to a significant and sometimes radical alteration in the prevailing watershed hydrology and associated water balance.

The combined effect of larger runoff volumes and increased drainage efficiency is an increase in peak flow rate and the duration of high flows in the receiving watercourse. These changes in the flow regime are referred to as ***hydromodification.***

The result of hydromodification from a land use change can include:

- Channel enlargement and increased erosion resulting in property loss and damage to infrastructure,
- Increased flooding,
- Impaired water quality,
- Degradation of habitat and associated biota, and
- Decline in aesthetic value and recreational potential.

Combined with the effects of decreases in infiltration volumes directed to shallow and deep groundwater, which supplies baseflow to local watercourses and wetlands and is a source of drinking water for many Ontarians, the dramatic increase in water borne pollution such as litter, heavy metals and nutrients, in addition to increases in stream water temperature - alteration to the hydrology of the watershed and the associated water balance can have a significant and often irreversible impact.

The goal of maintaining and restoring the natural or pre-development hydrologic integrity of the watershed and its associated water balance is to avoid alterations to instream erosion rates, water quality degradation, losses in groundwater recharge rates, increased flow, impacts to the natural environment as well as avoid unfunded infrastructure liabilities. As such, avoiding changes to the natural watershed hydrology and the associated water balance as a result of development must be the primary focus of stormwater practitioners.

To effectively mitigate the impacts, stormwater strategies must include a means to reduce runoff volume with the objective of maintaining the pre-development water balance.

3.3 Conventional Stormwater Management

The management of stormwater runoff was conceived as a means to allow land use change, specifically urban development, to occur while mitigating the effects on the receiving channel associated with hydromodification, flooding and water quality. While significant progress has been made in this regard, it is increasingly apparent that current stormwater management practices do not provide sufficient mitigation to the identified impacts. Studies have repeatedly found that the current practices to offset the hydrologic effects of urbanization are insufficient to prevent increased channel erosion and deterioration of aquatic habitats[19] [20].

Ontario has relied primarily on end-of-pipe control measures in the form of detention facilities (dry ponds, wet ponds and constructed wetlands). Originally, such facilities were designed for the purpose of attenuating large flood flows. In the 1980's and early 1990's design standards for detention ponds were revised to provide water quality treatment through settling of suspended sediments. More recently (beginning in the late 1990's), ponds began to be designed for the management of increased erosion potential associated with hydromodification and in the mid 2000's for thermal protection of receiving waterbodies. However, there are fundamental problems with the reliance on detention facilities as the basis for the management of hydrologic changes in watershed as they do not address or mitigate impacts to the water balance.

Detention facilities typically receive stormwater runoff from relatively large contributing areas such as an entire subdivision and located at the outfall of a storm sewer system prior to release of stormwater runoff to the receiving watercourse or waterbody. They are detention based measures intended to hold or store stormwater runoff and release it in a controlled manner to the receiving channel. Although water losses through evapotranspiration, and in some cases losses through infiltration through the bottom of the pond or wetland occur, these losses are not generally significant in the majority of detention facilities. As such, runoff volumes are not reduced and the pre-development infiltration portion of water balance is not maintained.

The significant impacts of the 'business as usual' approach to stormwater management and reliance on end-of-pipe control can be easily observed within many urban and suburban watersheds, watercourses and waterbodies in the province of Ontario and beyond.[21], [22], [23], [24], [25], [26]

3.4 Watershed Impervious Area

With urbanization, surface drainage efficiency is enhanced, resulting in a significant shift in the hydrology and associated water balance toward a regime with high runoff yield and a rapid flow response. Even low levels of urbanization within a watershed beginning with an increase in impermeable surfaces of just 4%, can result in changes to stream channel characteristics and aquatic communities[27]. These impacts have been shown to follow a continuum of impacts and environmental degradation as total watershed impervious area resulting from development increase, specifically:

- As total watershed impervious area changed from 5% to 10%, the physical and biological measures within a watershed generally change most rapidly[28]. With more intensive urban development in the watershed, habitat degradation and loss of biological productivity continues, but at a slower rate.[29]
- At approximately 10% total watershed imperviousness channel adjustments of local watercourses (primarily as enlargement) will occur[30]; fisheries biodiversity and abundance are initially and significantly impacted[31].
- At 10% total watershed imperviousness of watersheds with traditional ditch and pipe systems, about 10% of the total rainfall volume becomes runoff that enters receiving waters; this runoff volume is the root cause of aquatic habitat degradation[32]
- A 30% total watershed imperviousness has been shown to increase the flood flow peaks of the 100-year event by a factor of 1.5. In contrast, events occurring on average once in 2 years or annually, increased by factors of 3.3 to 10.6 respectively.[33]
- In addition, at 30% total watershed imperviousness, urban watershed may be unable to sustain abundant self-supporting populations of cold-water fish.[34]
- At urbanization levels between 25% and 55% (built form) serious irreversible degradation of the have been predicted and shown to take place.[35]

- At 50% total watershed imperviousness, poor water quality and concentrations of metals in sediments begin to show significant impact to aquatic biological communities.[36]

To offset the identified impacts, an increased emphasis on maintaining the natural water balance and replicating the predevelopment hydrologic cycle is required. An appropriate performance target must be set.

The approach supported by many Canadian, US and international jurisdictions is the selection of a performance target which can maintain the form and function of the natural systems and avoid the 'initial and significant impacts' associated with urbanization which is correlated with a total watershed imperviousness of 10% as detailed above. A total watershed imperviousness of 10% is clearly a tipping point beyond which significant and sometime irreversible impacts are expected to occur.

Acknowledging, as stated previously, that 'at 10% total watershed imperviousness of watersheds with traditional ditch and pipe systems, about 10% of the total rainfall volume becomes runoff that enters receiving waters and that this runoff volume is the root cause of aquatic habitat degradation'[37], a performance target for the management of runoff volume which limits the total runoff volume to 10% (or less) of total rainfall volume has the potential to avoid:

- The most rapid periods of physical and biological alterations as well as terrestrial and aquatic habitat degradation within a watershed,
- Channel enlargement (erosion),
- Impacts to fisheries biodiversity and abundance,
- Increase the flood flow peaks,
- Irreversible environmental degradation, and
- Poor water quality (concentrations of metals in sediments).

As such, an appropriate performance target for managing runoff volume is to limit total runoff volume to 10% (or less) of total rainfall volume. This means that 90% of rainfall volume must be controlled and returned to natural hydrologic pathways of the water balance in proportions in keeping with the conditions prior to development. This requires the control of 90% of the annual average rainfall, commonly determined through the use of the 90th percentile storm.

3.5 Background – Why the 90th Percentile?

One of the earliest references to the 90th percentile storm can be found in a 1979 publication by the United States Environmental Protection Agency (USEPA), as part of a stormwater management system case study in Salt Lake City[38]. The system was analyzed for varying storm events (50, 64, 80, and 90th percentile storms) along with their respective pollutant reductions and dissolved oxygen content. The case study concluded that the 90th percentile storm just met the water quality guidelines being evaluated. While the concept was first introduced in 1979, it took many more years for the concept to re-emerge and gain widespread acceptance.

The origins of the "One-inch-rule", the "90 Percent Rule" are most commonly traced back to The Design of Stormwater Filtering Systems by Claytor (1996). Chapter 2 of this document entitled Runoff and Water Quality Characteristics of Small Sites suggests that based on an analysis of the rainfall frequency spectrum for Washington, D.C. by Schueler (1992) that a BMP sized to capture and treat the three (3) month storm frequency of 1.25 inches (31.8 mm) will effectively treat 90% of the annual average rainfall. Stating further, that while such a practice will also capture and at least partially treat the first 1.25 inches (31.8 mm) of larger events, therefore resulting in a capture efficiency greater than 90% annual average rainfall events.

At its time of publication, many jurisdictions required storage of the first 0.5 inch (12.5 mm) or ‘first-flush’, however at the time little research on the cumulative pollutant load bypassing facilities sized on that principle has been completed, with the exception of Chang et al.,1990. Research in Texas by Chang[39] found that the total annual load capture using the 0.5 inch (12.5 mm) decreased significantly as impervious areas approached 70% (e.g. a highly urbanized environment). Subsequent studies such as the Michigan Department of Environmental Quality 2014 Post-Construction Storm Water Runoff Controls Program discussed previously, subsequently confirmed that “all the pollutants washed off in the first flush of runoff from impervious surfaces are contained in the first 25 mm of runoff” (MDEQ, 2014).

Further analysis by Claytor for an 11-year period for four (4) locations within the Chesapeake Bay Area, found the one (1) inch rainfall provided an average capture percentage of 85% to 91% of the rainfall events. This analysis provided justification for using the one (1) inch rainfall event and became known as the “**One-inch-rule”**, the **“90 Percent Rule”** or the **“90 Percent Capture Rule”**.

Claytor (1996) emphasized that regional rainfall characteristics will differ from location to location and that additional rainfall frequency analysis is required in order to have more reliance on the 90 Percent Capture Rule value suggesting that a rainfall frequency spectrum (RFS) analysis be conducted using local precipitation data using a longer data set. The data set length or analysis techniques should be selected such that extreme events and drought periods become less statistically significant on the capture value derived.

Since that time numerous jurisdictions have developed regional Rainfall Frequency Spectrum (RFS) curves, adopted and modified the 90th percent rule approach. The technical basis for the 90 Percent Rule is that the stormwater practice is explicitly designed to capture and treat 90% of the annual rainfall events that produce runoff.

3.5.1 Rainfall Frequency Spectrums (RFS)

Rainfall Frequency Spectrum (RFS) curves (also known as “rainfall distribution plots”) are suggested as “useful tools to assist stormwater managers with the development of stormwater management criteria, particularly the criteria that relate to smaller storm events (runoff reduction or recharge, water quality).” The RFS can link the various criteria with particular rainfall events.[40]

A Rainfall Frequency Spectrum (RFS) is a tool that stormwater managers should use to analyze and develop local stormwater management criteria and to provide the technical foundation for the criteria. Over the course of a year, many precipitation events occur within a community. Most events are quite small, but a few can create significant rainfall. An RFS illustrates this variation by describing how often, on average, various precipitation events (adjusted for snowfall) occur during a normal year. [41]

The development of a RFS is generally a first step in the creation of stormwater criteria relating to the 90 percent rule. Data used to generate the RFS and ultimately the 90 percent capture depth are based on a regional analysis of the regional rainfall patterns. **Figure 3.1** is an example of an RFS derived from daily rainfall data for the Toronto Lester B. Pearson International Airport Environment and Climate Change Canada (ECCC) climate station for the period of January 1st, 1970 to December 31st, 2005. The example RFS developed from daily rainfall totals (excluding all events less than both 2 mm and 5 mm) illustrates the theoretical 90th and 95th percentile rain fall event and its location on the curve at the “knee” of the curve. “It is at this point that the theoretical optimization of treatment occurs” [42] as such as the target percentile moves past the “knee” of the curve diminishing returns can be expected, meaning that the size of size and cost of the BMP increases significantly while the total number of storms treated increases only marginally. This is often referred to as the ‘law of diminishing returns’ which is used to refer to point at which the benefits gained are less than the amount of effort (money or energy) invested.

The rainfall depth associated with the “knee” of the curve equates to the 90th percentile event of approximately 21-25 mm, while the true “knee” of the curve occurs closer to the 95th percentile of approximately 28-33 mm. A similar result was reported for the Minneapolis/St. Paul Airport for the period of 1971 through 2000 as part of the MIDS development, which reported that both the 90th and 94th percentile “represent valid interpretations of the knee of the precipitation depth curve”. [43]

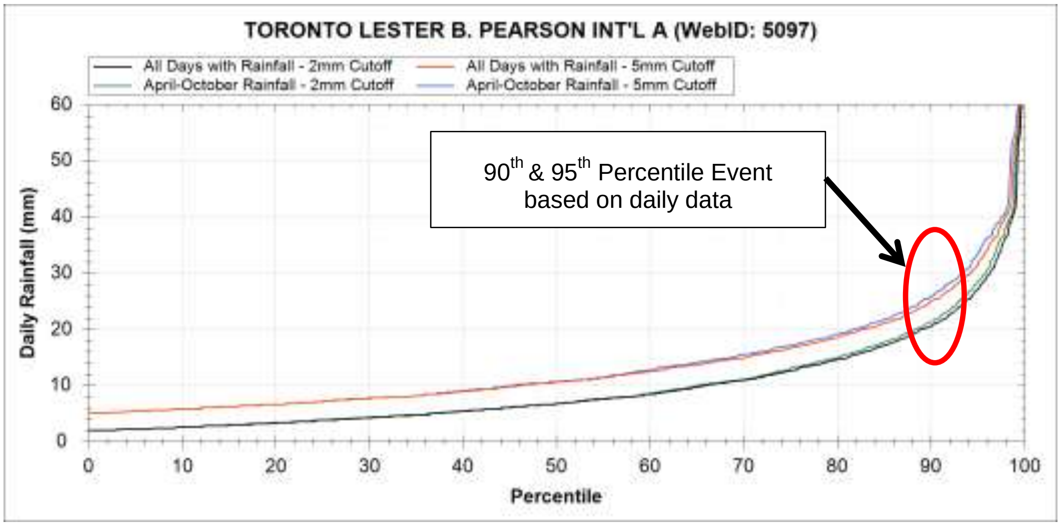


Figure 3.1 - Daily rainfall frequency curves derived from daily rainfall data at ECCC climate station TORONTO LESTER B. PEARSON INT’L A.

In general, the USEPA (1979 & 2009) and CWP (2008) recommends the 95th percentile storm as the volume target for water quality, but has no hardline requirement and allows each jurisdiction to determine the percentile storm that suits their jurisdiction best.

The USEPA further recommends that:

- for each location, specific analysis that a 20 to 30-year record of 24 hour events be utilized in the analysis in order to adequately define the statistical variability of the rainfall record

- that smaller events less than 0.1 inch (2.5 mm) and snowfall events that do not immediately melt be excluded from the from the data set and analysis. These events typically do not produce runoff, are at the lower threshold of rain gauge resolution, and could potentially cause the analyses of the 95th percentile storm runoff volume to be inaccurate. As discussed previously:

  - events less than 0.1 inch (2.5 mm) events typically do not produce any measurable runoff due to absorption, interception and evaporation by permeable, impermeable and vegetated surfaces and are at the lower threshold of rain gauge resolution.
  - The exclusion of snowfall events acknowledges that snowfall is not the process by which runoff is produced. Most generally, the process of snowmelt and therefore runoff generation, occurs over an extended period of time and as such does not typically result in significant peak flows, capture system bypass and/or overflow. Conversely, infrequent rapid melt events are most relevant in regard to flood control criteria as opposed to water quality (or water balance).

- Because the goal of the 90% capture rule is to select the event that represents 90% of the annual cumulative precipitation depth (rather than 90% of the number of events) additional analysis is needed to determine which percentile event is most appropriate for application in each location.

3.6 Hourly Rainfall Analysis

Hourly rainfall data for the Province of Ontario were obtained from the Meteorological Service of Canada (MSC), a division of Environment and Climate Change Canada (ECCC). Hourly data in Canada comes in several datasets mainly dependent on the type of instrument used to collect the data.

- **Hourly rainfall - HLY03** (*element 123*): Is measured by tipping bucket. This dataset is quality controlled, however, is typically only available April 1st through October as the equipment does not function reliably during sub-zero conditions. Some data is available at stations with rain gauge heaters.
- **Hourly rainfall - HLY21** (*element 123*): Is measured by Fischer/Porter weighing gauges. This is largely a historical dataset, with less resolution than modern weighing gauges which employ a digital load cell coupled to data logger.
- **Hourly precipitation - HLY01** (*element 262*): Is measured by a digital weighing gauge and is available year round. Under ideal conditions, this gauge captures all precipitation forms including snow, sleet, hail, and mixed rain/snow events. The data is generally only available in a raw format with limited quality control.

See http://climate.weather.gc.ca/prods_servs/documentation_index_e.html for a further discussion of these datasets.

3.6.1 Post-Processing and Data Cleanup

Hourly data from the three datasets were merged for each available station. Tipping bucket rainfall data was favored as these data: 1) span the largest temporal period, and 2) have been quality checked to a higher standard than recently collected measurements at weighing-type stations. **Figure 3.2** illustrates the raw hourly data observed at the Hamilton Royal Botanical Gardens climate station where a tipping bucket and a weighing gauge were operated concurrently for several years.

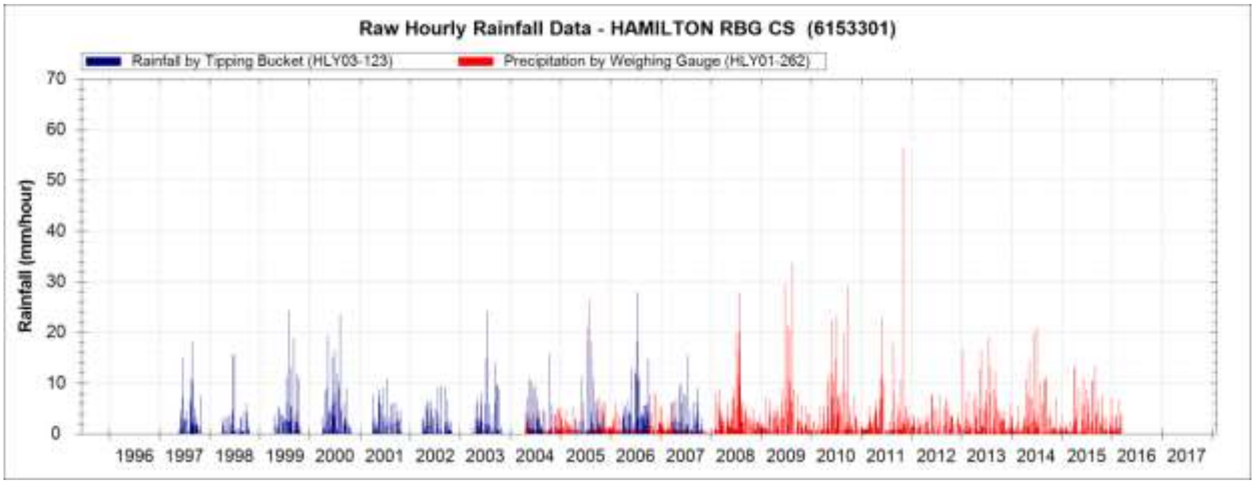


Figure 3.2 - Raw hourly data obtained for ECCC Climate station HAMILTON RBG CS.

The hourly datasets from the weighing-type gauges are provided by ECCC "as is" and have not been rigorously quality checked. Occasionally there are erroneous or un-flagged spikes in these rainfall time series. After an examination of high intensity rainfall events southern Ontario, an upper limit of 80 mm/hour was used to screen out these erroneous events from the record.

Tipping buckets, which represent the source of the bulk of the hourly data, have historically been operated in Ontario April 1st through October 31st. (Unheated gauges do not produce useful data, and are covered during the winter months.) Given that the goal of this exercise is to estimate rainfall event return periods, each dataset was truncated to this 7-month period for each year. This was also done to create a consistent observation window for the three datasets. This truncation, as discussed previously, acknowledges that the exclusion of snowfall events acknowledges that snowfall is not the process by which runoff is produced. Most generally, the process of snowmelt and therefore runoff generation, occurs over an extended period of time and as such does not typically result in significant peak flows, capture system bypass and/or overflow. Conversely, infrequent rapid melt events are most relevant in regard to flood control criteria as opposed to water quality (or water balance).

Figure 3.3 presents the grouped and processed hourly data for the Hamilton Royal Botanical Gardens climate station.

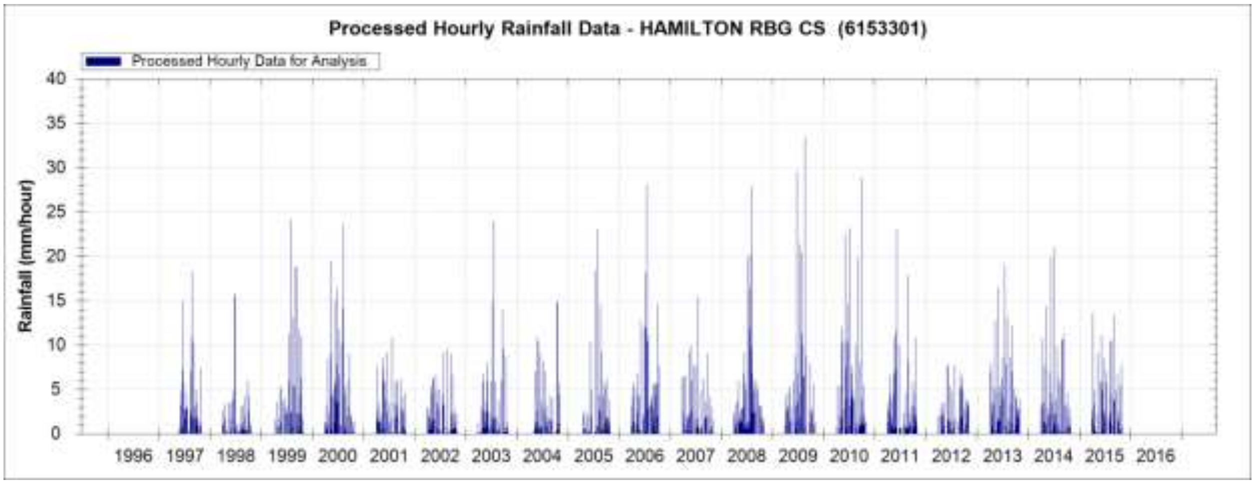


Figure 3.3 - Grouped and processed hourly data obtained for ECCC Climate station HAMILTON RBG CS.

After data processing, the hourly observations collected by Fischer/Porter weighing gauges (HLY21 - element 123) were discarded. The sensitivity of the equipment is much coarser than at stations equipped with tipping buckets or modern weighing gauges; the gauges also appear to underreport somewhat. An example hourly hyetograph of the data collected at a typical Fischer/Porter gauge is presented on **Figure 3.4**. The resulting rainfall depth frequency curve derived from the Fischer/Porter data is shown on **Figure 3.5**. Discarding the Fischer/Porter gauges results in 5 stations being dropped from the final hourly volume target analysis.

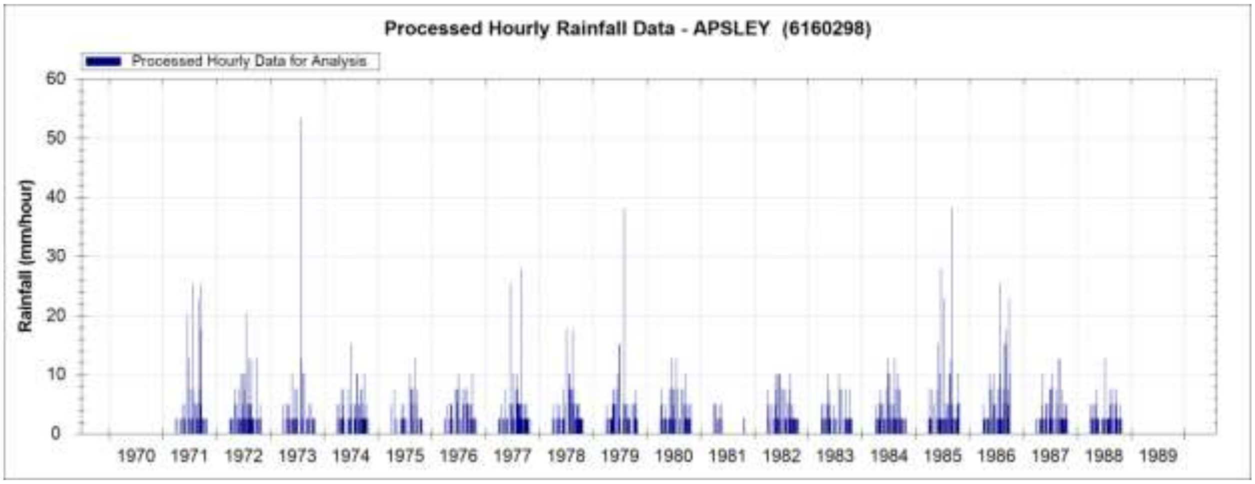


Figure 3.4 - Grouped and processed hourly data obtained for ECCC Climate station APSLEY.

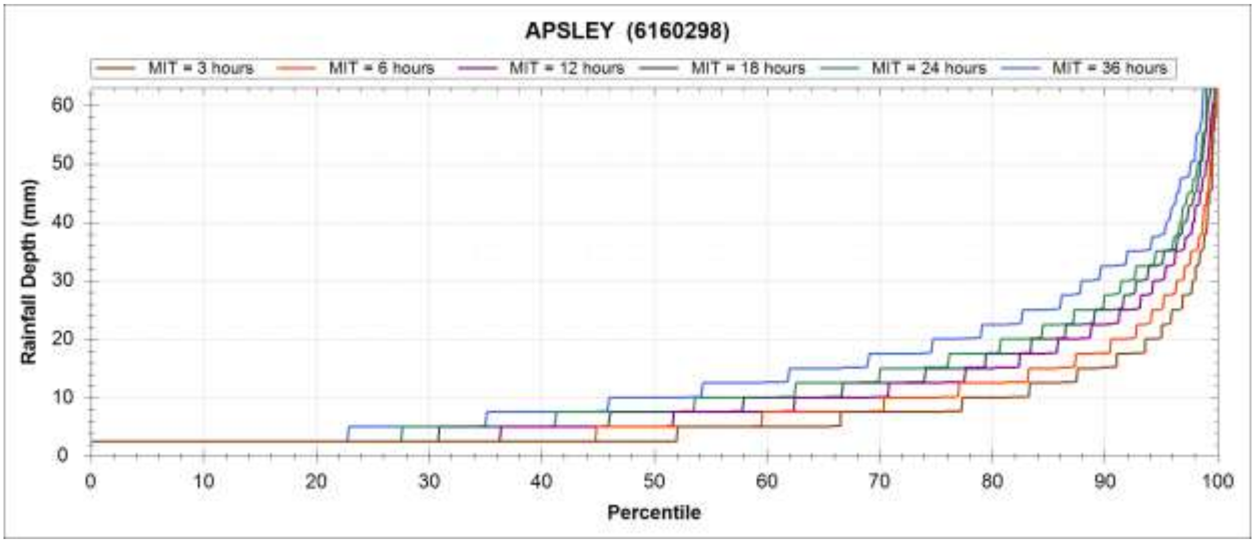


Figure 3.5 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station APSLEY.

3.6.2 Selecting the Analysis Stations

Fifteen years of data were required to include a station in the analysis pool. A station-year was considered "complete" if there were 6-months of rainfall data captured over the 7-month analysis window. While some stricter criteria would be ideal (e.g., such as the World Meteorological Organization (WMO) standard "3 and 5" rule), the hourly data is subject to frequent gaps and flagged events. The six-month criterion was selected to maximize the number of stations available for analysis. Years with partial record (i.e., less than 6 months of data) were also included within the analysis record. **Figure 3.6** illustrates the 99 climate stations selected for the rainfall event analysis in Ontario.

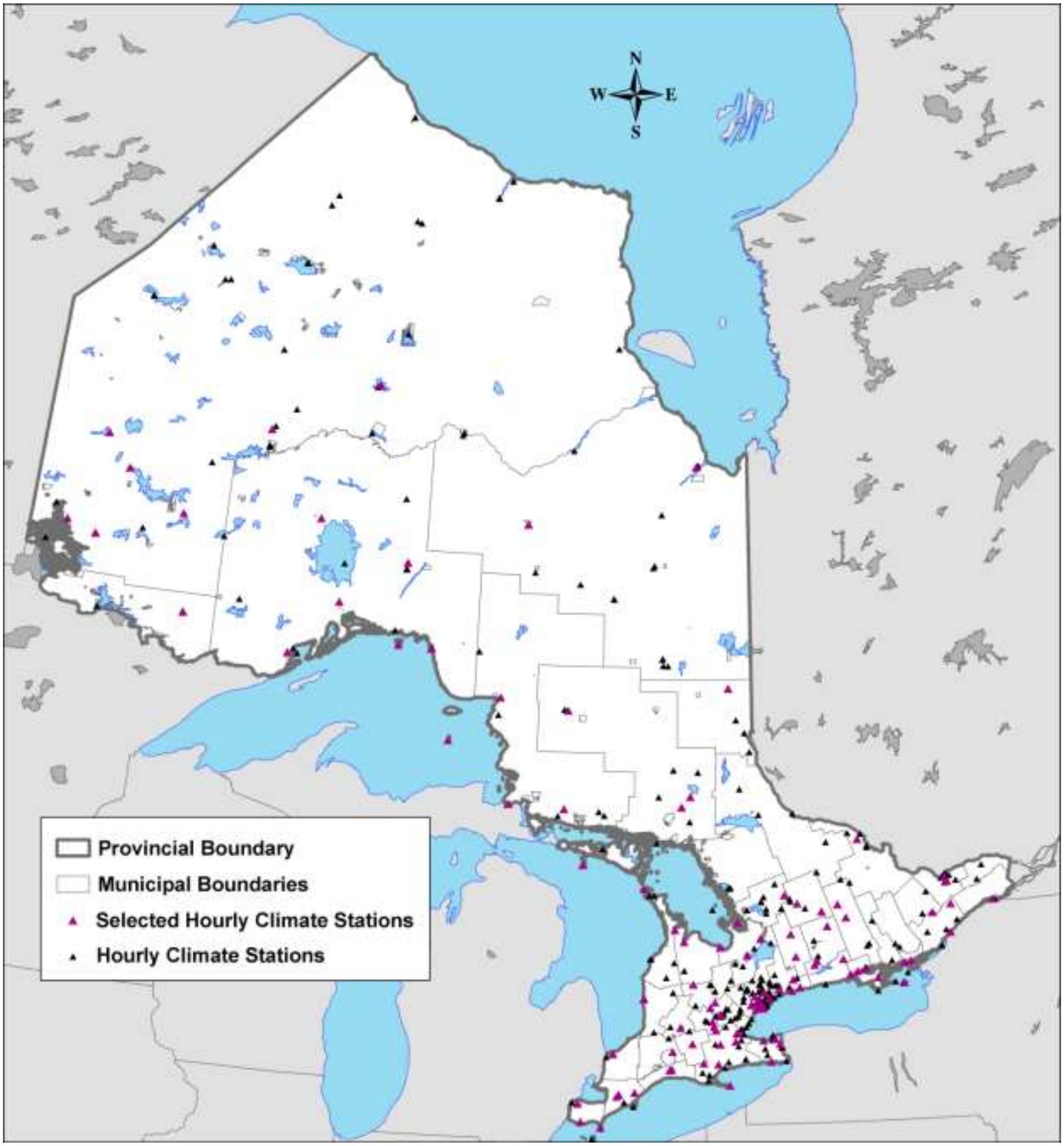


Figure 3.6 - ECCC hourly climate stations with sufficient period of record for inclusion in the volume treatment target analysis.

3.6.3 Rainfall Event Separation Methodology

Individual rainfall events were isolated within each station hyetograph with the Minimum Interevent Time method. A Minimum Interevent Time (MIT) is defined such that rainfall pulses separated by a time less than this value are considered part of the same event (Bedient and Huber, 2002).

There is no clear direction or recommended approach for the determination of a MIT. The USEPA, for example do not have a precise recommendation, due to variations in rainfall statistics over the U.S. In one regional study, (USEPA, 1979), a minimum inter-event period of 10 hours was recommended. The study did, however, recognize that there exist a number of difficulties in this approach of selecting an inter-event period. For example, the appropriate tolerance limits for considering records uncorrelated must be chosen, or that the correlation procedure does not limit itself to the correlation of rainfall records which are separated by a given number of consecutive dry hours, etc.

A second study discussed in USEPA (1979) used a 3-hour inter-event period when it studied yearly rainfall from 11 different cities throughout the U.S. The study suggested that various criteria may indicate that a different storm definition is more appropriate for certain cities. The statistical properties will change somewhat given a different storm definition, however, the general trends and seasonal patterns will remain basically unchanged.

A rainfall event dataset was created for several Minimum Interevent Time's (MIT's); 3, 6, 12, 18, 24, and 36 hours for each selected analysis station in Ontario. Storms with depths of less than 2 mm and 5 mm were discarded as these events may not produce runoff. (Separate analyses are presented discarding the 2 mm and 5 mm minimum storms respectively.)

Figure 3.7 presents hourly rainfall observed near Hamilton during July, 2009 with storms identified with a 6 hour MIT. **Figure 3.8** illustrates the events isolated with an 18 hour MIT for the same period. Selecting a higher MIT may lump possibly independent events together, producing a rainfall storm series with fewer events with higher magnitudes.

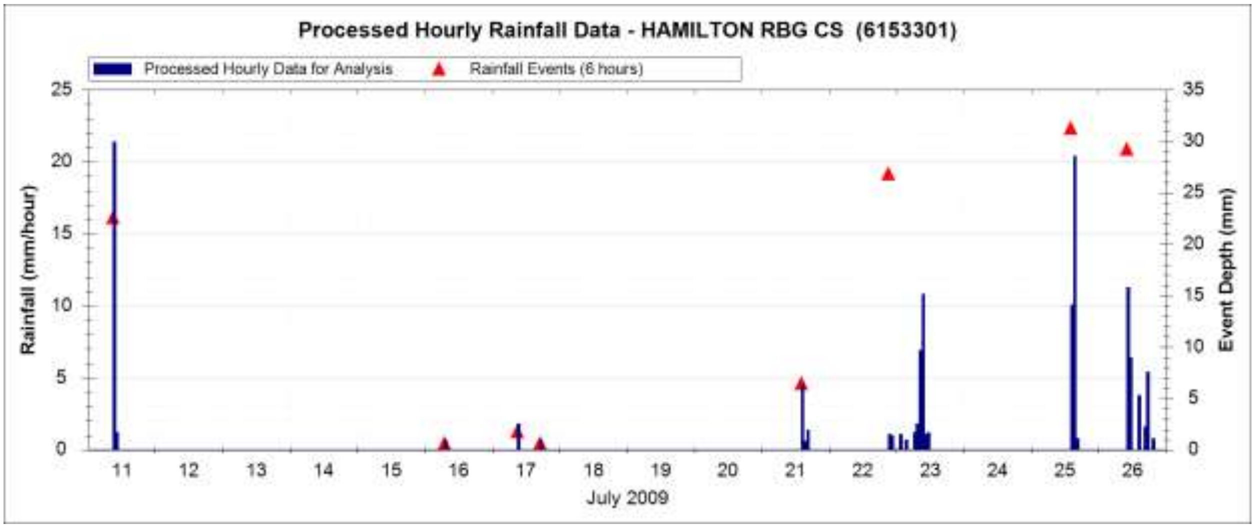


Figure 3.7 - Hourly rainfall data with event depths produced with a 6 hour Minimum Interevent Time (MIT) at HAMILTON RBG CS (July, 2009).

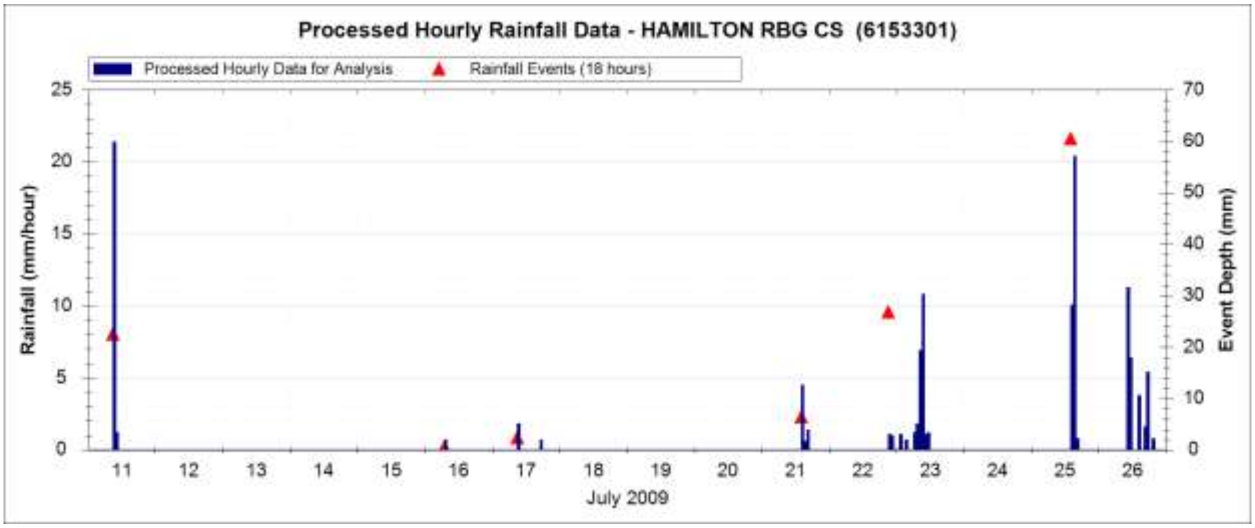


Figure 3.8 - Hourly rainfall data with event depths produced with an 18 hour Minimum Interevent Time (MIT) at HAMILTON RBG CS (July, 2009).

To evaluate the choice of MIT, data from the ECCC station TORONTO was examined (**Figure 3.9**). Event statistics for ECCC station TORONTO are presented in **Table 3.1** storms with a total volume of less than 0.5 mm were removed from the analysis series. This station has 56 years of available hourly record, and represents one of the longest hourly rainfall records in the province.

The effect of the choice of MIT can be seen in the average duration and volume of the identified events. As the MIT increases above 12-hours, some events are identified in the series which last more than 80 hours. Between the 6-hour and 18-hour MIT, the average event duration increases by 89% while the average event volume increases by only 28%. As shown on **Figure 3.10**, the choice of MIT has a clear impact on the frequency spectrum, with longer values parsing larger events from the rainfall record.

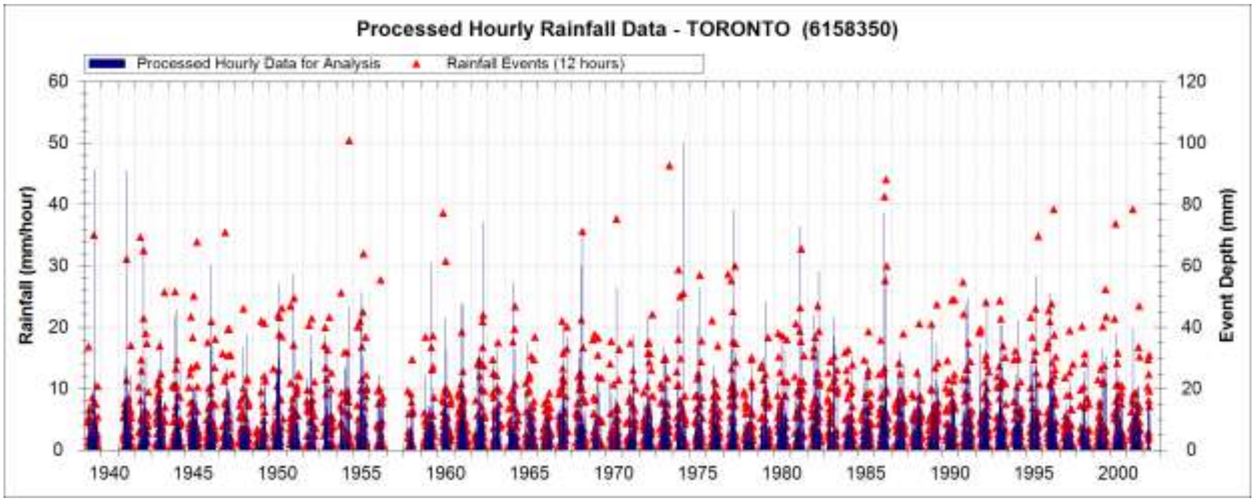


Figure 3.9 - Processed hourly rainfall data with events parsed with 12-hour Minimum Interevent Time, ECCC station TORONTO.

Table 3.1 - Parsed storm event statistics, ECCC station TORONTO.

Event Parameters		Minimum Interevent Time (Hours)					
		3	6	12	18	24	36
Number of Events		3907	3397	2923	2658	2447	2121
Event Volume (mm)	Minimum	0.5	0.5	0.5	0.5	0.5	0.5
	Median	3.6	4.4	5.3	6	6.6	7.9
	Average	7.0	8.1	9.4	10.4	11.3	13.0
	Maximum	98.2	98.2	100.9	105	108.1	108.1
	Coefficient of Variation	1.29	1.25	1.21	1.17	1.16	1.13
Event Duration (hours).	Median	3	5	6	8	9	13
	Average	4.9	6.6	9.6	12.5	15.8	23.5
	Maximum	39	69	82	113	128	222
	Coefficient of Variation	0.91	0.97	1.04	1.08	1.10	1.16

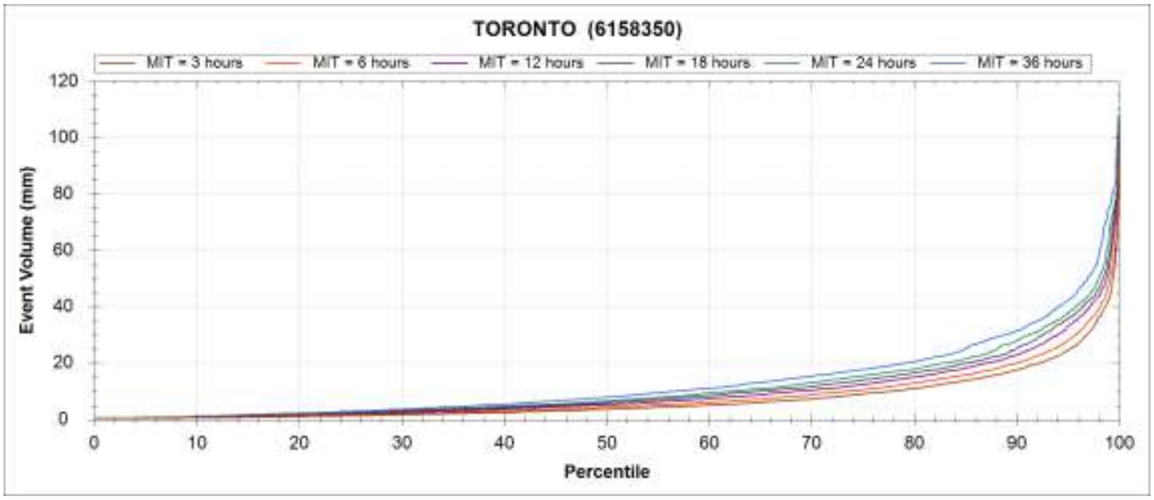


Figure 3.10 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station TORONTO.

One recommended approach to guide the selection of an MIT presupposes that the distribution of event volumes is well described by an exponential distribution. To evaluate the goodness-of-fit to the exponential distribution, the coefficient of variation (CV) of the event volume series is calculated (CV = standard deviation of the event volumes divided by the mean of the series). For a range of possible MIT values, the CV closest to 1.0 is favoured (exploiting the property of the exponential distribution that the standard deviation is equal the mean). The CV calculated for each series is presented on **Table 3.**1 with larger MIT values producing values closer to 1.

This approach is supported by the USEPA (1979) which also recommends that an inter-event period (or MIT) be chosen by calculating rainfall -storm statistics and selecting a minimum inter-event period that yields a coefficient of variation as close to 1 as possible. We can quickly examine the goodness of fit of the event volume series to the exponential distribution by plotting the percentiles on a semi-log plot as in **Figure 3.11**. If the event volume data are described by an exponential distribution, each series should plot as a straight line. While the data around the mean appears to fit well, both tails of the percentile plots are skewed. This suggests the rainfall data in Ontario is likely better represented by another distribution (such as the log-normal or the generalized extreme value distribution). This is significant for the target volume analysis, as the events of interest are above the 90th percentile, where a poor fit is observed. Choosing an MIT by a fitting to an inappropriate distribution could produce erroneous results.

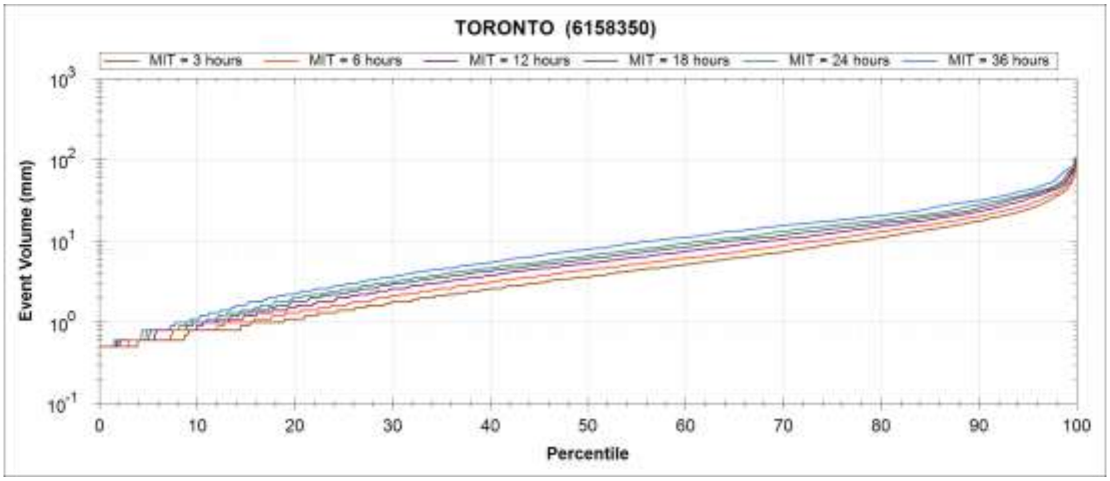


Figure 3.11 - Log rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station TORONTO.

Further insight into the choice of MIT can be gained by examining the duration of the parsed rainfall events. From **Table 3.1** and **Figure 3.10** we can generalize that smaller MIT values isolate events of shorter duration. During frontal storms, this may yield several smaller events rather than a single event that combines the dependant periods of rainfall. The duration percentiles of the events can be generated in a similar fashion to the event volumes, and **Figure 3.12** presents the duration spectrum of the MIT generated event series. When considering the 3-hour MIT, 90% of the events have duration of less than 10 hours; this MIT is likely overestimating the number of events. Conversely, when applying a 24-hr MIT, 30% of the events have durations that exceed 1 day. The larger MITs (18, 24, and 36-hour) are likely lumping independent events, while the 3-hour and possibly the 6-hour MIT are splitting multiple dependant events.

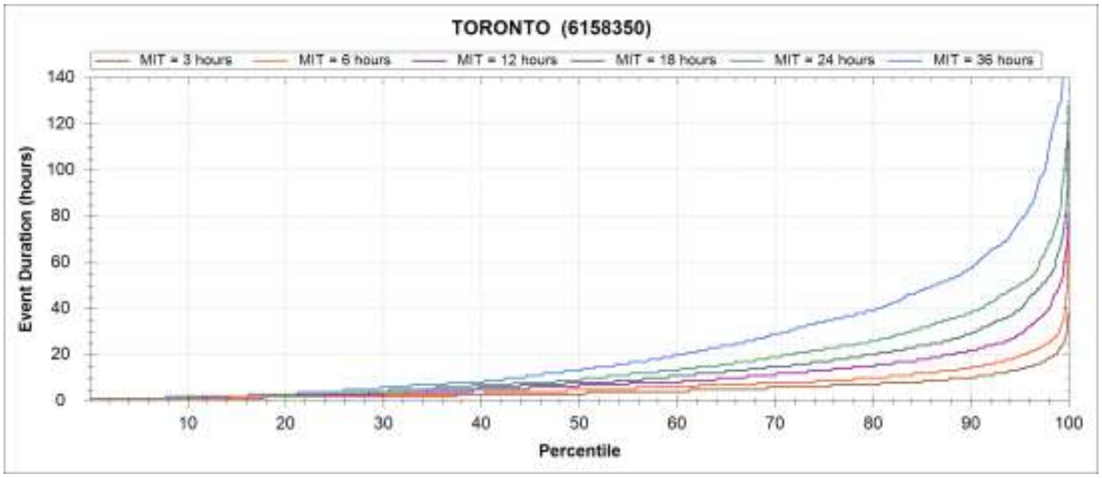


Figure 3.12 - Rainfall event duration frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station TORONTO.

While apparently isolated events can be parsed from the rainfall time series with the MIT method, it does not evaluate the true independence of a given storm event. Frontal systems may last days, while a convective storm could last only hours. The approach serves only to produce an estimate of the independent event series, and accordingly, isolating a single MIT can be a subjective task. Based on the above analysis, and a manual inspection analysis of the parsed events at multiple Ontario climate stations, the 12-hour MIT was selected as the best estimator with which to generate the event time series within Ontario.

The recommendation for a 12-hour MIT is supported by a 1989 USEPA study of storm event characteristics, including the areas surrounding the Great Lakes and Lake Ontario, which reported an annual average number of 75 storms, the average storm event of 0.5 inches (12.5 mm), and an average storm duration of approximately 12 hours, suggesting an average MIT of 12 hours (in a 24-hour period). Similarly, the MOECC F-5-5 procedure recommends an intervening time of twelve hours or greater separating precipitation events[44]. **Figure 3.13** illustrates the average storm event duration for the Great Lakes Region.

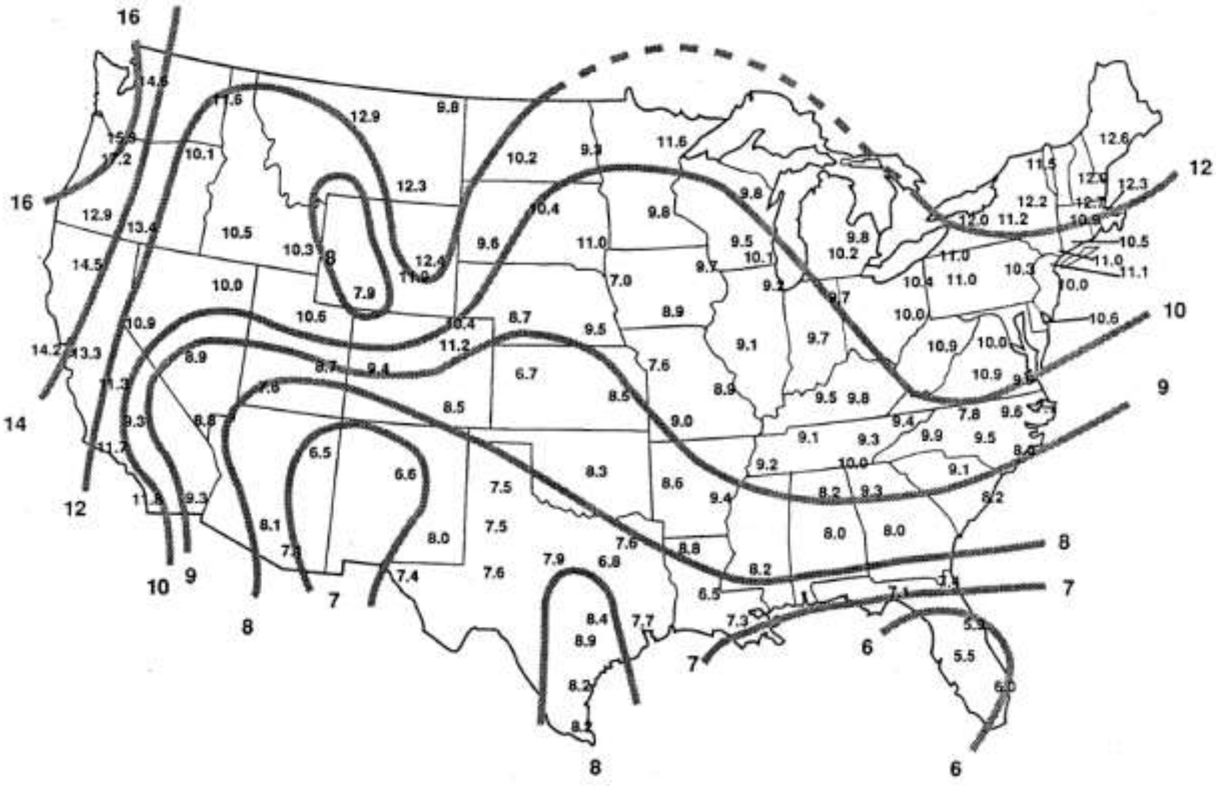


Figure 3.13 - Average storm event durations (USEPA, 1989)

For completeness, frequency and duration curves have been produced for each of the 6 MIT's investigated in this study and are provided in a digital appendix. In addition to producing event frequency curves for each MIT, curves for the 2 mm and 5 mm volume threshold were also derived for each station (**Figure 3.14** and **Figure 3.15).**

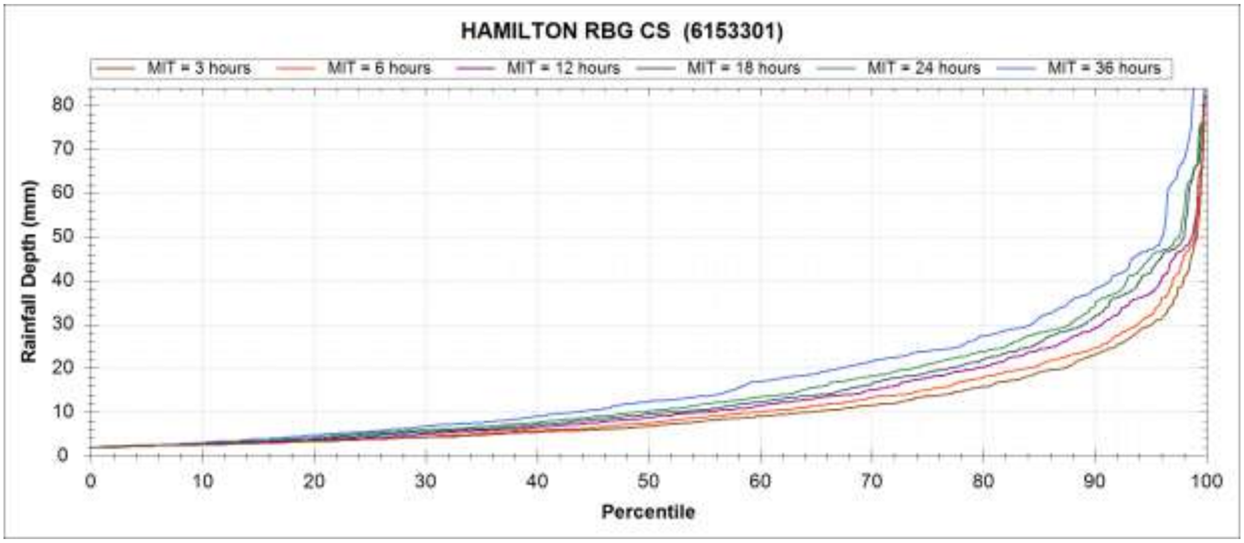


Figure 3.14 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station HAMILTON RBG CS – 2 mm cut-off.

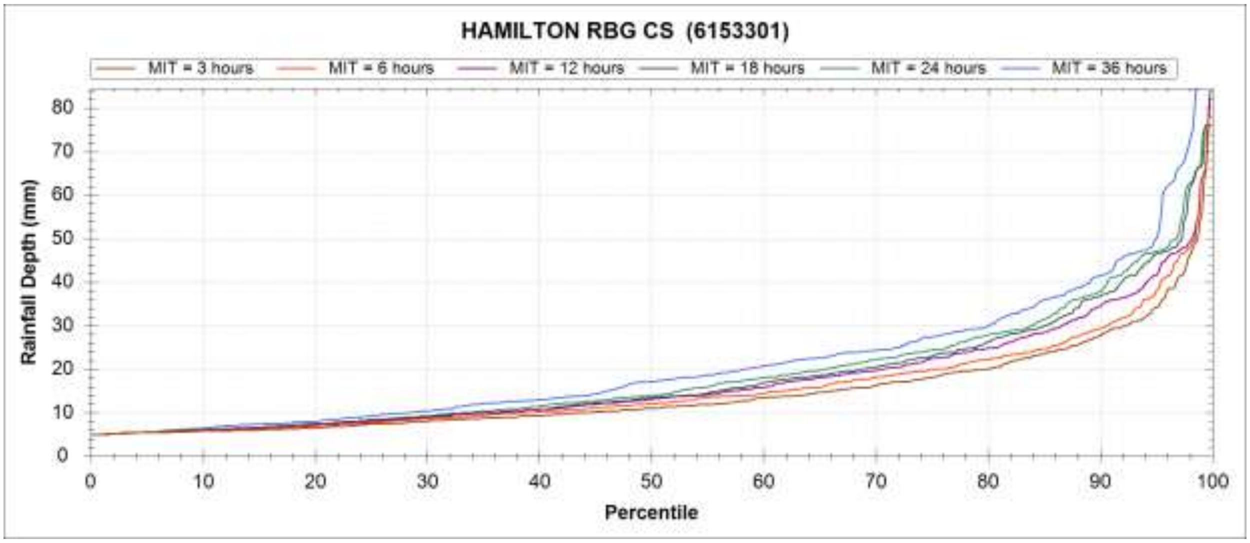


Figure 3.15 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station HAMILTON RBG CS – 5 mm cut-off.

3.6.4 Regional Results

Rainfall event percentiles were calculated at each station (and for each MIT with both a 2 mm and 5 mm lower threshold). Of greatest interest for this study are the 90th percentile event volumes, although the 50th, 75th, 80th, 90th, 95th, and 99th percentiles were derived at each station and are presented in the digital appendix (**Appendix A**). **Table 3.2** and **Table 3.3** present a statistical summary of the 90th and 95th rainfall event depth percentiles calculated from the hourly climate dataset (values parsed with the recommended 12-hour MIT are shaded.) Sample regional mapping is presented within this section, while rain event frequency plots and tabulated percentiles for key Ontario cities are included in the following section.

Table 3.2 - Summary of event rainfall depths calculated at hourly climate stations (ignoring event volumes below 2 mm).

	Years with complete data	90th Percentile Storm Depth (mm)						95th Percentile Storm Depth (mm)					
		Minimum Interevent Time (Hours)						Minimum Interevent Time (Hours)					
		3	6	12	18	24	36	3	6	12	18	24	36
Minimum	15	18.5	21.0	23.6	25.2	27.4	30.2	25.0	27.6	31.2	33.8	35.7	38.2
Median	23	21.6	24.0	27.0	29.4	32.1	36.4	29.0	32.0	35.8	38.9	41.8	48.8
Average	26.5	21.6	24.0	27.1	29.7	31.9	36.7	29.1	32.1	35.9	39.2	42.3	48.8
Maximum	59	24.3	27.5	31.9	36.0	38.6	44.9	34.8	39.3	43.9	49.5	51.8	60.5

Table 3.3 - Summary of event rainfall depths calculated at hourly climate stations (ignoring event volumes below 5 mm).

	Years with complete data	90th Percentile Storm Depth (mm)						95th Percentile Storm Depth (mm)					
		Minimum Interevent Time (Hours)						Minimum Interevent Time (Hours)					
		3	6	12	18	24	36	3	6	12	18	24	36
Minimum	15	23.0	25.0	26.9	29.0	31.0	34.9	29.5	31.3	35.0	35.8	38.0	39.8
Median	23	26.6	29.0	31.8	34.1	35.8	41.0	34.7	37.2	40.8	43.6	46.5	52.8
Average	26.5	26.8	28.9	31.7	34.1	36.2	41.1	34.7	37.4	40.9	43.9	46.8	52.9
Maximum	59	33.0	35.3	39.1	43.2	44.8	52.4	42.8	46.0	50.8	54.8	58.2	63.7

Figure 3.16 illustrates the 90th percentile depths for events parsed with the 12-hour Minimum Interevent Time. These percentiles were calculated after discarding the 2 mm storm event (assuming these rainfall events do not generate runoff). **Figure 3.17** presents the 90th percentiles if events with volumes less than 5 mm are discarded. Regional trends appear consistent between the plots, and percentiles between neighboring stations generally do not appear to vary more than 1-2 mm although there is significant variability in the mapped data. The magnitudes of the percentiles appear higher in southwest and northwest Ontario, and the distribution of event rainfall is likely influenced by the Great Lakes and Lake Winnipeg, Winnipegosis, and Lake of the Woods.

Contours were generated by ordinary Kriging (a method of interpolation) for the 90th percentile storm depths derived with the 12-hour MIT with both the 2 mm (**Figure 3.18**) and 5 mm (**Figure 3.19**) cut-off thresholds. A generally poor fit was obtained to the variograms, suggesting a high degree of spatial variability beyond neighbouring stations. The provided contours are only applicable to southern Ontario, and should only be used for draft discussion purposes.

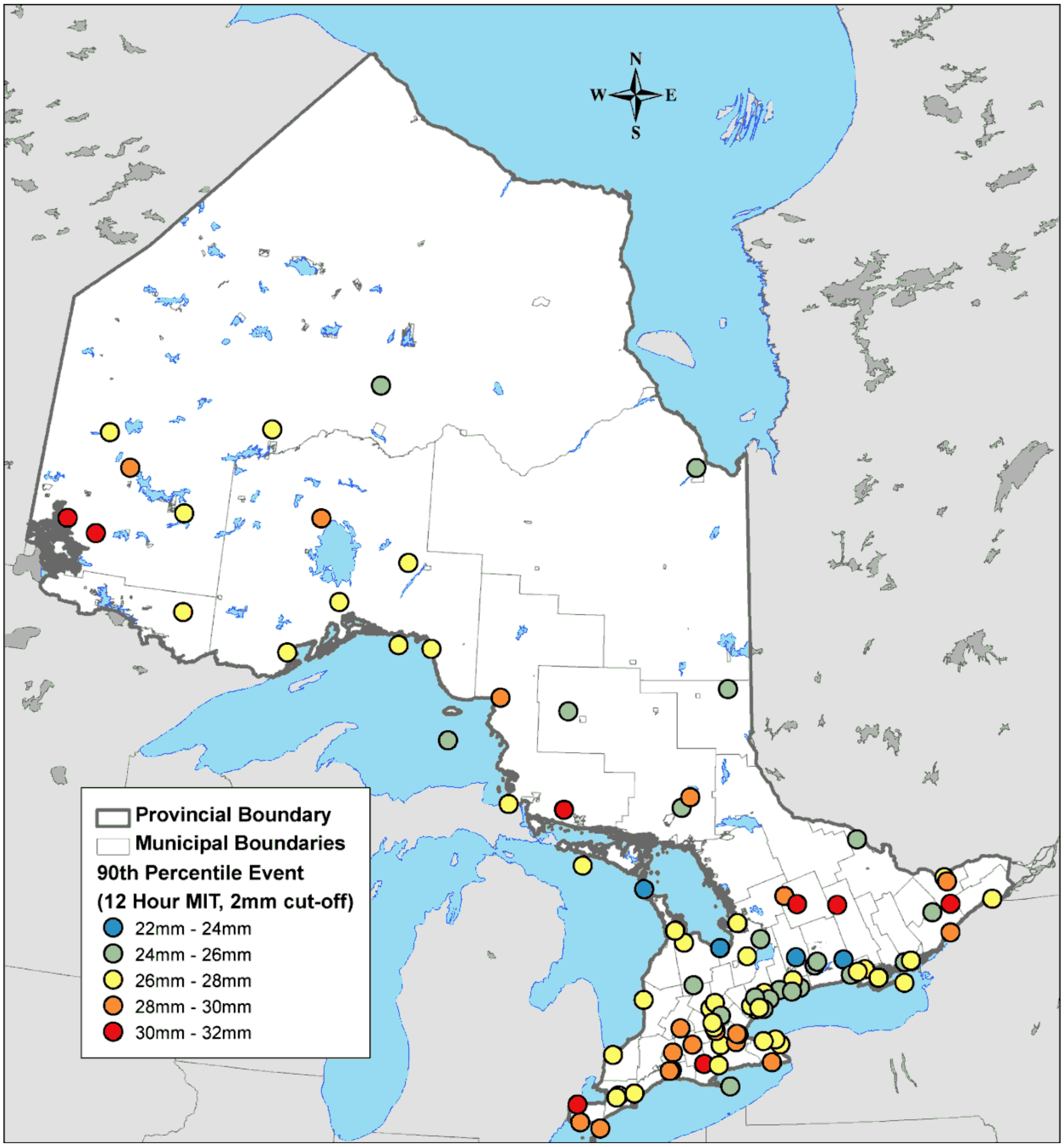


Figure 3.16 - 90th percentile rainfall event depths (from hourly record with a Minimum Interevent Time of 12 hours, where event depth exceeds 2 mm).

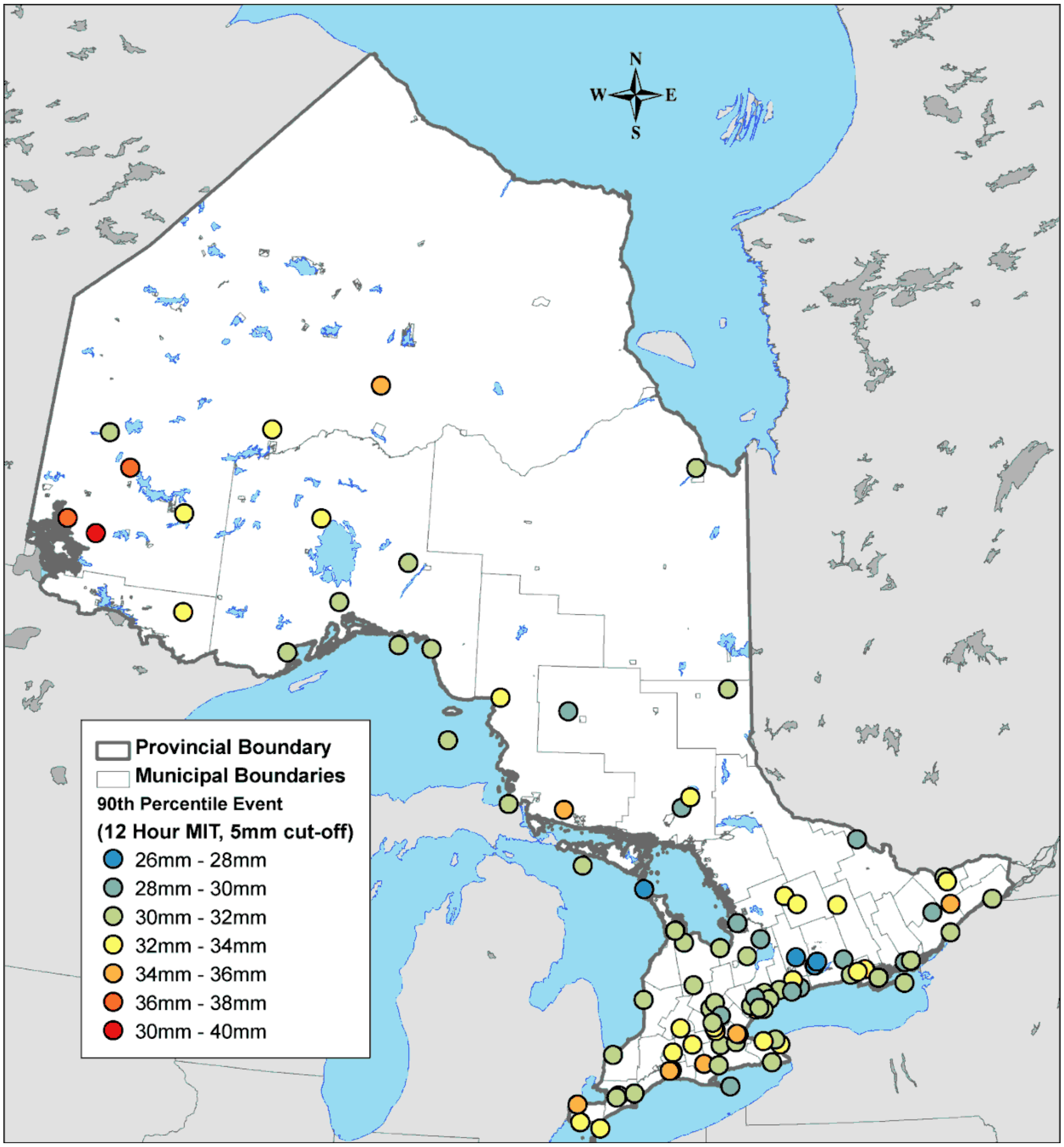


Figure 3.17- 90th percentile rainfall event depths (from hourly record with a Minimum Interevent Time of 12 hours, where event depth exceeds 5 mm).

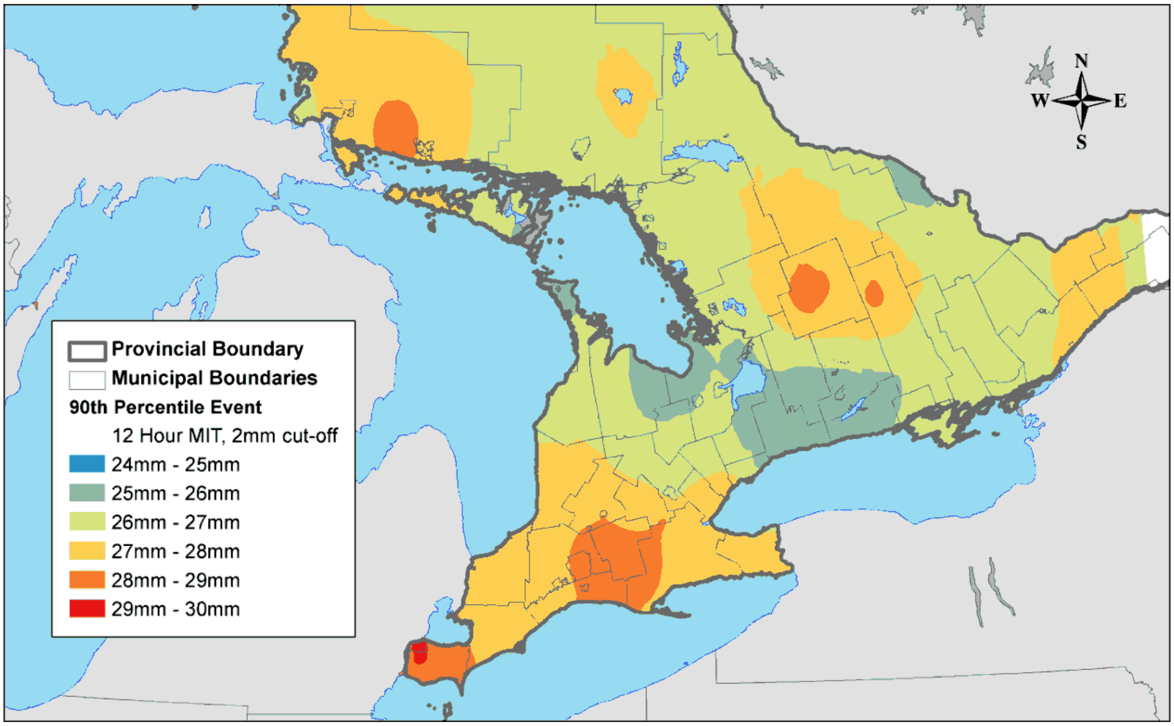


Figure 3.18 - 90th percentile rainfall contours (MIT:12 hr where event depth exceeds 2 mm)

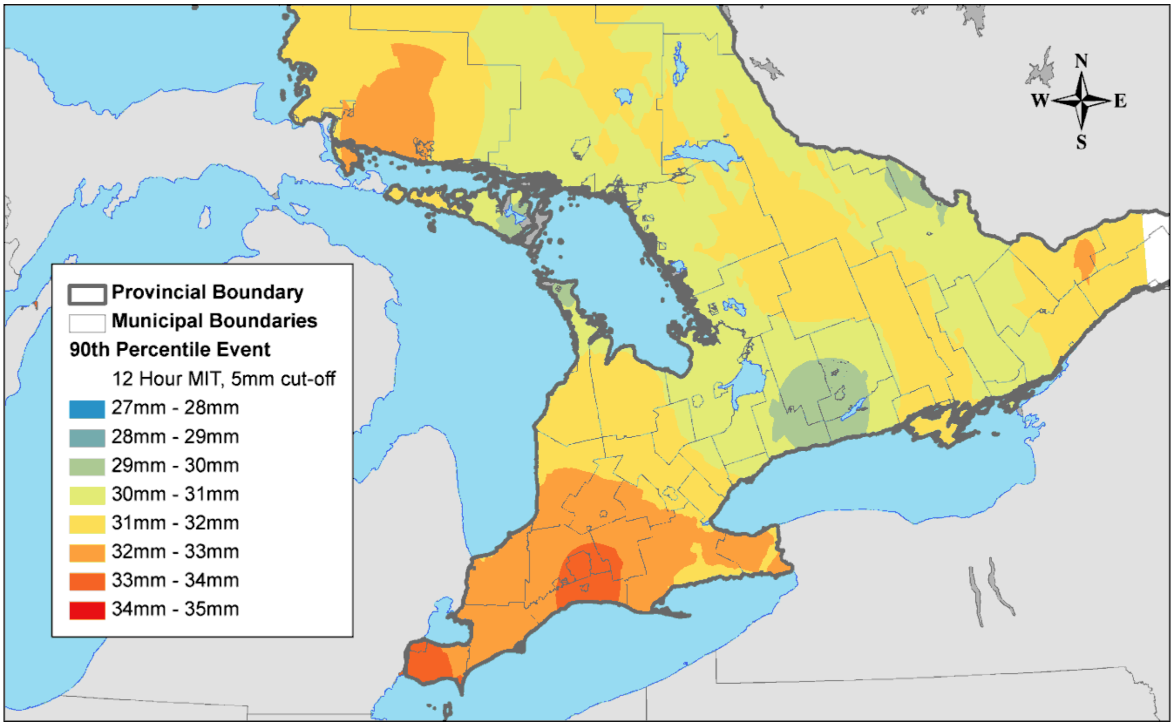


Figure 3.19 - 90th percentile rainfall contours (MIT: 12 hours, where event depth exceeds 5 mm).

3.6.5 Areas of Interest – 2 mm Cut-off

Rainfall event depth frequency curves for several major centers in Ontario are provided below with key rainfall depth percentiles in tabular form (note: additional station plots and percentiles (50th, 75th, 80th, 99th) are available in the digital appendix.) This analysis below ignores rainfall events with volumes than 2 mm.

3.6.5.1 Toronto

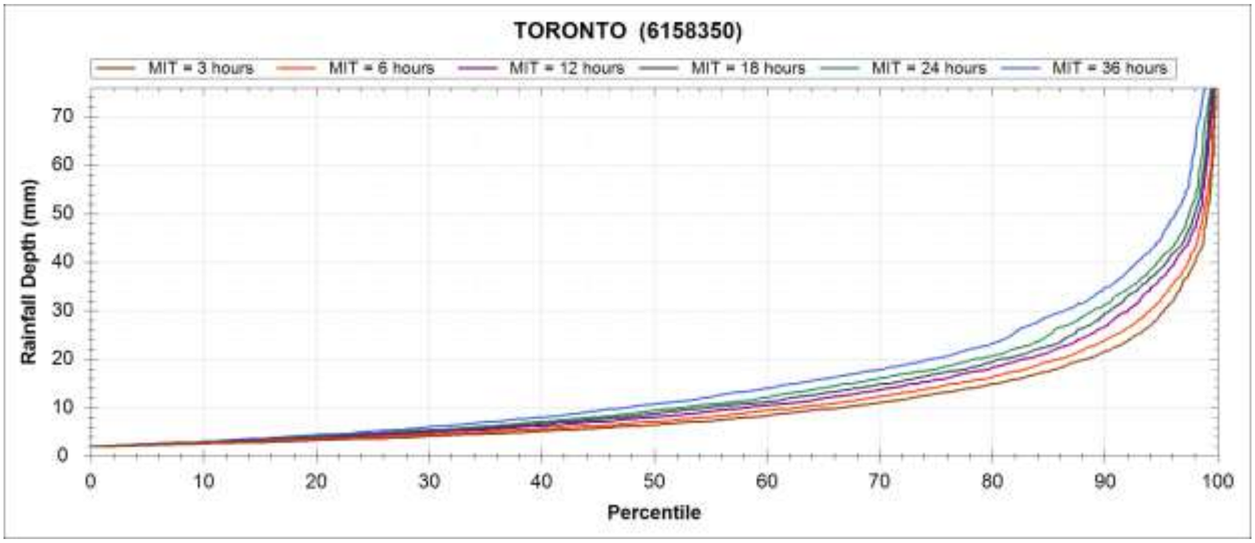


Figure 3.20 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station TORONTO – 2 mm cut-off.

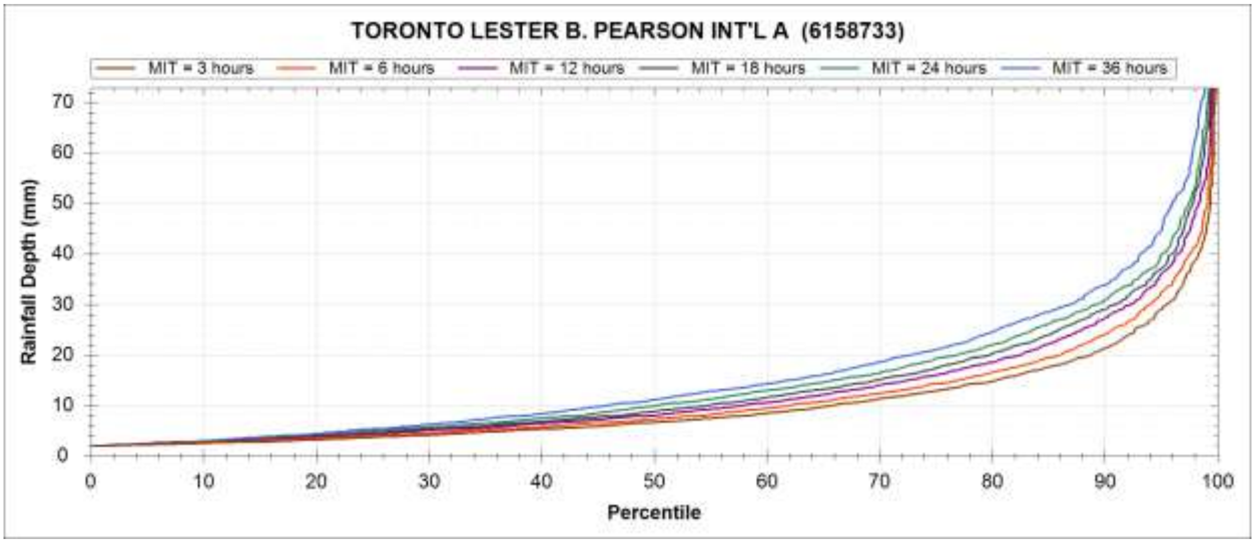


Figure 3.21 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station TORONTO LESTER B. PEARSON INT'L A – 2 mm cut-off.

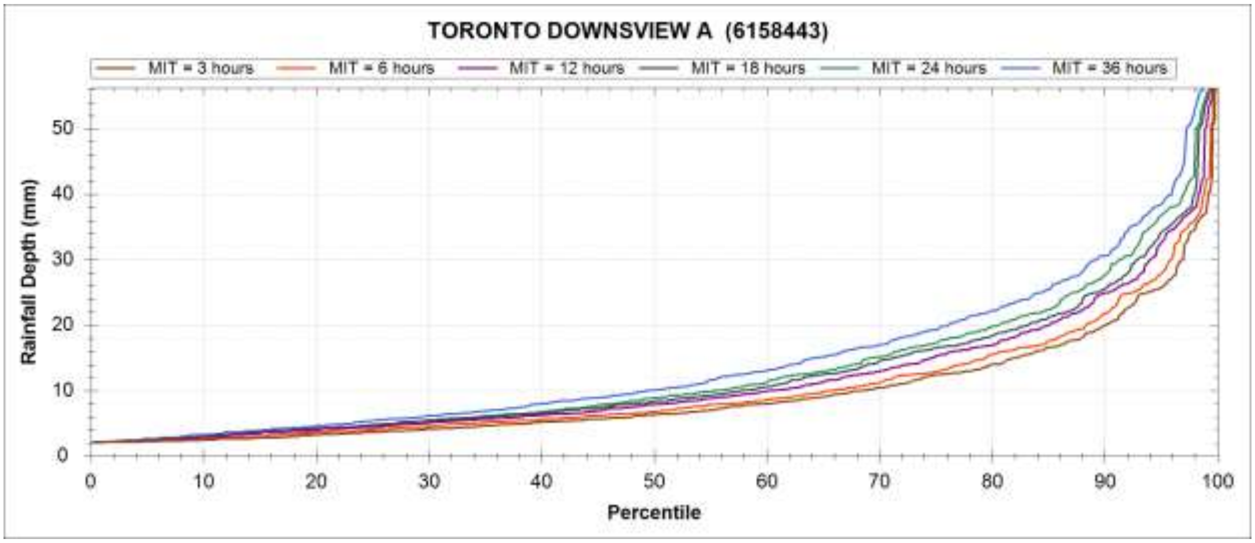


Figure 3.22 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station TORONTO DOWNSVIEW A – 2 mm cut-off.

Table 3.4 - 90th & 95th Percentile event rainfall depths for various MIT derived from hourly climate data collected proximal to the City of Toronto – 2 mm cut-off.

Station Name	Total Number of Years in Analysis	90th Percentile Storm Depth (mm)						95th Percentile Storm Depth (mm)					
		MINIMUM INTEREVENT TIME (HOURS)						MINIMUM INTEREVENT TIME (HOURS)					
		3	*6*	*12*	*18*	*24*	*36*	*3*	*6*	*12*	*18*	*24*	*36*
TORONTO	62	21.4	23.8	26.7	29.3	31	34.5	29.2	32.1	36.6	38.6	40.7	44.6
TORONTO BUTTONVILLE A	22	21.2	24.3	26.2	28.4	30.7	36	26.5	30.6	33.2	36.6	40	44.5
TORONTO DOWNSVIEW A	19	19.9	21.7	24.7	25.5	27.4	30.6	25.6	27.7	32.2	33.9	36.5	38.2
TORONTO ELLESMERE	29	20.9	23.5	25.8	28.5	30.6	35	26.6	31.7	35.5	37	40.1	43.6
TORONTO ETOBICOKE	17	22.4	24.5	29.7	30.7	32.8	35.1	30.5	32.7	38.4	39.4	45.1	45.8
TORONTO ISLAND A	24	20.6	23.2	25.2	28	29.4	33.3	28.5	32	33.3	36.6	39.2	44.2
TORONTO LESTER B. PEARSON INT'L A	54	21.2	24	27.2	28.9	30.7	33.8	29	32.2	35.9	37	39.6	44.3
TORONTO MET RES STN	23	21	23.6	26	28	29.9	34.5	27	29.6	34.1	35.8	39.4	43.7
TORONTO OLD WESTON RD	25	21	24.1	26.8	29	30.8	34.3	30	31.8	35.4	38.5	40.7	44.6
Average	*30.6*	*21.1*	*23.6*	*26.5*	*28.5*	*30.4*	*34.1*	*28.1*	*31.2*	*35.0*	*37.0*	*40.1*	*43.7*
Median	*24.0*	*21.0*	*23.8*	*26.2*	*28.5*	*30.7*	*34.5*	*28.5*	*31.8*	*35.4*	*37.0*	*40.0*	*44.3*

3.6.5.2 Ottawa

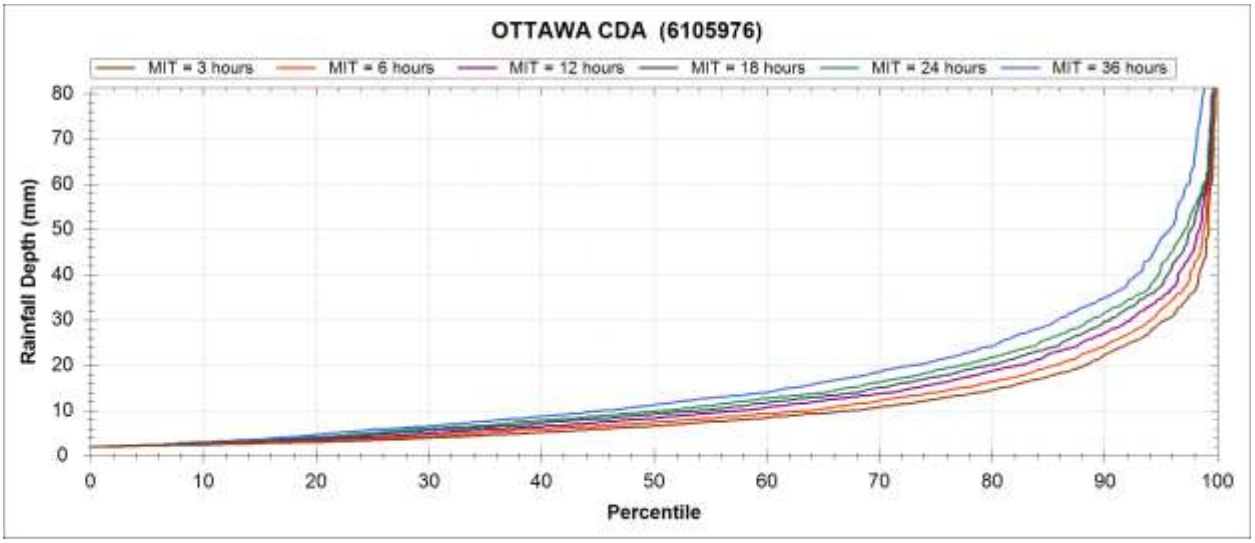


Figure 3.23 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station OTTAWA CDA – 2 mm cut-off.

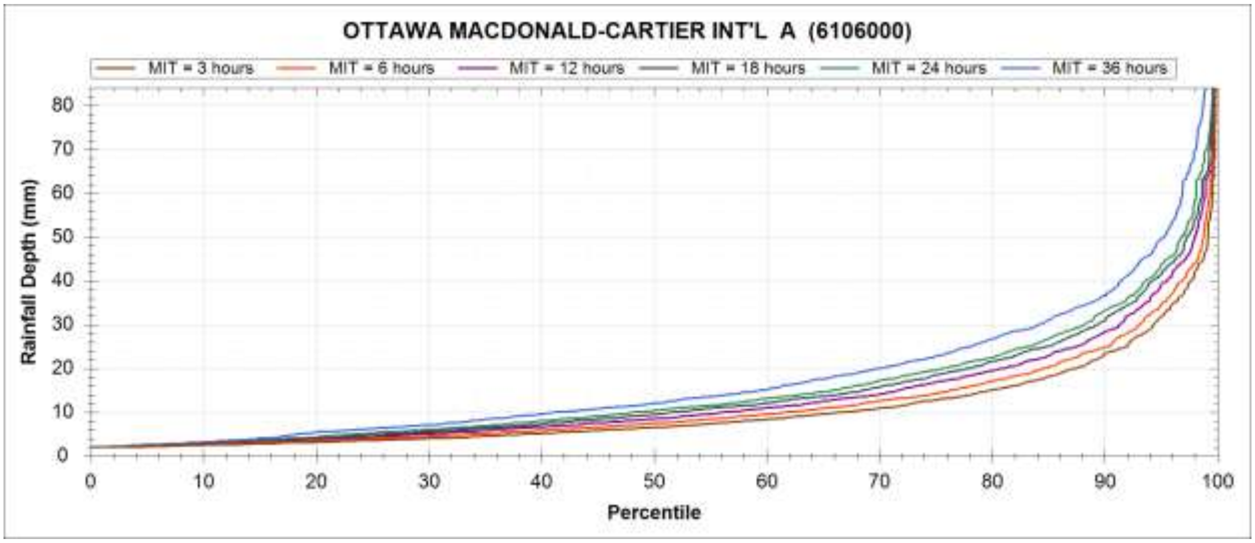


Figure 3.24 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station OTTAWA MACDONALD-CARTIER INT'L A.

Table 3.5 - 90th and 95th Percentile event rainfall depths for various Minimum Interevent Times derived from hourly climate data collected proximal to the City of Ottawa – 2 mm cut-off.

Station Name	Total Number of Years in Analysis	90th Percentile Storm Depth (mm)						95th Percentile Storm Depth (mm)					
		MINIMUM INTEREVENT TIME (HOURS)						MINIMUM INTEREVENT TIME (HOURS)					
		3	*6*	*12*	*18*	*24*	*36*	*3*	*6*	*12*	*18*	*24*	*36*
OTTAWA CDA	42	22.2	24.1	27	29.6	31.5	34.7	29.5	32.2	34.7	37.3	40.5	47.6
OTTAWA MACDONALD-CARTIER INT'L A	39	23.4	24.8	28.3	30.8	33.2	36.6	31.6	34.4	38.5	41.2	42.9	49.6
Average	*40.5*	*22.8*	*24.5*	*27.7*	*30.2*	*32.4*	*35.7*	*30.6*	*33.3*	*36.6*	*39.3*	*41.7*	*48.6*

3.6.5.3 Windsor

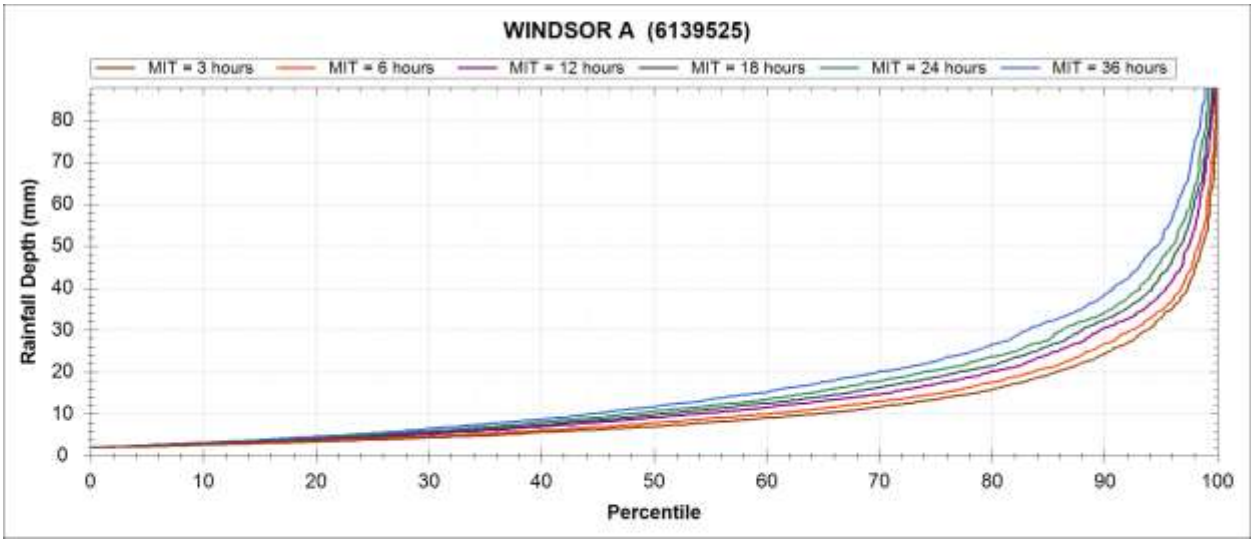


Figure 3.25 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station WINDSOR A – 2 mm cut-off.

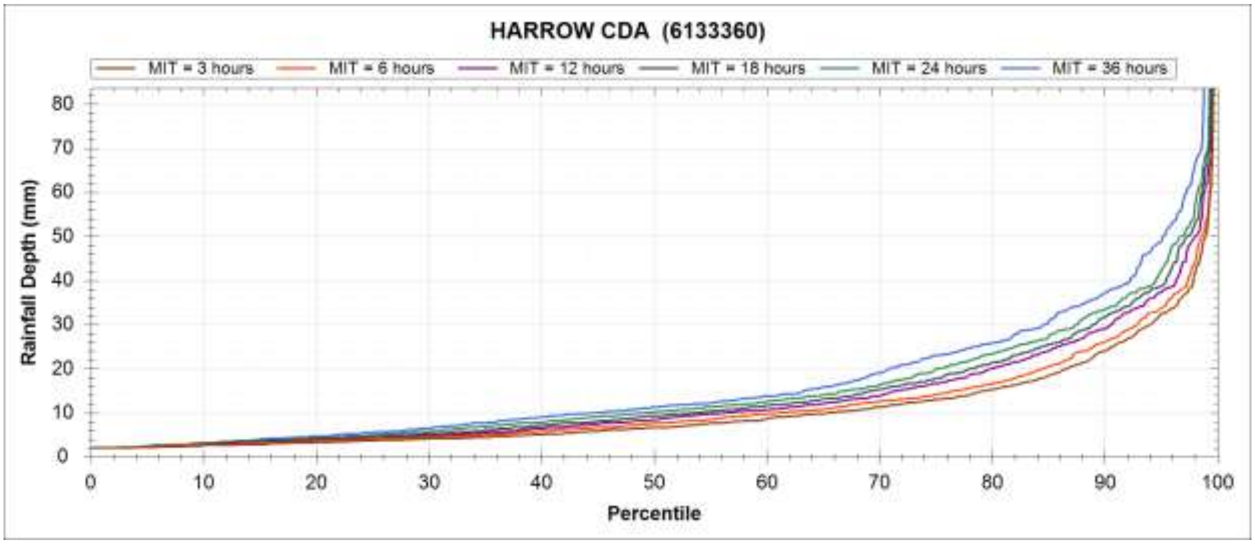


Figure 3.26 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station HARROW CDA – 2 mm cut-off.

Table 3.6 - 90th and 95th Percentile event rainfall depths for various Minimum Interevent Times derived from hourly climate data collected proximal to the City of Windsor – 2 mm cut-off.

Station Name	Total Number of Years in Analysis	90th Percentile Storm Depth (mm)						95th Percentile Storm Depth (mm)					
		Minimum Interevent Time (Hours)						Minimum Interevent Time (Hours)					
		3	*6*	*12*	*18*	*24*	*36*	*3*	*6*	*12*	*18*	*24*	*36*
WINDSOR A	48	24.2	26.7	30.5	32.4	34	38.2	32.6	34.5	38.4	43.1	46	50.9
HARROW CDA	25	23.9	25.9	28.9	31.5	33.4	37	32.3	33.6	37.1	38.6	41.8	48.5
Average	*36.5*	*24.1*	*26.3*	*29.7*	*32.0*	*33.7*	*37.6*	*32.5*	*34.1*	*37.8*	*40.9*	*43.9*	*49.7*

3.6.5.4 Sudbury

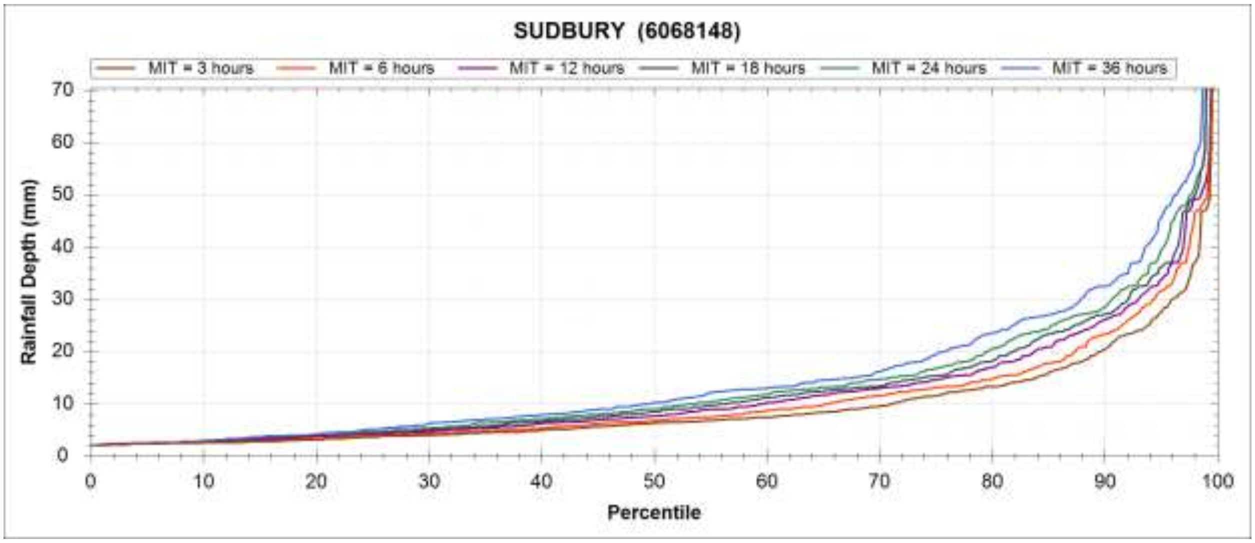


Figure 3.27 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station SUDBURY – 2 mm cut-off.

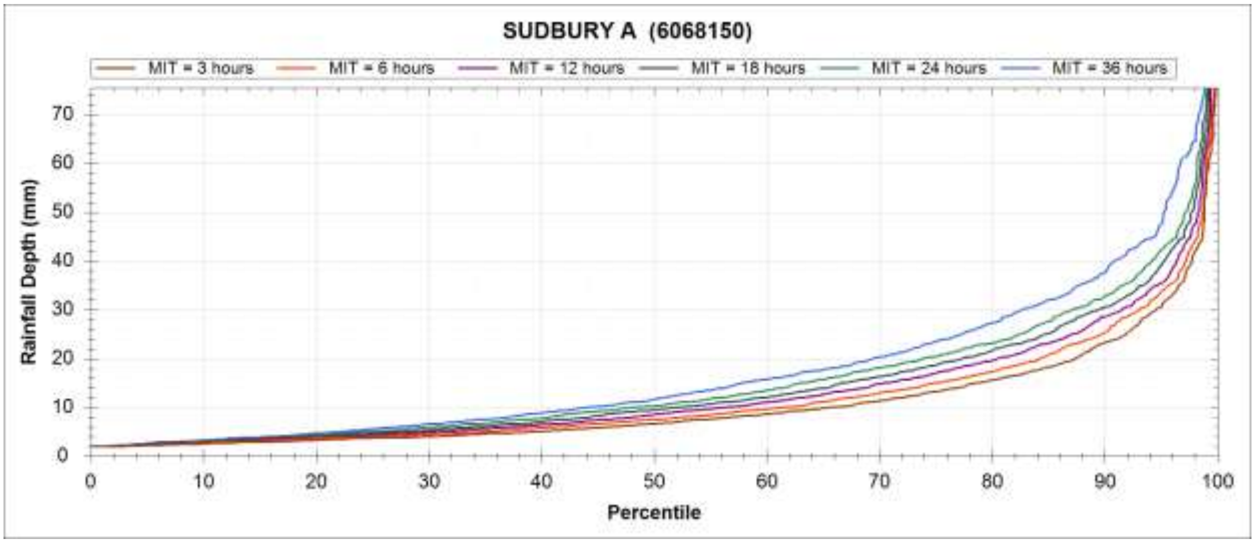


Figure 3.28 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station SUDBURY A – 2 mm cut-off.

Table 3.7 - 90th and 95th Percentile event rainfall depths for various Minimum Interevent Times derived from hourly climate data collected proximal to the City of Sudbury – 2 mm cut-off.

Station Name	Total Number of Years in Analysis	90th Percentile Storm Depth (mm)						95th Percentile Storm Depth (mm)					
		MINIMUM INTEREVENT TIME (HOURS)						MINIMUM INTEREVENT TIME (HOURS)					
		3	*6*	*12*	*18*	*24*	*36*	*3*	*6*	*12*	*18*	*24*	*36*
SUDBURY	16	20.3	23.2	26	27	28.4	32.4	27.4	31.4	33.6	36.1	38.1	45.1
SUDBURY A	36	23.2	25.2	28.5	30.5	32.6	37.6	30.6	33.4	35.3	38.9	42	47.4
Average	*26.0*	*21.8*	*24.2*	*27.3*	*28.8*	*30.5*	*35.0*	*29.0*	*32.4*	*34.5*	*37.5*	*40.1*	*46.3*

3.6.5.5 Thunder Bay

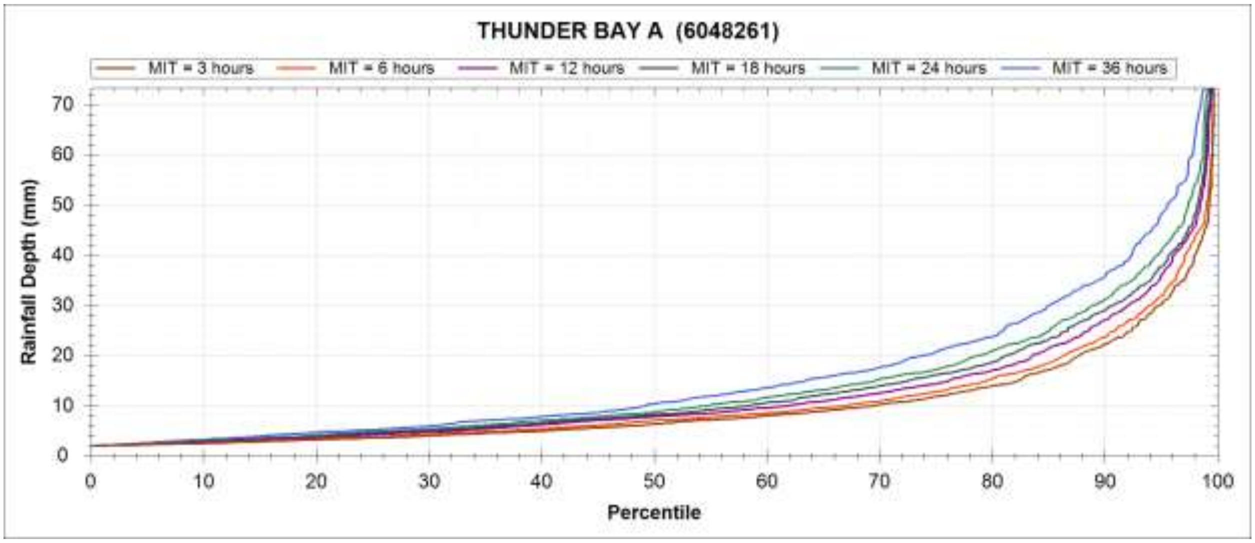


Figure 3.29 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station THUNDER BAY A – 2 mm cut-off.

Table 3.8 - 90th and 95th Percentile event rainfall depths for various Minimum Interevent Times derived from hourly climate data collected proximal to the City of Thunder Bay – 2 mm cut-off.

Station Name	Total Number of Years in Analysis	90th Percentile Storm Depth (mm)						95th Percentile Storm Depth (mm)					
		MINIMUM INTEREVENT TIME (HOURS)						MINIMUM INTEREVENT TIME (HOURS)					
		3	***6***	***12***	***18***	***24***	***36***	***3***	***6***	***12***	***18***	***24***	***36***
THUNDER BAY A	35	22.2	23.7	27	28.9	31.1	35.6	30.2	31.7	35.4	37.8	40.6	47.8

3.6.6 Areas of Interest – 5 mm Cut-off

Rainfall event depth frequency curves for several major centers in Ontario are provided below with key rainfall depth percentiles in tabular form note: additional station plots and percentiles (50th, 75th, 80th, 99th) are available in the digital appendix.) This analysis below ignores rainfall events with volumes than 5 mm.

3.6.6.1 Toronto

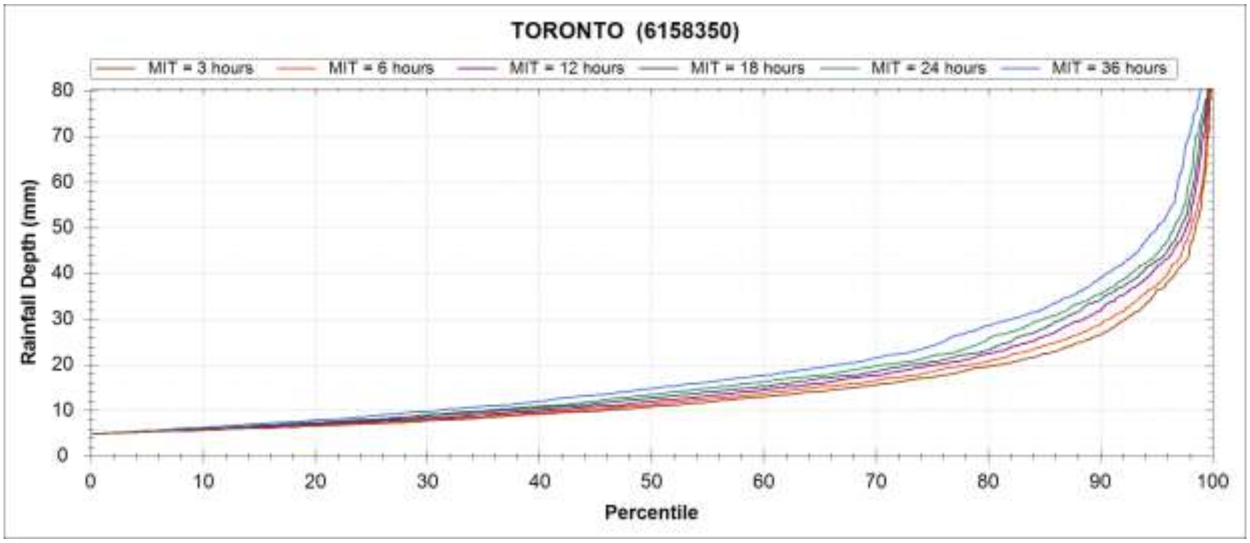


Figure 3.30 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station TORONTO – 5 mm cut-off.

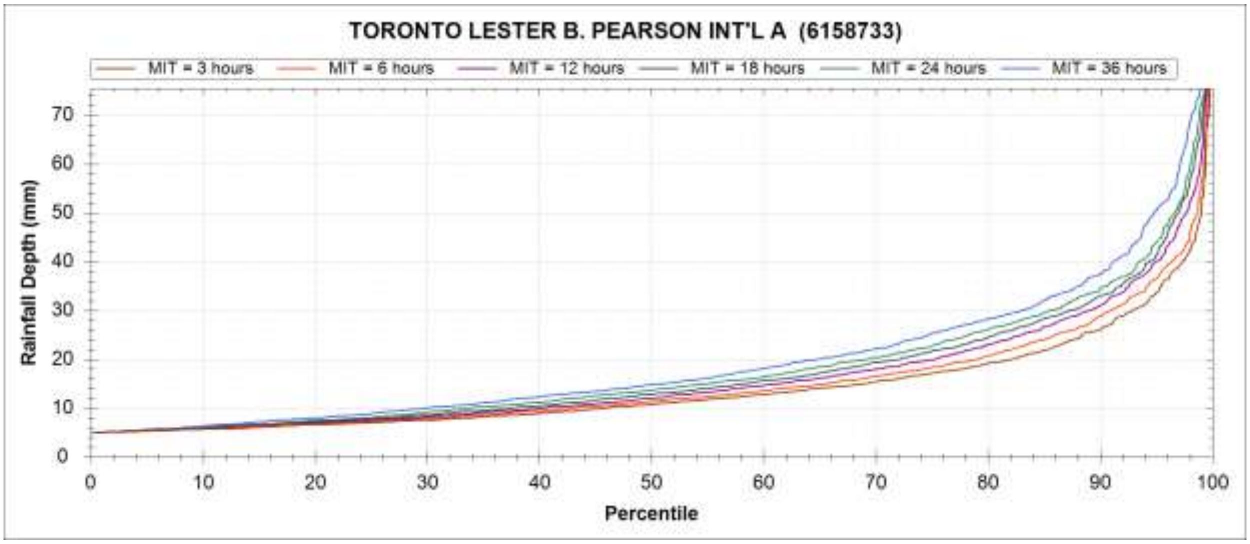


Figure 3.31 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station TORONTO LESTER B. PEARSON INT'L A – 5 mm cut-off.

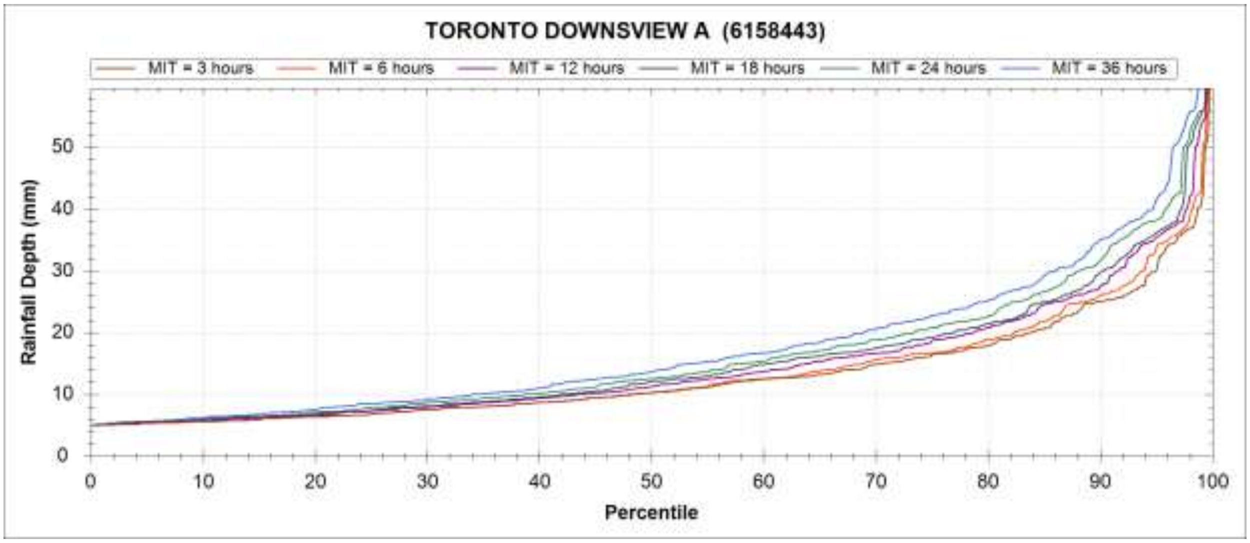


Figure 3.32 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station TORONTO DOWNSVIEW A – 5 mm cut-off.

Table 3.9 - 90th and 95th Percentile event rainfall depths for various Minimum Interevent Times derived from hourly climate data collected proximal to the City of Toronto – 5 mm cut-off.

Station Name	Total Number of Years in Analysis	90th Percentile Storm Depth (mm)						95th Percentile Storm Depth (mm)					
		Minimum Interevent Time (Hours)						Minimum Interevent Time (Hours)					
		3	*6*	*12*	*18*	*24*	*36*	*3*	*6*	*12*	*18*	*24*	*36*
TORONTO	62	26.5	28.8	31.8	34.1	35.5	39	35.7	37.1	41.2	42.7	44	49.2
TORONTO BUTTONVILLE A	22	25	27.7	30.7	32.8	34.2	40	32.8	35	36.7	41.5	42.9	51
TORONTO DOWNSVIEW A	19	25	25.6	26.9	29.3	31.1	34.9	29.8	32.9	35.3	35.8	38	39.8
TORONTO ELLESMERE	29	25	28.5	31.1	33.6	34.4	38.8	32.5	35	40	40.7	42.5	46.4
TORONTO ETOBICOKE	17	27.8	30.2	33.8	34.4	37.8	38.6	36.3	37.1	44.4	45.5	46.9	48.3
TORONTO ISLAND A	24	25.8	28.2	30.1	32.4	34.4	38.1	34.6	35.1	40.8	42.6	44.2	46.5
TORONTO LESTER B. PEARSON INT'L A	54	26.1	28.9	30.9	33	34.2	37.4	33.5	36.4	39.9	41.2	43.9	50.5
TORONTO MET RES STN	23	25.9	27	29.8	31.9	34.1	38.6	34	35.2	38.8	40.3	42.9	46.4
TORONTO OLD WESTON RD	25	27	29.8	31.2	32.6	34.4	38.5	35.2	37.3	40.3	43.3	44.4	48.9
Average	30.6	26.0	28.3	30.7	32.7	34.5	38.2	33.8	35.7	39.7	41.5	43.3	47.4
Median	27.1	26.0	28.2	30.6	32.5	34.3	38.1	33.6	35.5	39.5	41.4	43.2	47.2

3.6.6.2 Ottawa

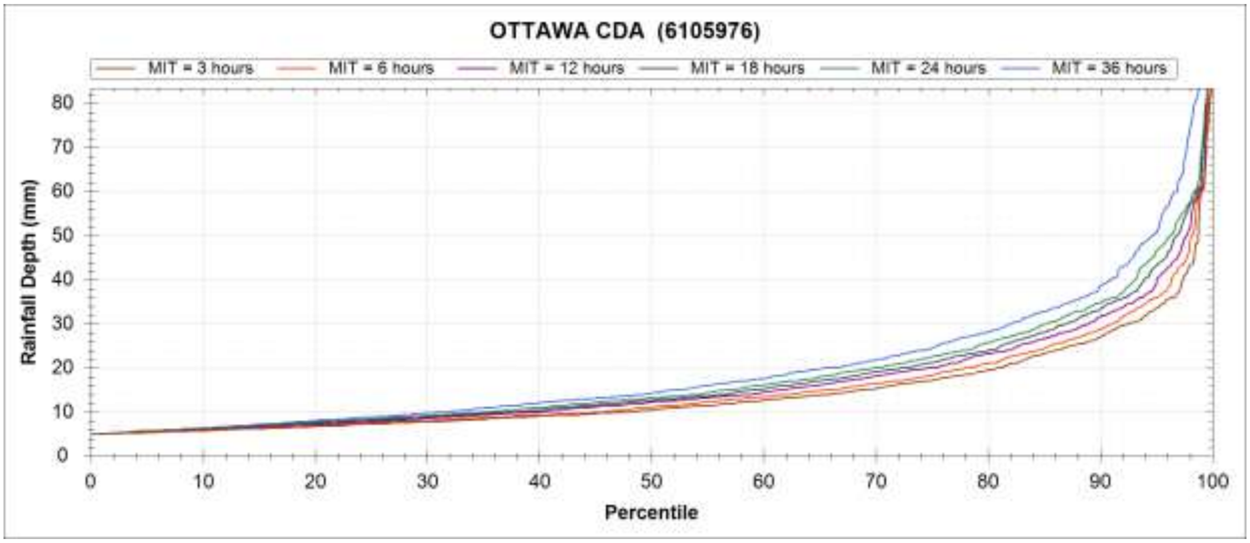


Figure 3.33 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station OTTAWA CDA – 5 mm cut-off.

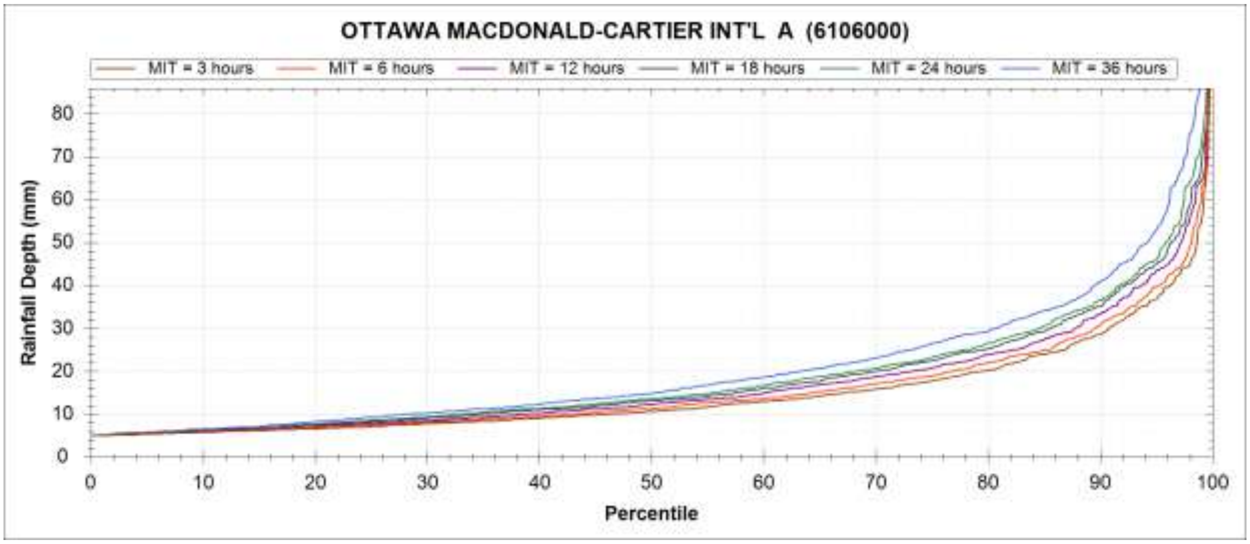


Figure 3.34 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station OTTAWA MACDONALD-CARTIER INT'L A.

Table 3.10 - 90th and 95th Percentile event rainfall depths for various MIT derived from hourly climate data collected proximal to the City of Ottawa – 5 mm cut-off.

Station Name	**Total Number of Years in Analysis**	**90th Percentile Storm Depth (mm)**						**95th Percentile Storm Depth (mm)**					
		Minimum Interevent Time (Hours)						**Minimum Interevent Time (Hours)**					
		3	***6***	***12***	***18***	***24***	***36***	***3***	***6***	***12***	***18***	***24***	***36***
OTTAWA CDA	42	26.9	28.6	31.5	33.3	34.7	38.2	33.5	35.8	38.6	42.9	46.2	50.6
OTTAWA MACDONALD-CARTIER INT'L A	39	28.6	30.6	33.3	35.1	36.6	40.8	36.8	39.6	42.9	44.8	45.8	52.6
Average	40.5	27.8	29.6	32.4	34.2	35.7	39.5	35.2	37.7	40.8	43.9	46	51.6

3.6.6.3 Windsor

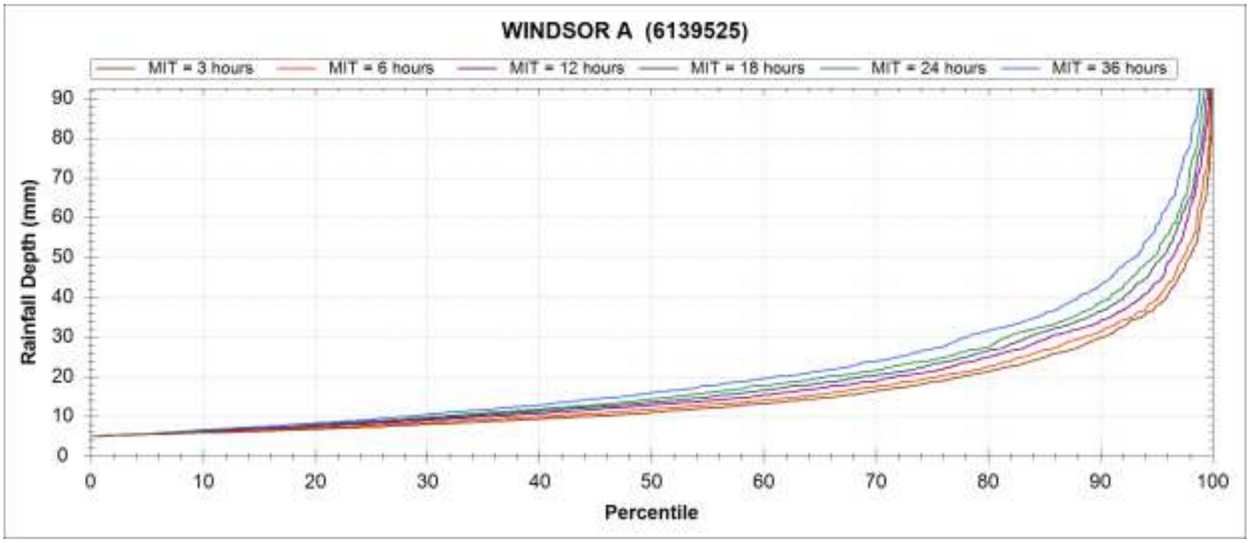


Figure 3.35 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station WINDSOR A – 5 mm cut-off.

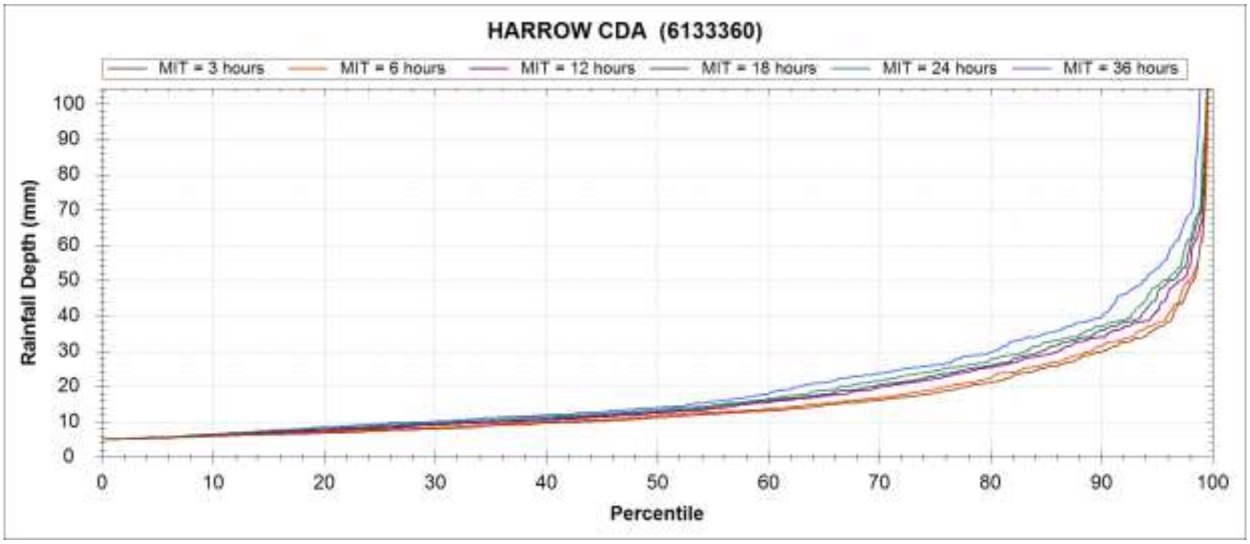


Figure 3.36 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station HARROW CDA – 5 mm cut-off.

Table 3.11 - 90th and 95th Percentile event rainfall depths for various Minimum Interevent Times derived from hourly climate data collected proximal to the City of Windsor – 5 mm cut-off.

Station Name	**Total Number of Years in Analysis**	**90th Percentile Storm Depth (mm)**						**95th Percentile Storm Depth (mm)**					
		Minimum Interevent Time (Hours)						**Minimum Interevent Time (Hours)**					
		3	***6***	***12***	***18***	***24***	***36***	***3***	***6***	***12***	***18***	***24***	***36***
WINDSOR A	48	29.7	31.2	34.1	36.4	38.5	42.8	37.6	39.1	43.6	48.6	50.5	57.2
HARROW CDA	25	29.8	31.3	34	35.6	37.1	39.4	36.2	37.6	40.8	44.3	48.2	52.6
Average	36.5	29.8	31.3	34.1	36.0	37.8	41.1	36.9	38.4	42.2	46.5	49.4	54.9

3.6.6.4 Sudbury

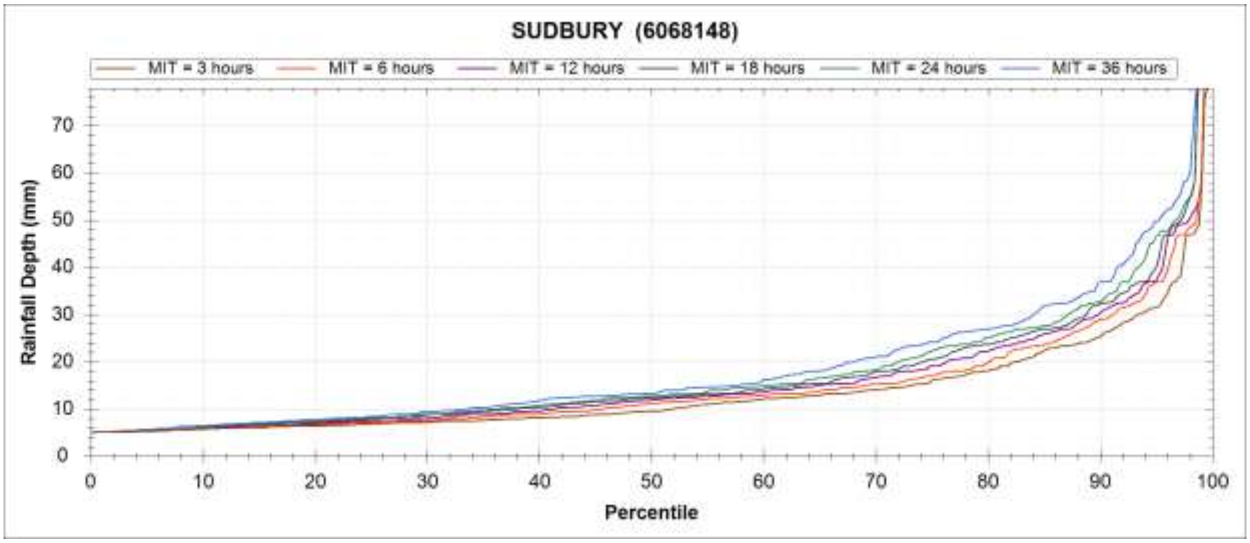


Figure 3.37 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station SUDBURY – 5 mm cut-off.

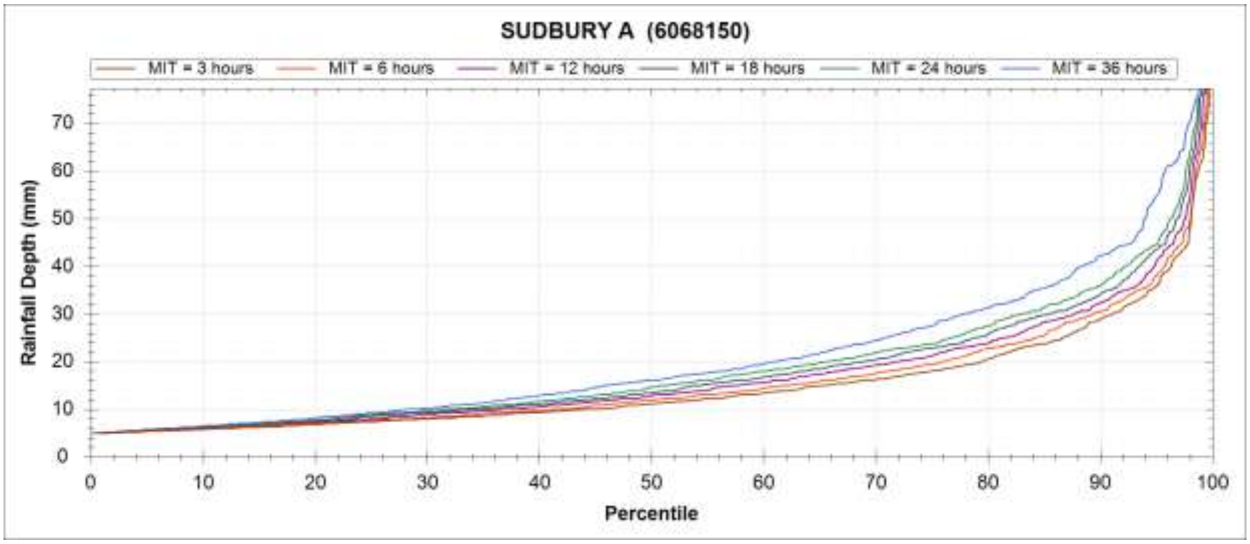


Figure 3.38 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station SUDBURY A – 5 mm cut-off.

Table 3.12 - 90th and 95th Percentile event rainfall depths for various MIT derived from hourly climate data collected proximal to the City of Sudbury – 5 mm cut-off.

Station Name	**Total Number of Years in Analysis**	**90th Percentile Storm Depth (mm)**						**95th Percentile Storm Depth (mm)**					
		Minimum Interevent Time (Hours)						**Minimum Interevent Time (Hours)**					
		3	***6***	***12***	***18***	***24***	***36***	***3***	***6***	***12***	***18***	***24***	***36***
SUDBURY	16	25.1	28.4	29.9	32.1	32.5	36.7	31.4	36.7	37	39.4	45.1	48.5
SUDBURY A	36	28.9	30.4	32.3	34	35.8	42.1	35.6	38	40.5	43.5	44.5	54.2
Average	26.0	27.0	29.4	31.1	33.1	34.2	39.4	33.5	37.4	38.8	41.5	44.8	51.4

3.6.6.5 Thunder Bay

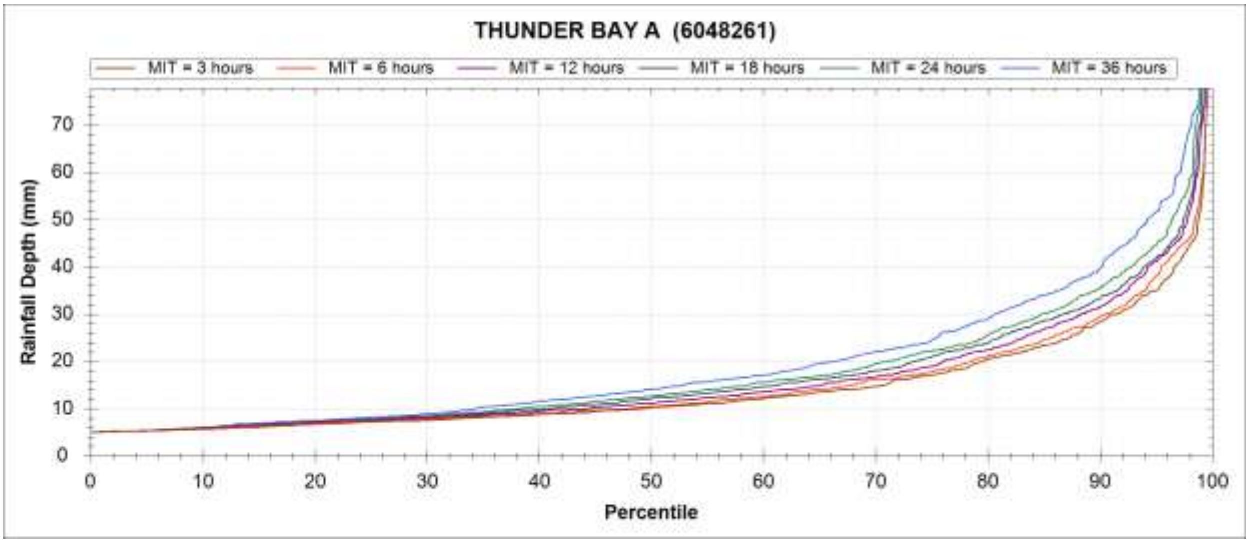


Figure 3.39 - Rainfall event depth frequency curves derived from hourly rainfall data for various Minimum Interevent Times at ECCC climate station THUNDER BAY A – 5 mm cut-off.

Table 3.13 90th and 95th Percentile event rainfall depths for various Minimum Interevent Times derived from hourly climate data collected proximal to the City of Thunder Bay – 5 mm cut-off.

Station Name	Total Number of Years in Analysis	90th Percentile Storm Depth (mm)						95th Percentile Storm Depth (mm)					
		Minimum Interevent Time (Hours)						**Minimum Interevent Time (Hours)**					
		3	***6***	***12***	***18***	***24***	***36***	***3***	***6***	***12***	***18***	***24***	***36***
THUNDER BAY A	35	28.3	29.2	31.2	33.1	35.2	39.3	34.9	38	41.1	41.7	44.6	51.3

3.7 Daily Rainfall Analysis

Daily climate data were obtained for each climate station in Ontario for the period 1840 through 2015. This data is publicly available through http://climate.weather.gc.ca/. No single database is available; this data was sequentially scraped for each station-month with an automated program. These data are also available through the US National Climatic Data Center (www.gis.ncdc.noaa.gov) maintained by the National Oceanic and Atmospheric Administration. The site features an interactive map and offers search and mapping tools for sites in Ontario that are unavailable through websites operation by Canadian Ministries.

Precipitation type (or form) is not available at every station, some stations report total daily precipitation volume while others report both rainfall and snowfall volumes, or in some cases just the total daily rainfall volume. Form is typically not reported at automated weighing-type gauges, while frequently only rainfall is reported at stations instrumented with tipping buckets. **Figure 3.40** presents the available daily precipitation record at TORONTO ISLAND A where total precipitation, rainfall, and snowfall is reported for differing periods.

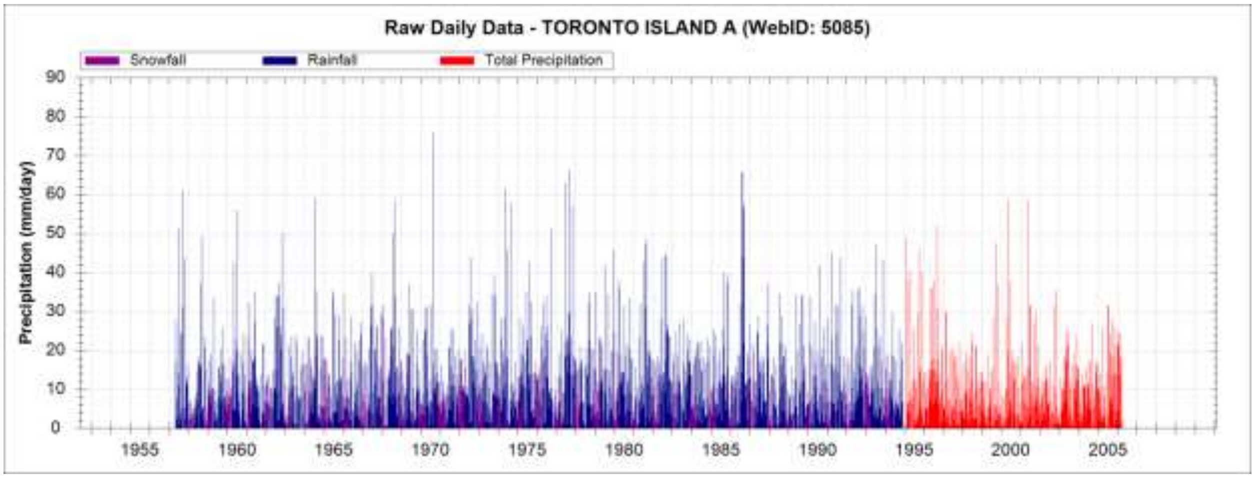


Figure 3.40 - Raw daily data obtained for ECCC Climate station TORONTO ISLAND A.

3.7.1 Selecting the Analysis Stations

There are 1,464 active and historical climate stations within the daily dataset in Ontario with substantial precipitation data. The period of record of the daily climate dataset is many decades longer than the hourly dataset. Given the large numbers of stations, many with 50 or 100 years of record, a consistent analysis period is required. As this analysis should reflect current climate conditions as best as possible, a start date of Jan 1st, 1970 was selected. Earlier dates were considered; however, the period between 1955 and 1969 saw several significant droughts in the Province. Given that the overall number and apparent quality of active stations maintained by ECCC has decreased in the past decade, an end date of Dec 31st, 2005 was selected. This leaves a 36-year period within which the analysis can be conducted.

Monthly precipitation averages were calculated at each station following the WMO standard "3 and 5" rule which excludes months with more than 3 consecutive days of missing data or more than 5 days total with missing data (WMO, 1989). Annual average precipitation was calculated at stations with at least 30 years of complete precipitation record as determined with the "3 and 5". **Figure 3.41** presents the average annual precipitation in southern Ontario as derived from the daily precipitation record between 1970 and 2005 inclusive. As only 84 stations passed the 30-year criteria, mostly near in urban areas, the contouring is only applicable to southern Ontario.

For each station, a processed rainfall hyetograph was created spanning the period 1970 through 2005. The record was filtered to remove snow and mixed events. At stations where only total precipitation is reported, the daily maximum temperature was used to estimate type. During days where the maximum temperature was above 2°C, precipitation was assumed to fall entirely as rain. Where total precipitation was reported without temperature, daily events between November 1st and March 31st were excluded.

Figure 3.42 presents the processed daily rainfall hyetograph for ECCC climate station TORONTO ISLAND A.

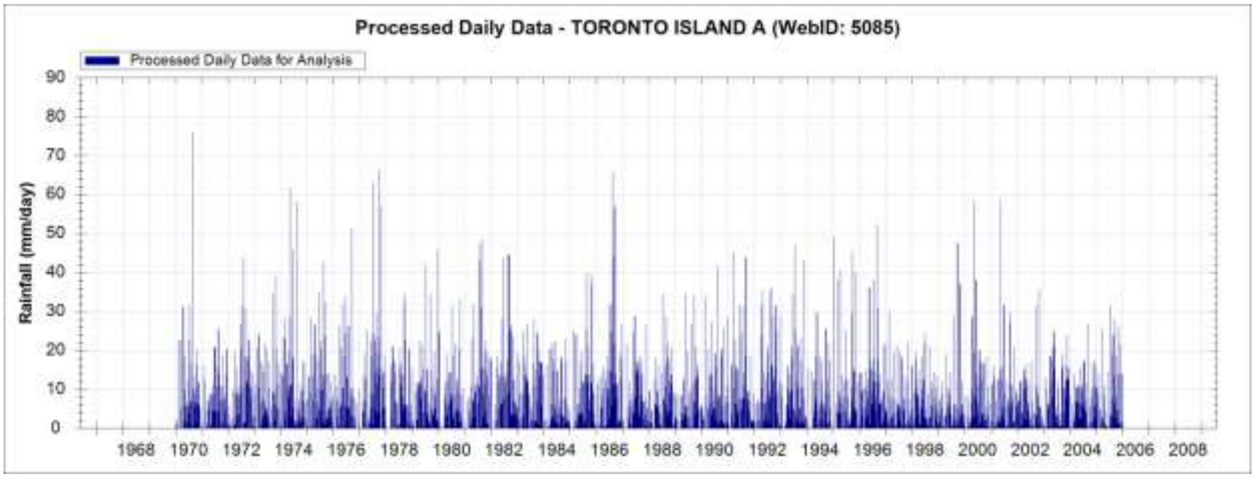


Figure 3.42 - Processed daily rainfall hyetograph for ECCC climate station TORONTO ISLAND A.

Stations were again evaluated with the WMO "3 and 5" rule. Only stations with at least 20-years with complete data between the months of April and October were selected. This represents stricter criteria than the preceding hourly analysis, but is warranted considering the increased station density. Again, years with partial record were included within the analysis, the monthly "3 and 5" rule only served to guide station selection. **Figure 3.43** presents the 233 daily stations which meet the selection criteria.

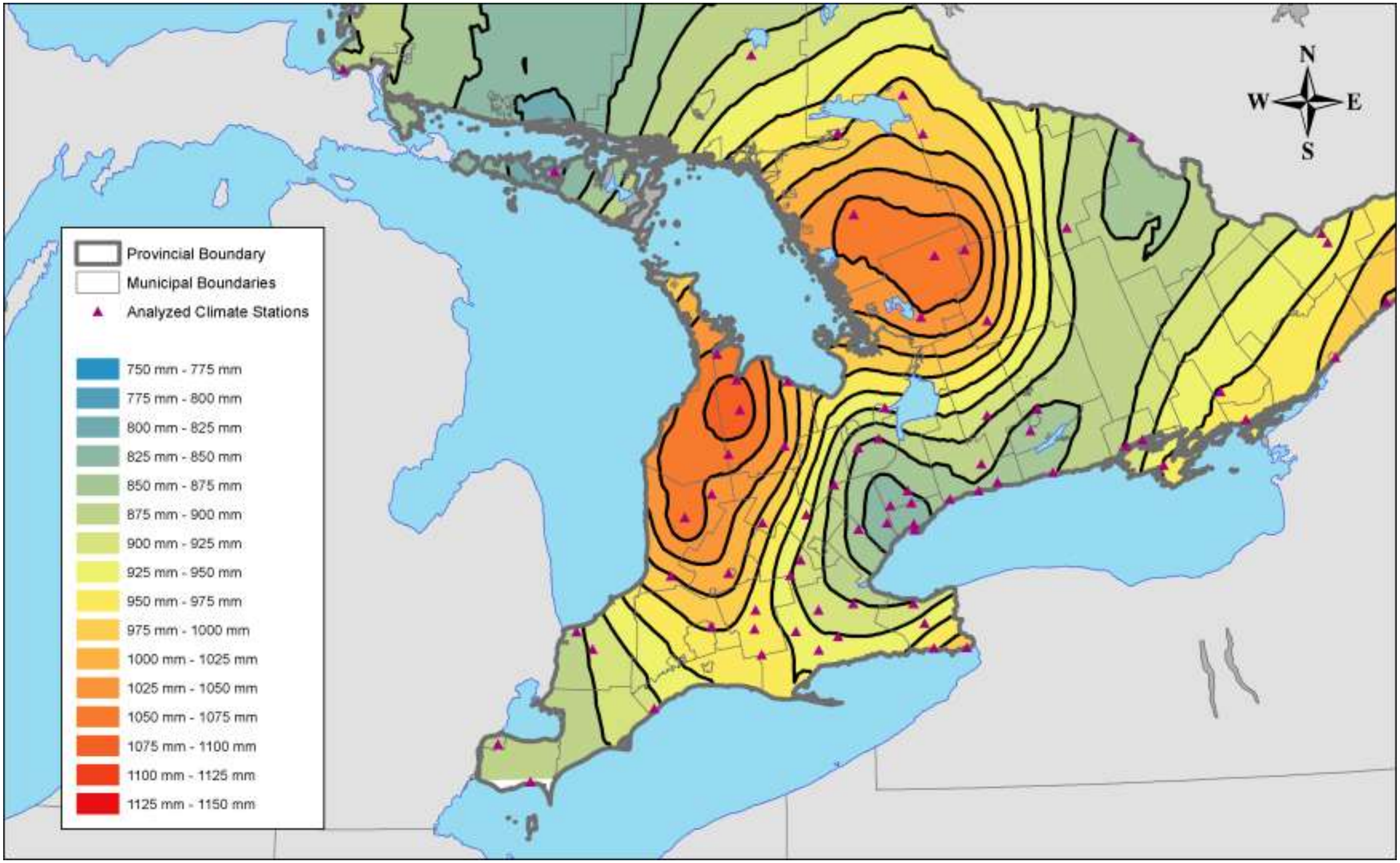


Figure 3.41 - Average annual precipitation in southern Ontario (1970-2005).

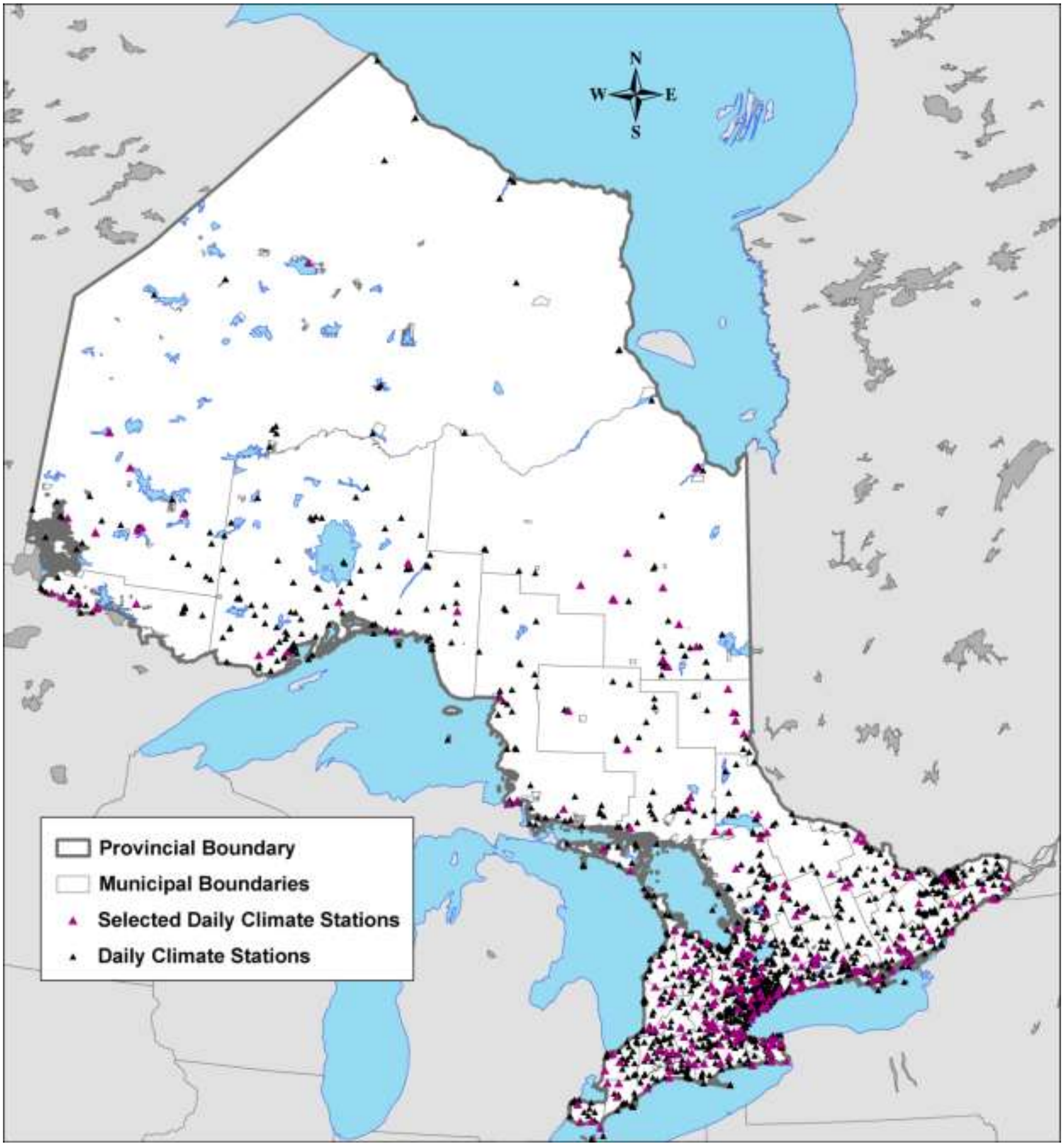


Figure 3.43 - Daily ECCC climate stations selected for inclusion in the volume treatment target analysis.

3.7.2 Regional Results

Daily rainfall volume percentiles (50th, 75th, 80th, 90th, 95th, 99th) were calculated at each station with both a 2 mm and 5 mm lower daily volume cut-off threshold. Two observation series were considered: 1) a daily series which includes all days with observed rainfall, and 2) a daily series which only included rainfall events between April 1st and October 31st of a given year. This was undertaken to determine if winter rain events were significantly altering overall rainfall statistics. Summary statistics for the percentiles calculated province-wide are provided on **Table 3.14**. Sample regional mapping is presented within this section, while daily frequency plots and tabulated percentiles for key Ontario cities are included in the following section.

Table 3.14 - Summary of daily rainfall volumes calculated at Ontario ECCC climate stations.

	Annual Average Precipitation (mm)*	*Number of Years of Complete data in Analysis*	*90th Percentile Daily Volume (mm)*				*95th Percentile Daily Volume (mm)*			
			All Rainfall Events		*Apr. 1st - Oct. 31st*		*All Rainfall Events*		*Apr. 1st - Oct. 31st*	
			2 mm Cut-off	*5 mm Cut-off*	*2 mm Cut-off*	*5 mm Cut-off*	*2 mm Cut-off*	*5 mm Cut-off*	*2 mm Cut-off*	*5 mm Cut-off*
Minimum	654	20	16.8	21.6	17.3	21.8	22.4	25.0	23.0	25.5
Median	908	28	20.6	25.0	21.4	25.6	27.0	31.4	28.0	32.5
Average	919	28	20.7	25.0	21.4	25.7	27.1	31.5	28.0	32.7
Maximum	1183	36	24.3	31.4	24.6	32.0	33.0	40.4	33.2	40.8

Figure 3.44 and **Figure 3.45** illustrate the 90th percentile daily volumes for the 2 mm and 5 mm lower cut-off threshold respectively. These plots consider the entire annual rainfall series. **Figure 3.46** and **Figure 3.47** present the 90th percentiles as above but consider only days with rainfall between April 1st and October 31st. Local interstation variability is improved over the hourly analysis and clearer regional patterns can be observed. The 90th percentile daily volumes appear to vary only by a few millimeters across southern Ontario, suggesting that consistent regional volume targets could be generated with the daily climate data. The 95th percentile daily volumes are presented on **Figure 3.48** and **Figure 3.49** illustrate for the 2 mm and 5 mm lower cut-off threshold respectively

Contours were generated by ordinary Kriging for the 90th percentile daily rainfall volumes considering the truncated observation series (April 1st and October 31st) with a 2 mm (**Figure 3.50**) and 5 mm (**Figure 3.51**) cut-off threshold. A better fit is obtained than with hourly derived event percentiles, as the station density is increased and the variability between local stations is reduced. Contours for the 95th percentile events are presented on **Figure 3.52** and **Figure 3.53**. A thorough examination of the semivariograms employed in the generation of the contours should be conducted prior to inclusion the final guidelines. Other interpolation methods, such as nearest neighbor or inverse distance squared may be appropriate in some regions.

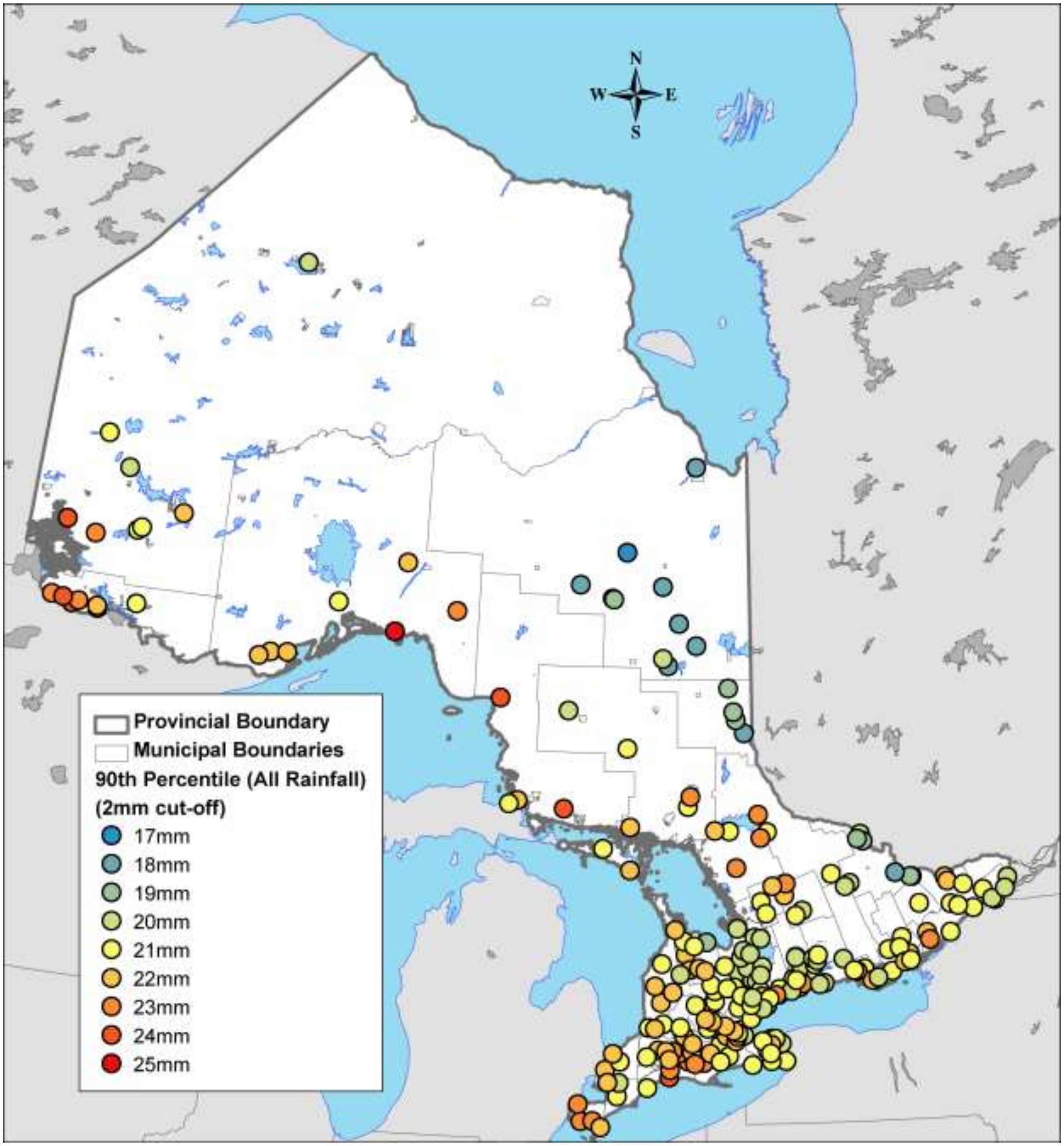


Figure 3.44 - 90th percentile daily rainfall volumes (all days where rainfall exceeds 2 mm).

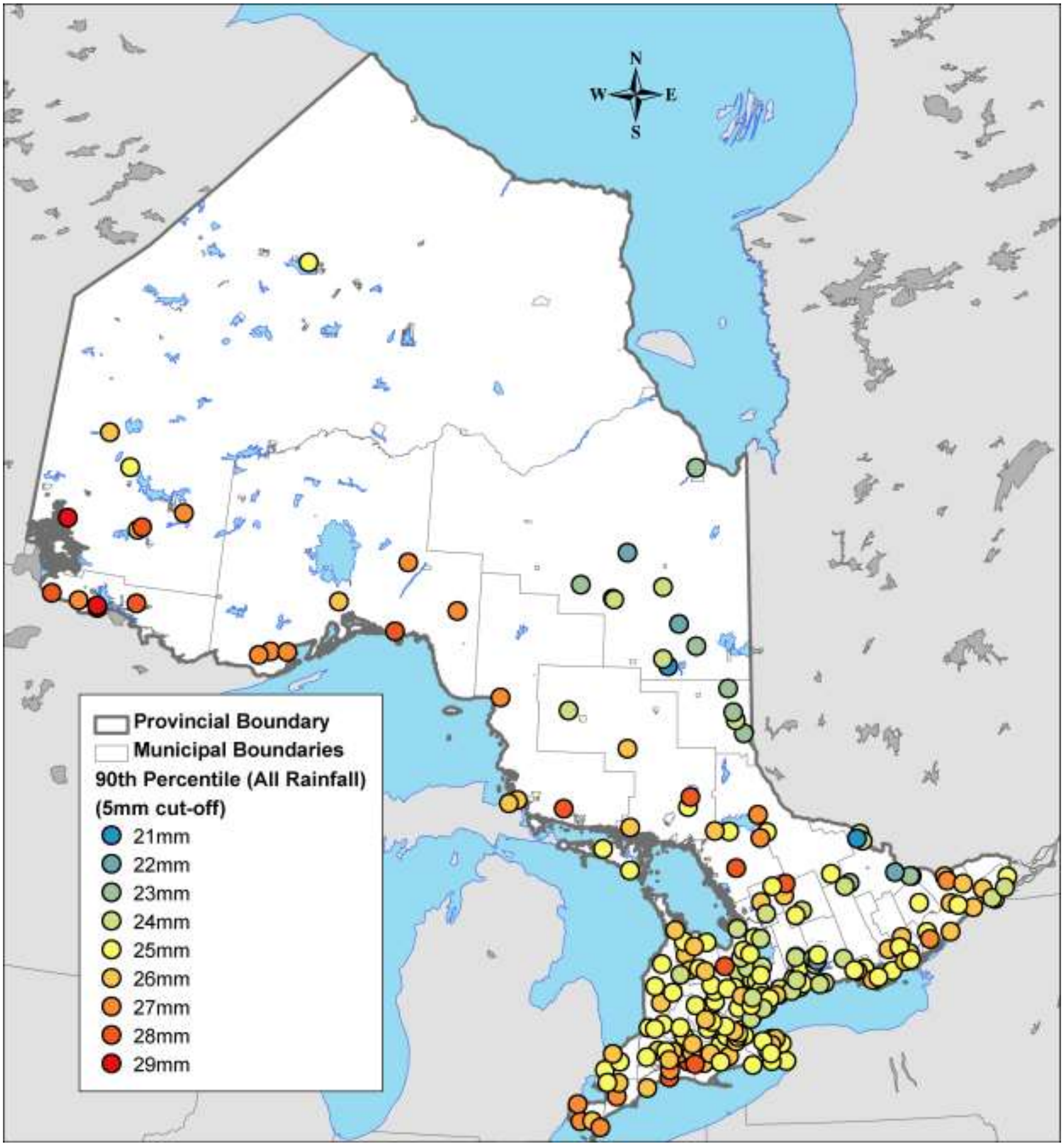


Figure 3.45 - 90th percentile daily rainfall volumes (all days where rainfall exceeds 5 mm).

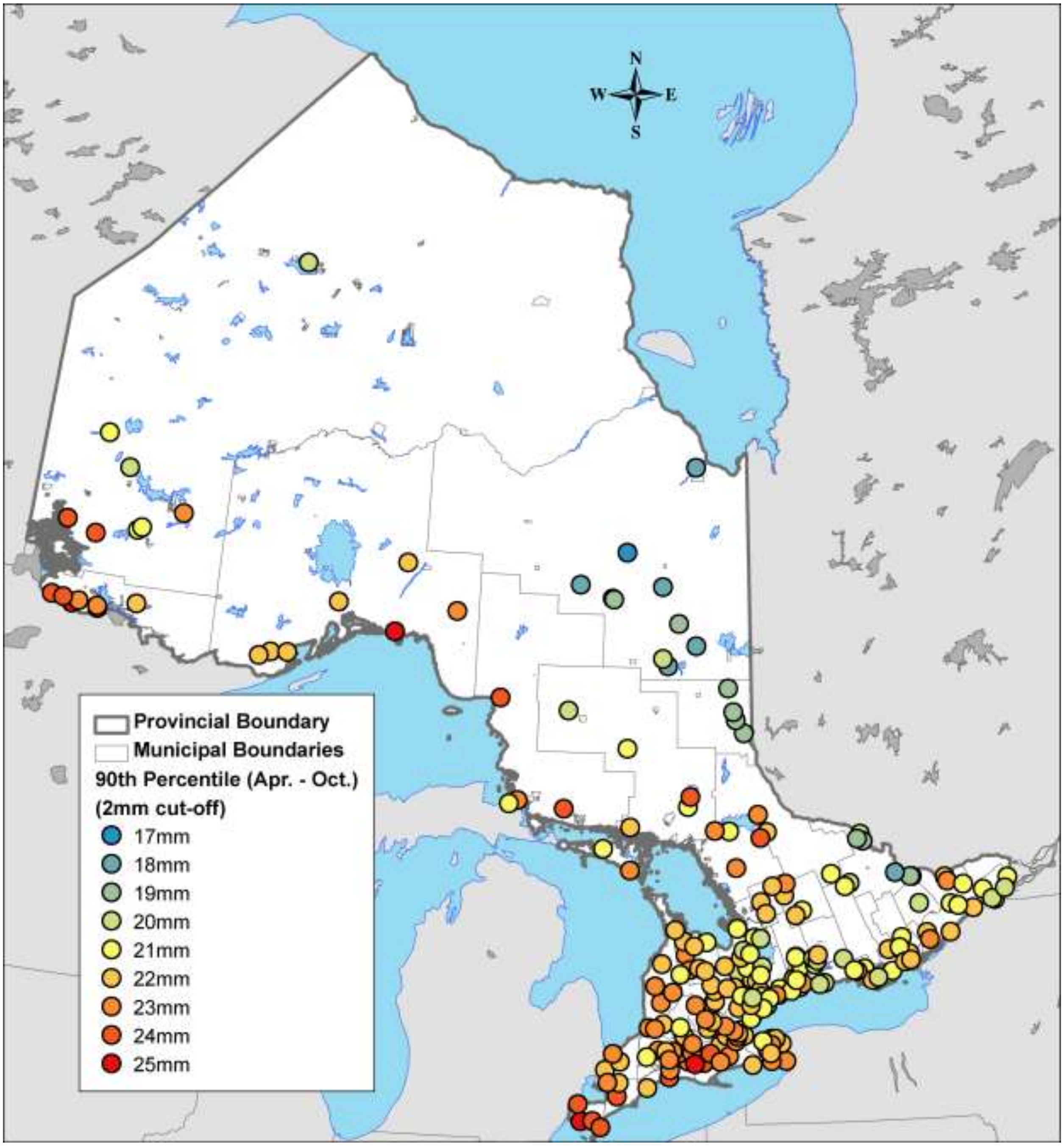


Figure 3.46 - 90th percentile daily rainfall volumes (April through October, where rainfall exceeds 2 mm).

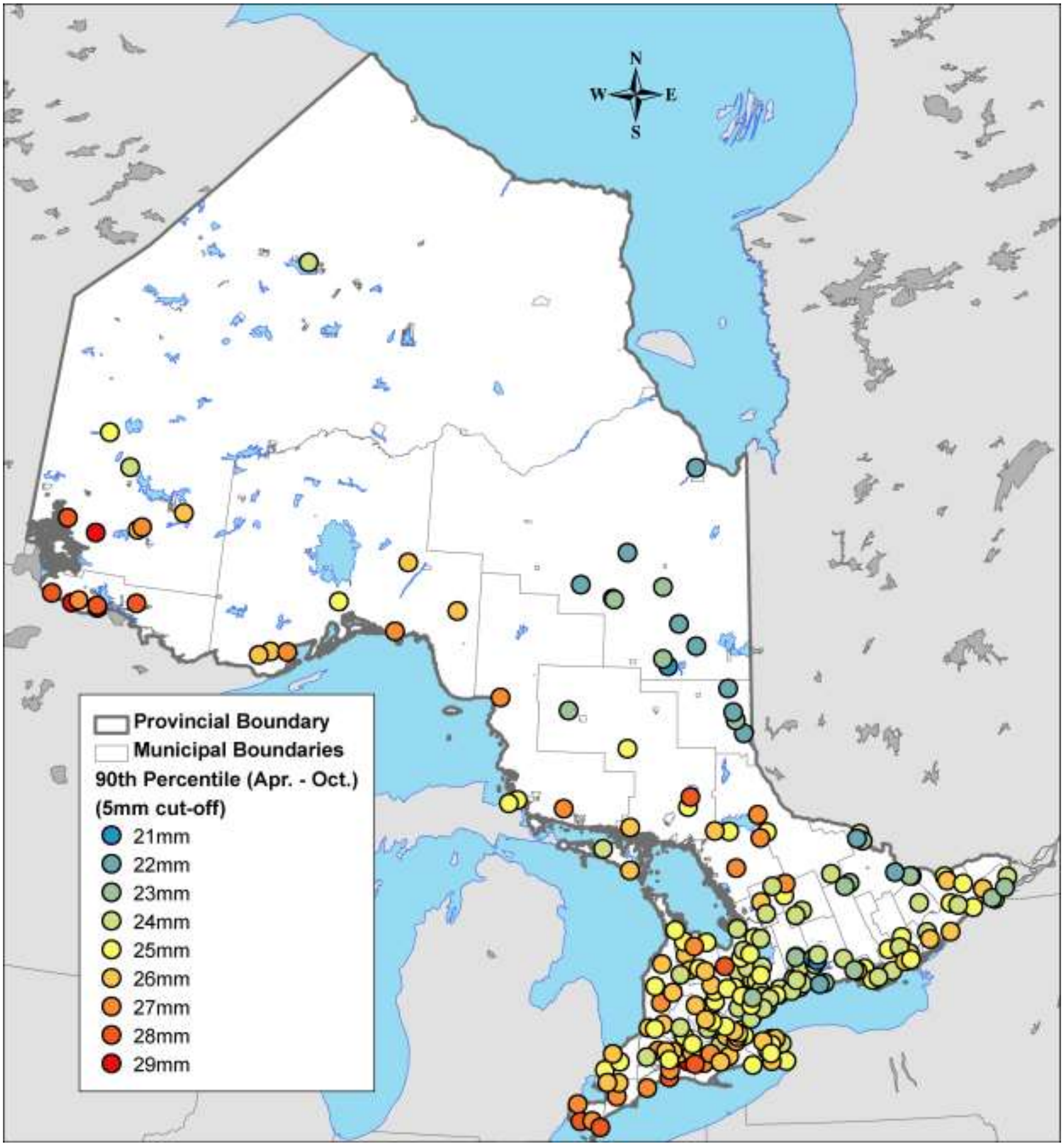


Figure 3.47 - 90th percentile daily rainfall volumes (April through October, where rainfall exceeds 5 mm).

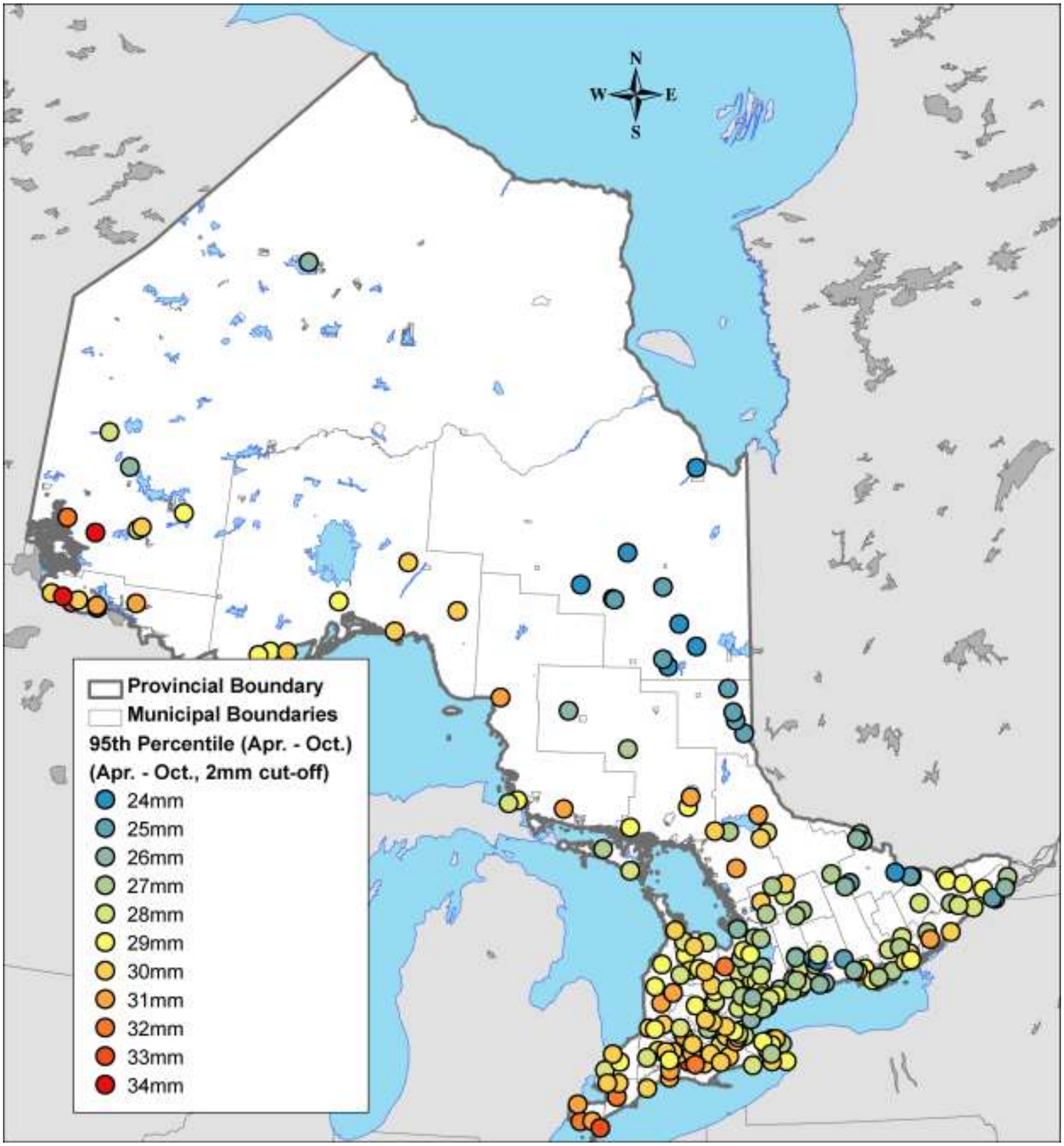


Figure 3.48 - 95th percentile daily rainfall volumes (April through October, where rainfall exceeds 2 mm).

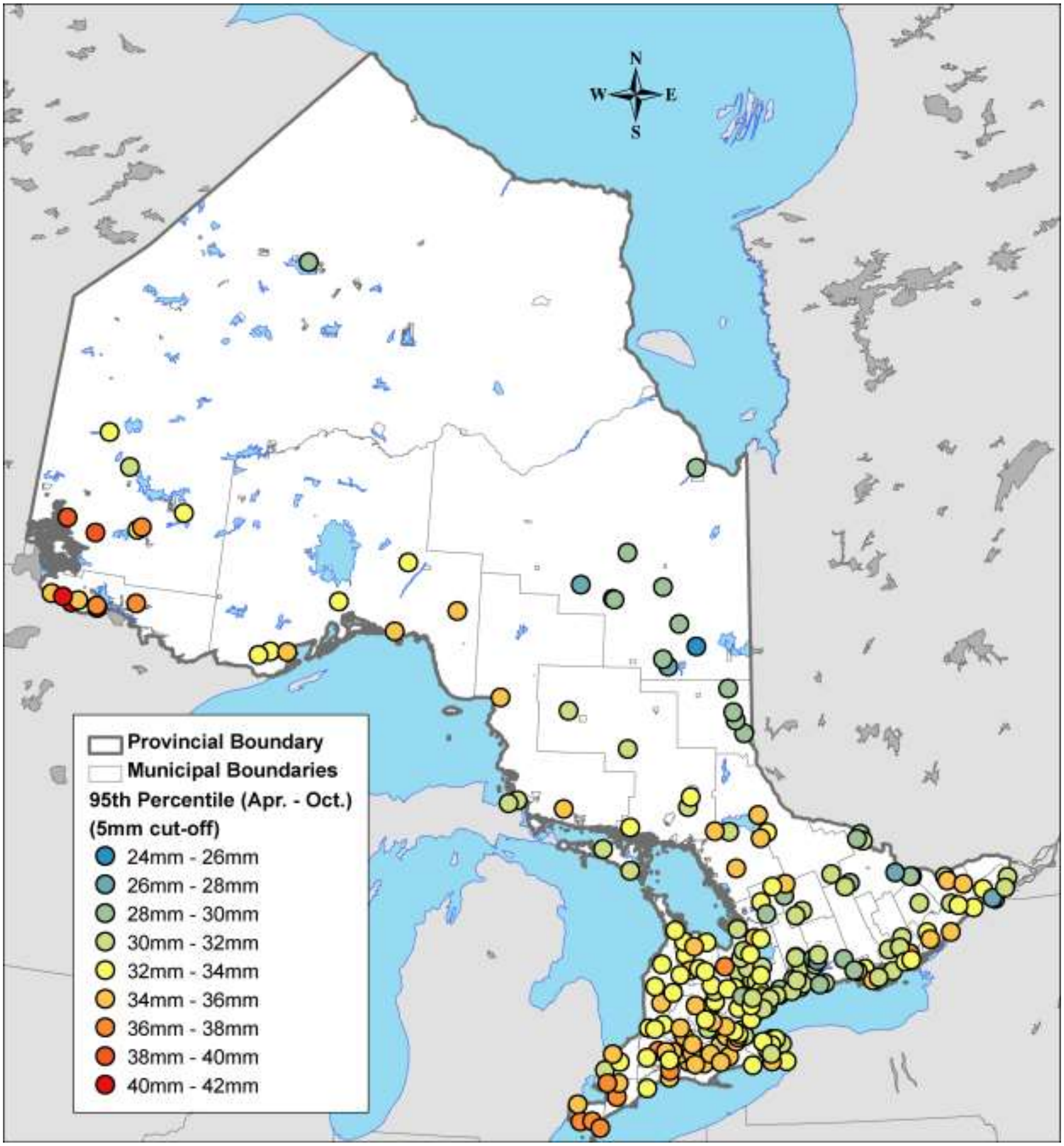


Figure 3.49 - 95th percentile daily rainfall volumes (April through October, where rainfall exceeds 5 mm).

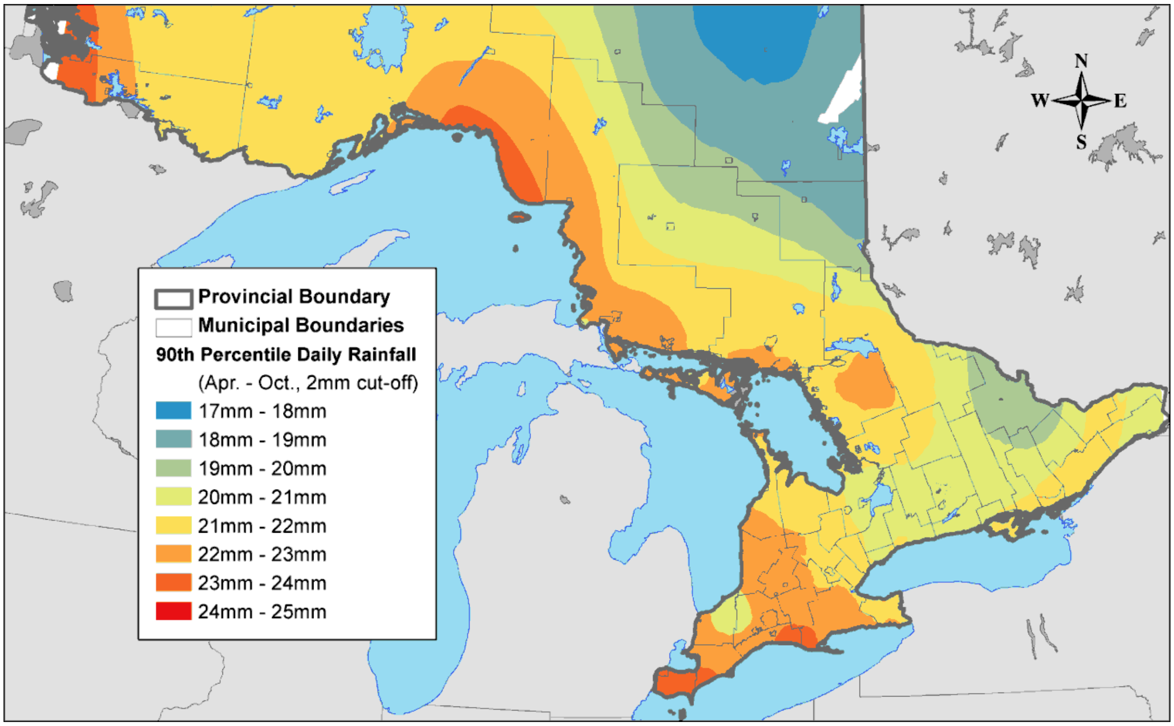


Figure 3.50 - 90th percentile daily rainfall contours (April - October, where daily volume exceeds 2 mm).

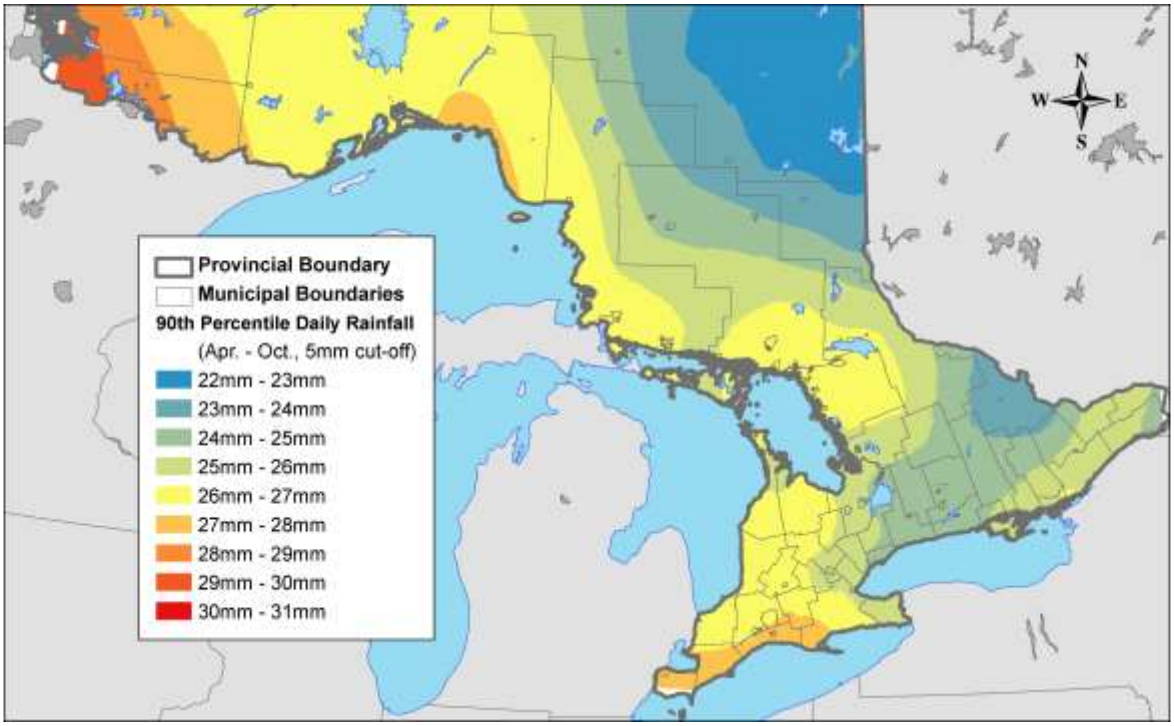


Figure 3.51 - 90th percentile daily rainfall contours (April - October, where daily volume exceeds 5 mm).

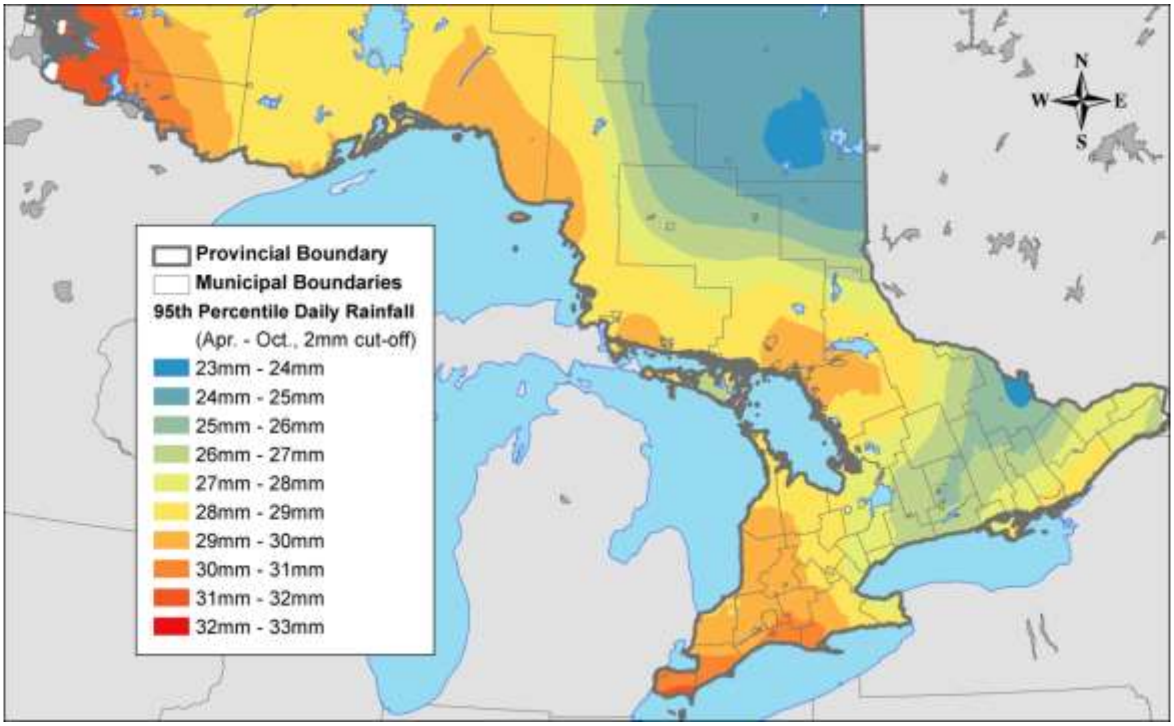


Figure 3.52 - 95th percentile daily rainfall contours (April - October, where daily volume exceeds 2 mm).

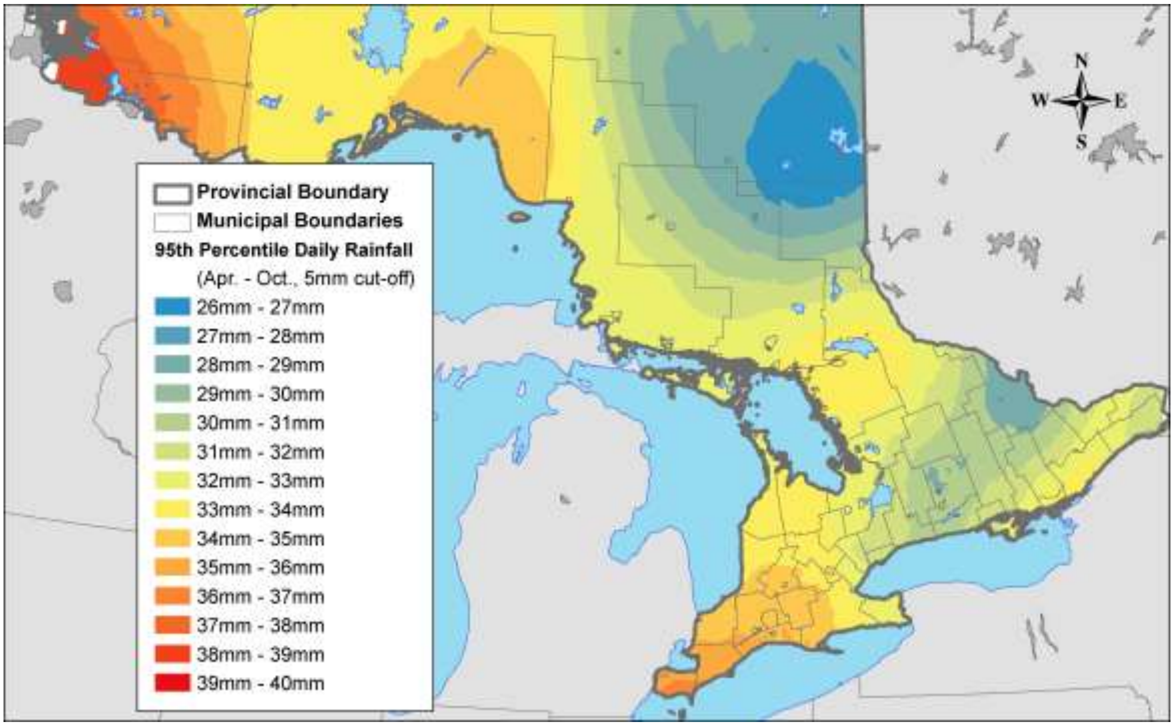


Figure 3.53 - 95th percentile daily rainfall contours (April - October, where daily volume exceeds 5 mm).

3.7.3 Areas of Interest

Daily rainfall frequency curves for several major centers in Ontario are provided below with key rainfall depth percentiles in tabular form (note: additional station plots and percentiles (50th, 75th, 80th, 99th) are available in the digital appendix.) (* Mean annual precipitation for the analysis period is provided at stations where sufficient data is available to allow its calculation, see **Figure 3.42**).

3.7.3.1 Toronto

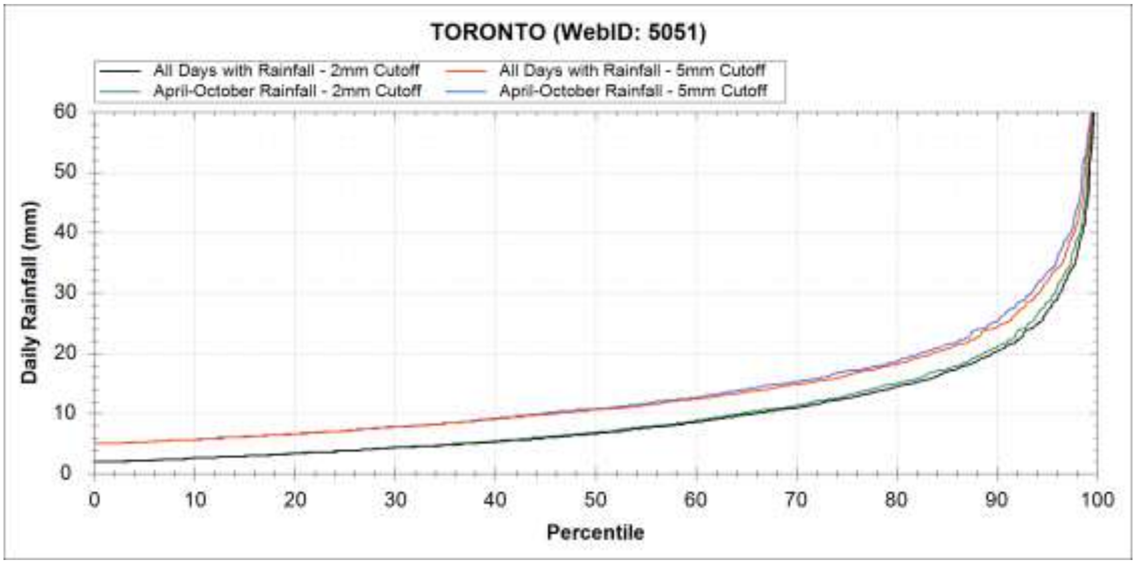


Figure 3.54 - Daily rainfall frequency curves derived from daily rainfall data at ECCC climate station TORONTO.

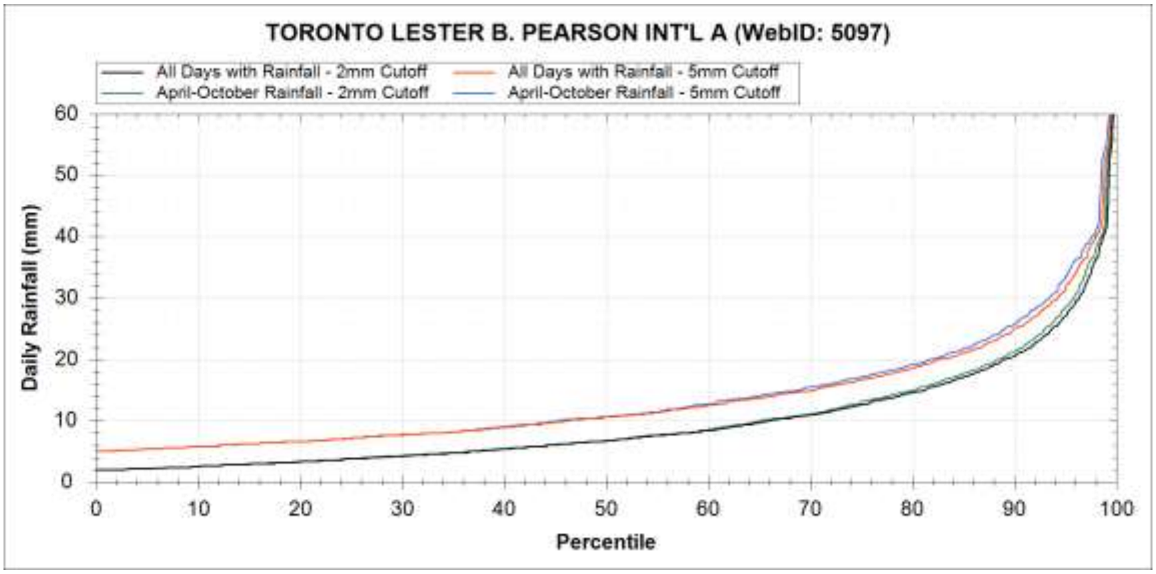


Figure 3.55 - Daily rainfall frequency curves derived from daily rainfall data at ECCC climate station TORONTO LESTER B. PEARSON INT'L A.

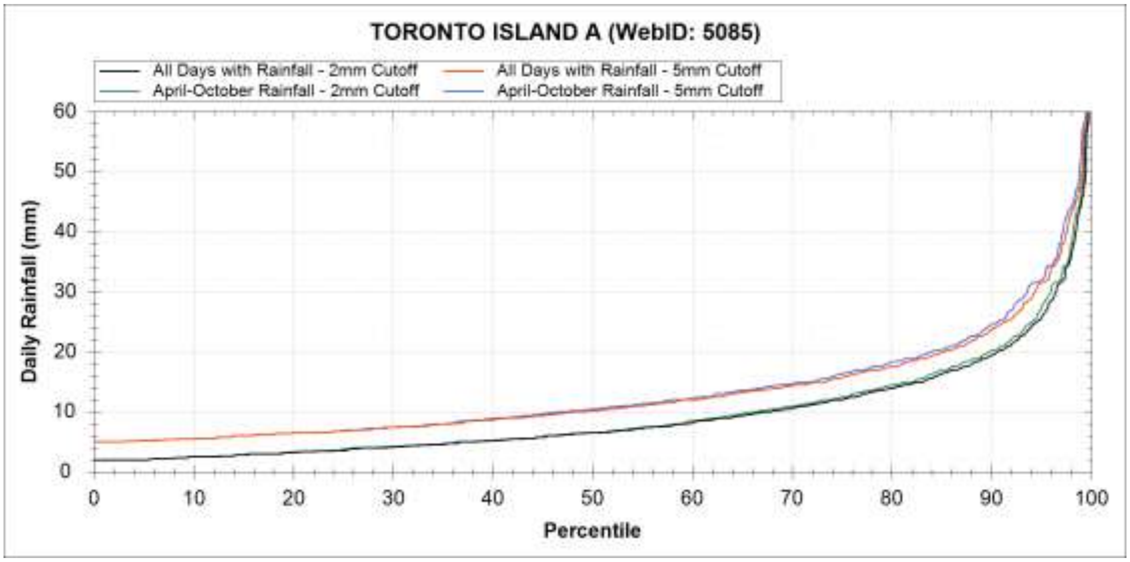


Figure 3.56 - Daily rainfall frequency curves derived from daily rainfall data at ECCC climate station TORONTO ISLAND A.

Table 3.15 - 90th and 95th Percentile event daily rainfall volumes from daily climate data collected proximal to the City of Toronto.

Station Name	*Annual Average*		*Number of Years in Analysis*	*90th Percentile Daily Volume (mm)*				*95th Percentile Daily Volume (mm)*			
	Precipitation(mm)	*Oct. to Apr. Rainfall (mm)*		*All Rainfall Events*		*Apr. 1st - Oct. 31st*		*All Rainfall Events*		*Apr. 1st - Oct. 31st*	
				2 mm Cut-off	*5 mm Cut-off*	*2 mm Cut-off*	*5 mm Cut-off*	*2 mm Cut-off*	*5 mm Cut-off*	*2 mm Cut-off*	*5 mm Cut-off*
FRENCHMANS BAY	864	541	33	20.8	24.1	21.1	24.6	25.2	29.5	25.9	29.8
LAKEVIEW MOE	-	512	20	20.7	24.0	21.6	24.2	25.0	28.4	25.2	28.0
RICHMOND HILL	878	545	34	20.4	24.4	21.2	25.0	27.2	31.6	28.2	32.8
ROUGE PARK	-	519	20	22.9	25.2	22.9	25.2	28.3	31.0	28.3	31.0
THORNHILL GRANDVIEW	857	540	35	20.0	23.9	21.0	25.2	26.5	31.2	28.0	32.0
TORONTO	827	508	33	20.2	24.2	20.8	25.2	26.8	31.6	28.4	33.2
TORONTO ASHBRIDGES BAY	-	540	20	20.1	23.6	20.8	23.6	25.0	29.5	25.0	30.9
TORONTO ELLESMERE	-	512	22	20.3	24.8	20.3	25.0	27.3	30.8	27.2	31.0
TORONTO ISLAND A	777	489	32	19.5	23.6	20.2	24.4	25.5	31.4	27.0	31.9
TORONTO LESTER B. PEARSON INT'L A	787	503	35	20.5	24.9	21.2	25.6	27.0	31.0	28.4	33.0
WOODBRIDGE	797	511	33	19.2	23.1	19.9	23.8	24.5	29.4	25.7	31.0
Average	827	518	29	20.4	24.2	21.0	24.7	26.2	30.5	27.0	31.3
Median	827	512	33	20.4	24.1	21.0	24.9	26.4	30.9	27.1	31.2

3.7.3.2 Ottawa

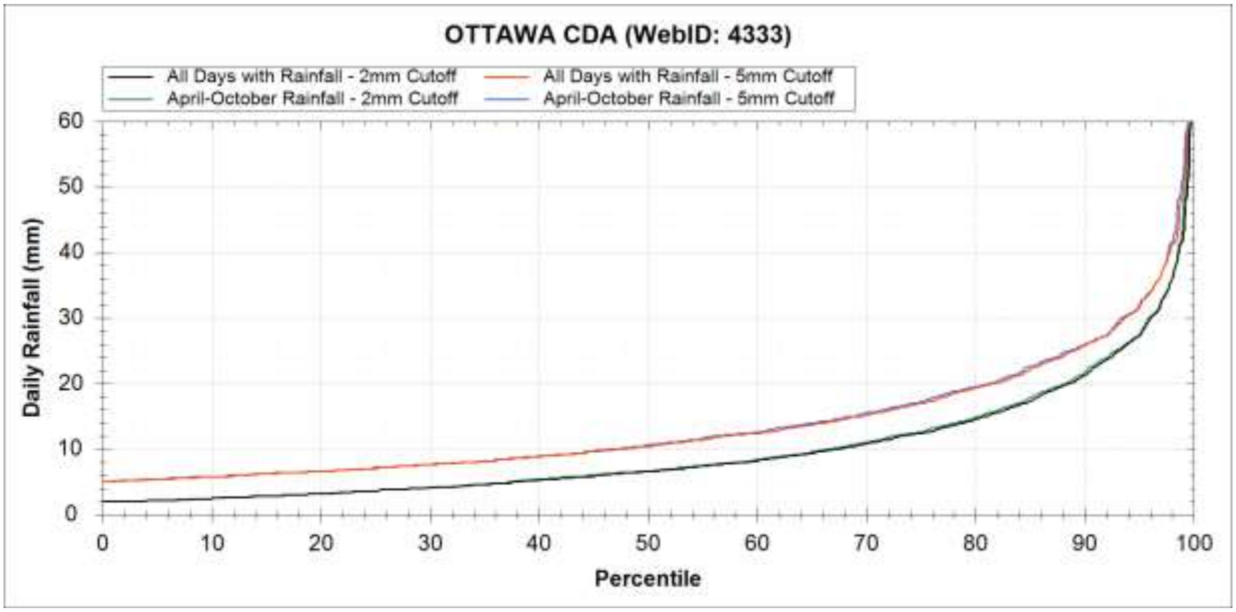


Figure 3.57 - Daily rainfall frequency curves derived from daily rainfall data at ECCC climate station OTTAWA CDA.

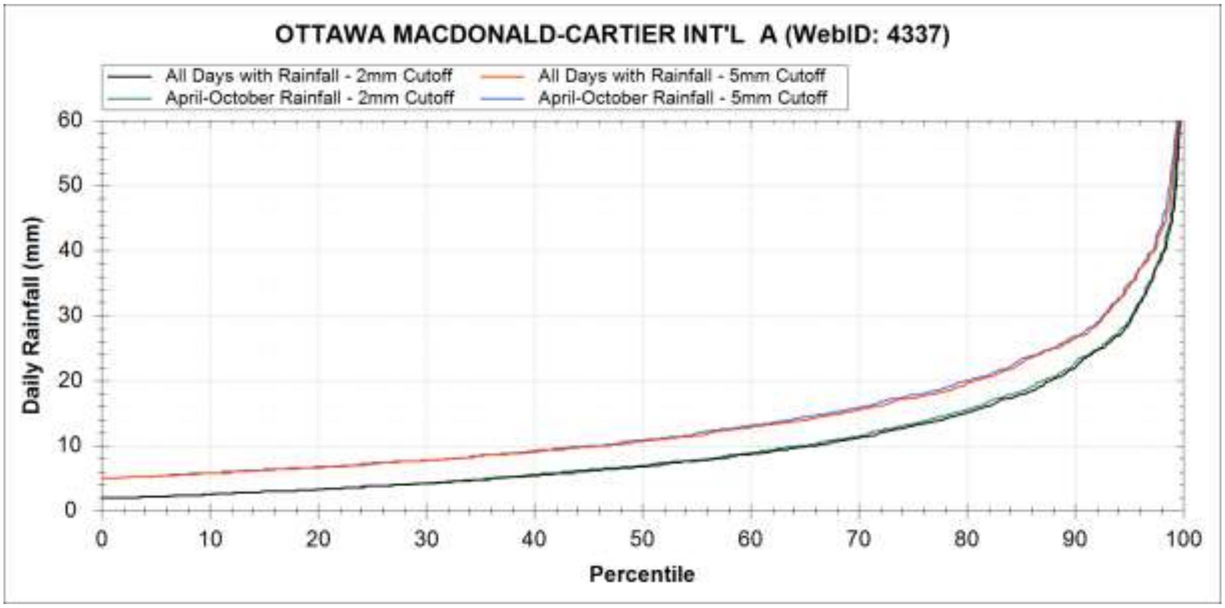


Figure 3.58 - Daily rainfall frequency curves derived from daily rainfall data at ECCC climate station OTTAWA MACDONALD-CARTIER INT'L A.

Table 3.16 - 90th and 95th Percentile event daily rainfall volumes from daily climate data collected proximal to the City of Ottawa.

Station Name	Annual Average		Number of Years in Analysis	90th Percentile Daily Volume (mm)				95th Percentile Daily Volume (mm)			
	Precipitation* (mm)	Oct. to Apr. Rainfall) (mm)		All Rainfall Events		Apr. 1st - Oct. 31st		All Rainfall Events		Apr. 1st - Oct. 31st	
				2 mm Cut-off	5 mm Cut-off	2 mm Cut-off	5 mm Cut-off	2 mm Cut-off	5 mm Cut-off	2 mm Cut-off	5 mm Cut-off
OTTAWA CDA	910	583	36	21.2	25.8	21.8	25.8	27.2	31.4	27.4	31.8
OTTAWA MACDONALD-CARTIER INT'L A	935	580	36	22.0	26.6	22.6	26.8	28.6	34.4	29.0	35.0
Average	922	581	36	21.6	26.2	22.2	26.3	27.9	32.9	28.2	33.4

3.7.3.3 Windsor

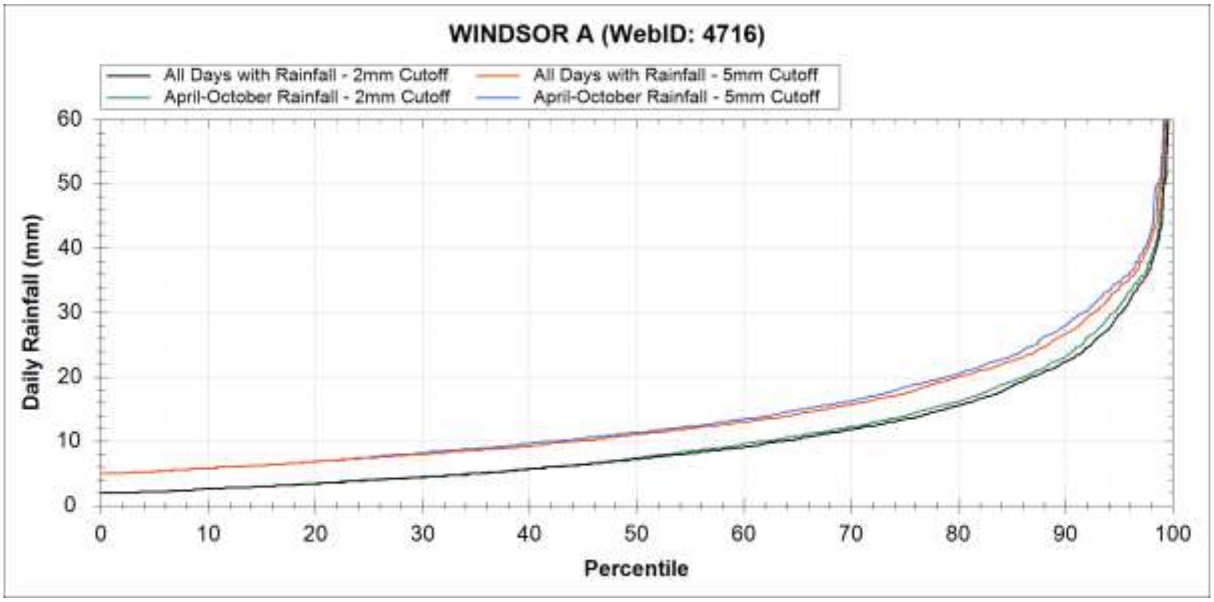


Figure 3.59 - Daily rainfall frequency curves derived from daily rainfall data at ECCC climate station WINDSOR A.

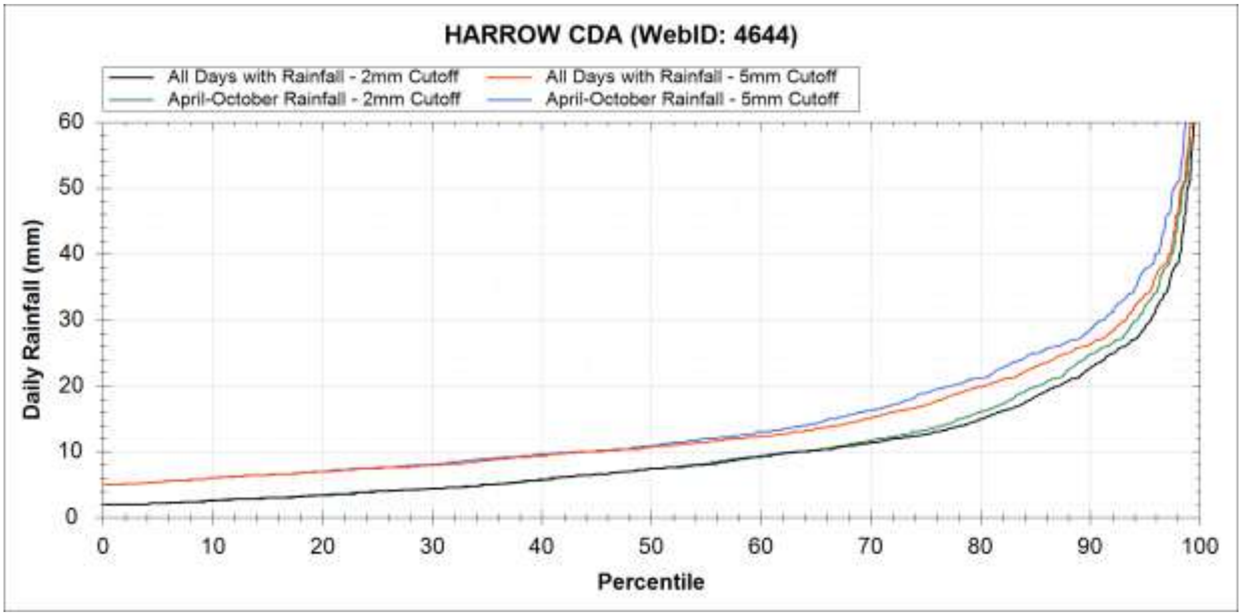


Figure 3.60 - Daily rainfall frequency curves derived from daily rainfall data at ECCC climate station HARROW CDA.

Table 3.17 - 90th and 95th Percentile event daily rainfall volumes from daily climate data collected proximal to the City of Ottawa.

Station Name	***Annual Average***		***Number of Years in Analysis***	***90th Percentile Daily Volume (mm)***				***95th Percentile Daily Volume (mm)***			
	Precipitation (mm)	***Oct. to Apr. Rainfall) (mm)***		***All Rainfall Events***		***Apr. 1st - Oct. 31st***		***All Rainfall Events***		***Apr. 1st - Oct. 31st***	
				2 mm Cut-off	***5 mm Cut-off***	***2 mm Cut-off***	***5 mm Cut-off***	***2 mm Cut-off***	***5 mm Cut-off***	***2 mm Cut-off***	***5 mm Cut-off***
HARROW CDA	-	576	22	22.6	26.2	24.6	28.4	28.6	33.6	31.4	37.2
WINDSOR A	898	566	35	22.4	26.6	23.1	27.9	29.7	33.6	30.8	34.8
Average	898	571	29	22.5	26.4	23.9	28.2	29.2	33.6	31.1	36.0

3.7.3.4 Sudbury

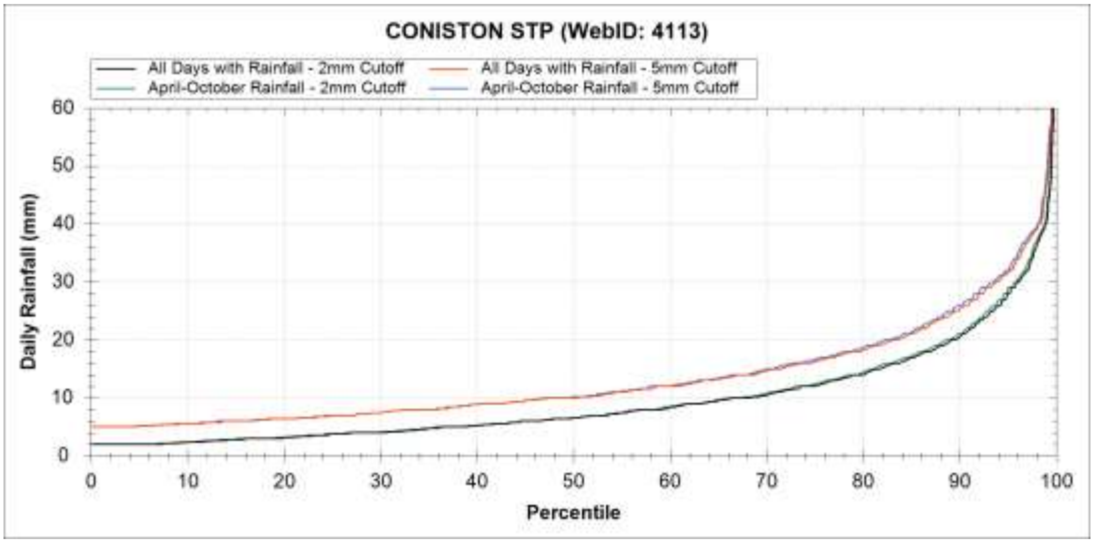


Figure 3.61 - Daily rainfall frequency curves derived from daily rainfall data at ECCC climate station CONISTON STP.

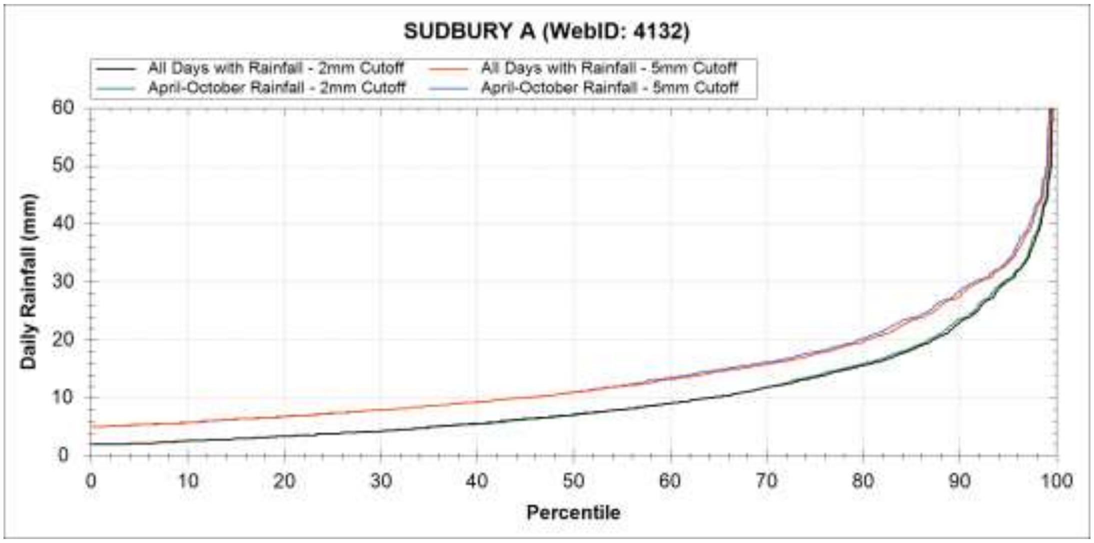


Figure 3.62 - Daily rainfall frequency curves derived from daily rainfall data at ECCC climate station SUDBURY A.

Table 3.18 - 90th and 95th Percentile event daily rainfall volumes from daily climate data collected proximal to the City of Sudbury.

Station Name	Annual Average		Number of Years in Analysis	90th Percentile Daily Volume (mm)				95th Percentile Daily Volume (mm)			
	Precipitation (mm)	Oct. to Apr. Rainfall) (mm)		All Rainfall Events		Apr. 1^{ST} - Oct. 31^{ST}		All Rainfall Events		Apr. 1^{ST} - Oct. 31^{ST}	
				2 mm Cut-off	5 mm Cut-off	2 mm Cut-off	5 mm Cut-off	2 mm Cut-off	5 mm Cut-off	2 mm Cut-off	5 mm Cut-off
CONISTON STP	-	553	28	20.5	25.0	21.0	25.9	28.0	31.5	29.0	32.0
SUDBURY A	910	578	36	22.9	27.4	23.6	28.4	30.2	33.2	30.4	33.6
Average	910		32	21.7	26.2	22.3	27.2	29.1	32.4	29.7	32.8

3.7.3.5 Thunder Bay

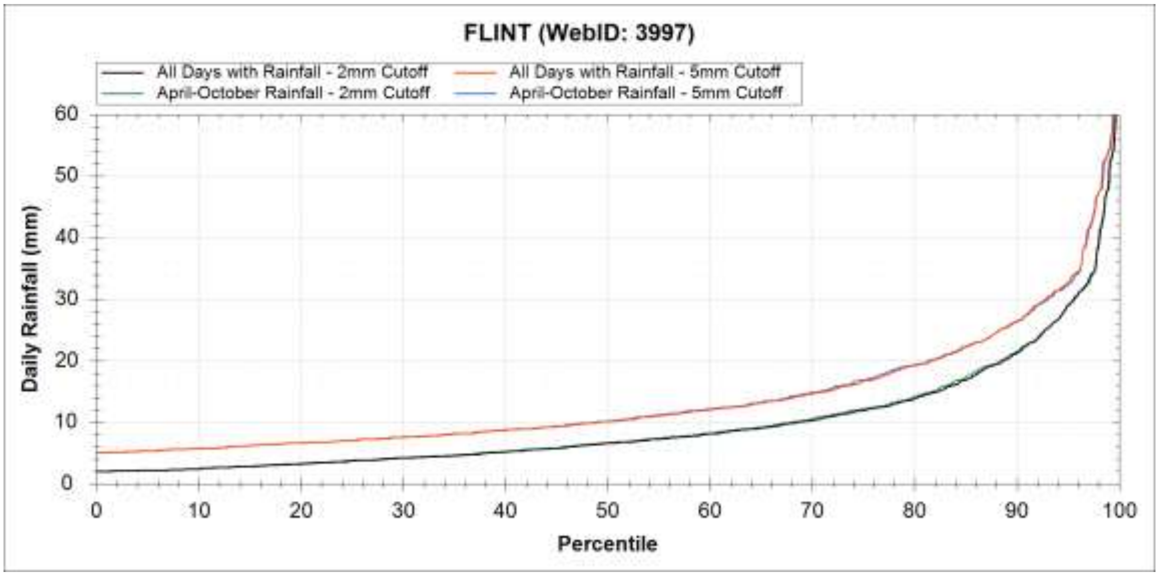


Figure 3.63 - Daily rainfall frequency curves derived from daily rainfall data at ECCC climate station FLINT.

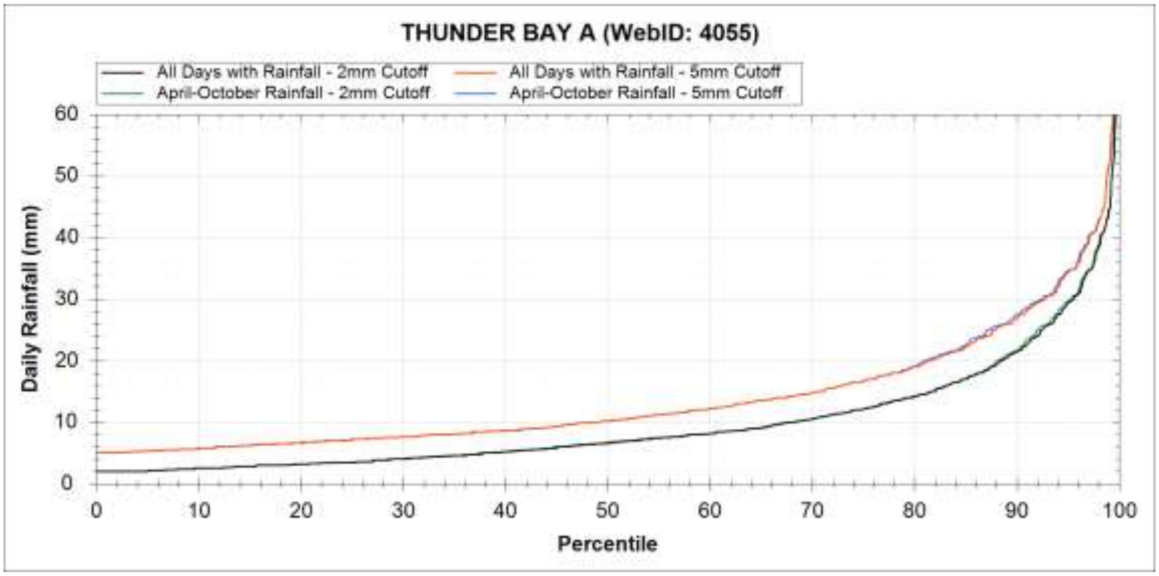


Figure 3.64 - Daily rainfall frequency curves derived from daily rainfall data at ECCC climate station THUNDER BAY A.

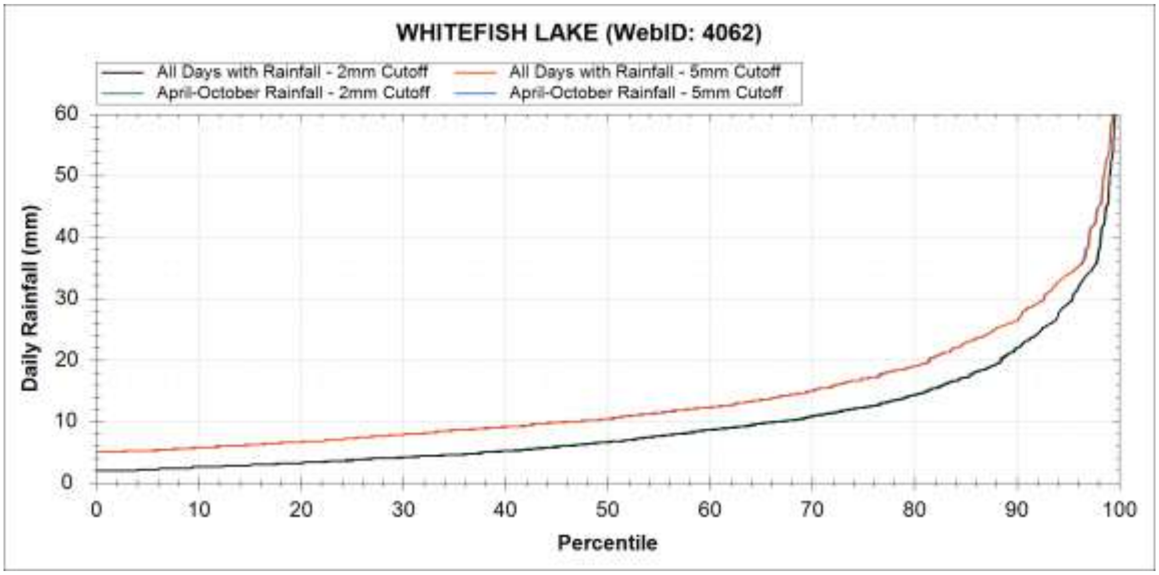


Figure 3.65 - Daily rainfall frequency curves derived from daily rainfall data at ECCC climate station WHITEFISH LAKE.

Table 3.19 - 90th and 95th Percentile event daily rainfall volumes from daily climate data collected proximal to the City of Thunder Bay.

Station Name	*Annual Average*		*Number of Years in Analysis*	*90th Percentile Daily Volume (mm)*				*95th Percentile Daily Volume (mm)*			
	Precipitation (mm)	*Oct. to Apr. Rainfall) (mm)*		*All Rainfall Events*		*Apr. 1st - Oct. 31st*		*All Rainfall Events*		*Apr. 1st - Oct. 31st*	
				2 mm Cut-off	*5 mm Cut-off*	*2 mm Cut-off*	*5 mm Cut-off*	*2 mm Cut-off*	*5 mm Cut-off*	*2 mm Cut-off*	*5 mm Cut-off*
FLINT	-	550	25	21.2	26.5	21.5	26.2	29.0	32.5	28.9	32.2
THUNDER BAY A	-	509	31	21.5	26.8	21.6	27.4	29.2	34.2	29.5	34.6
WHITEFISH LAKE	-	589	25	22.0	26.4	22.0	26.4	29.0	33.8	29.0	33.8
Average	-	549	27	21.6	26.6	21.7	26.7	29.1	33.5	29.1	33.5

3.8 Recommendations

The preceding sections presented an analysis of rainfall patterns in Ontario based on hourly and daily data. The intent of the analysis is to identify the appropriate daily or event based rainfall volume with which to define runoff control volume targets for the Province.

The hourly, event-based analysis provides a high degree of temporal resolution but parsing independent storm events from the record can prove difficult. Storm events were determined with a Minimum Interevent Time (MIT) approach, with a MIT of 12-hours recommended for use in Ontario. Excluding events smaller than 2 mm, an average 90th percentile of 27 mm was calculated for the Province. Unfortunately, due to the distance between hourly climate stations and the inconstant observation periods, the spatial variability in the mapped results is high.

The daily record was also analyzed, with several percentiles calculated from the daily rainfall series. Excluding events smaller than 2 mm produces a 90th percentile daily rainfall volume of 21 mm on average across the province. This value is smaller than that obtained from the hourly series, as events that span multiple days or that cross the 6 a.m.- 6 a.m. synoptic window are truncated. However, the use of the daily rainfall dataset to derive the target treatment volumes for Ontario would be favorable as:

1. Daily rainfall is reported at a significantly higher number of climate stations. This decreases the spatial variability in the supported mapping, and increases the likelihood of identifying geographically significant trends.
2. The available period of record within the daily dataset is considerably longer than in the hourly dataset. More data is available over a longer temporal period allowing a similar climatic period to be evaluated at the daily stations, further increasing spatial resolution.
3. The daily data generally undergoes a higher level of quality checking than the hourly record.
4. Deriving the daily rainfall volume percentiles is a straightforward process that can be easily reproduced by other practitioners with limited access to automated methods or advanced statistical packages.
5. The daily climate data can be readily obtained from a variety of public sources while the hourly data must be obtained through the ECCC on a cost recovery basis.

Of the numerous advantages inherent in applying the daily data above, of most importance is the improvement in spatial resolution. If a single percentile is to be applied on a provincial basis, utilizing a dataset which can adequately describe regional trends must be given high importance. However, the daily rainfall volume does appear to under predict volumes when compared to the hourly derived event volumes. Two (2) options have been identified to address this discrepancy:

1. Solution 1 - Consider the daily series while ignoring events below a 5 mm cutoff, this shifts the average 90th percentile value to 26 mm. However, it may prove more difficult to justify the elimination events below 5 mm from the analysis, as opposed to the elimination of events below 2 mm.
2. Solution 2 – Consider selecting a higher percentile in the daily rainfall record which most closely represents and aligns with the 90th percentile event determined using the hourly analysis with a 12-hours MIT, excluding events smaller than 2 mm.

To evaluate these two (2) options, event percentiles from hourly stations were compared to daily volumes at stations where both were calculated. **Figure 3.66** presents a comparison of the hourly derived event volumes (with a 2 mm cut-off) to the daily 90th percentile (5 mm cutoff) and

95th percentile daily volume (2 mm cut-off). Both daily series are generally in good agreement with the 90th percentile event volume, tightly clustered around the 1:1 line of equality with an average deviation of 1 mm. The 95th percentile (daily volume), which shares the same cut-off threshold of 2 mm, represents the more hydrologically conservative approximator by overestimating the 90th event volume by 1 mm or approximately 5%.

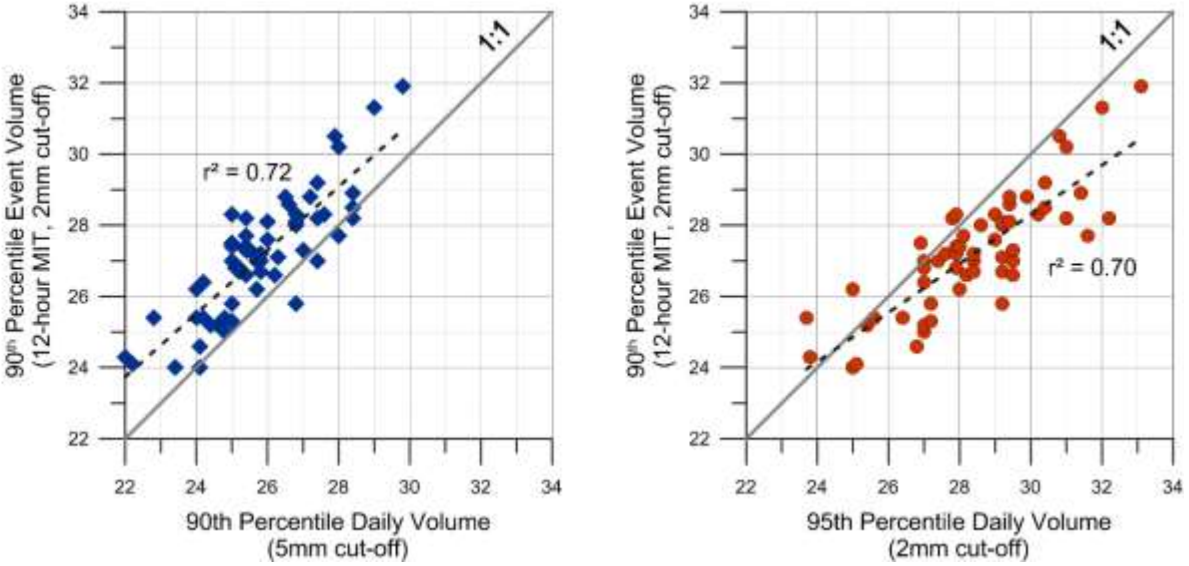


Figure 3.66 - Comparison of hourly derived 90th percentile event volume (2 mm cut-off) with a) the 90th percentile daily volume (5 mm cut-off), and b) the 95th percentile daily volume (2 mm cut-off).

Therefore, it is recommended that 90th percentile event as determined through the hourly rainfall analysis using a 12-hour MIT and excluding events smaller than 2 mm be selected as the volume target for Ontario. It is further recommended, that to increase the spatial resolution of across the province in order to identify and capture geographically significant trends the 95th percentile daily rainfall series (excluding days with less than 2 mm of rainfall) be used to represent the 90th percentile runoff control volume targets in Ontario.

It is further recommended that daily rainfall volumes be evaluated primarily between April 1st and October 31st. This allows for a consistent period to be employed in the analysis year over year, and ensures that the largest number of climate stations can be used in the analysis (many stations do not collect precipitation data outside these months). In addition, as presented in the previous sections, daily rainfall records from Apr. 1st - Oct. 31st show little variance as compared to all rainfall events (full year) and in all cases average 90th and 95th percentile events rainfall collected from April to October were 0.8 to 1 mm and 0.6 to 1.1 mm higher for the 2 mm and 5 mm cutoff respectively. As such due to limited useable total precipitation data, rainfall volumes between April 1st and October 31st will be used for stormwater management in Ontario, until more information is available.

Table 3.20 presents a Summary Comparison of hourly (90th percentile, 12-hours MIT) vs. daily rainfall events (95th percentile, Apr. 1st - Oct. 31st) - ignoring event volumes below 2 mm. **Figure 3.67** presents the recommended regional volume target for Ontario.

Table 3.20 - Summary of event rainfall depths calculated at hourly climate stations (90th Percentile) and daily climate stations (95th Percentile, Apr. 1st - Oct. 31st) - ignoring event volumes below 2 mm

	Years with complete data	Hourly: 90th % Depth (mm)	Years with complete data	Daily: 95th % Depth (mm)
		MIT (HOURS)		MIT (HOURS)
		12		*n/a*
Minimum	15	23.6	20	23.0
Median	**23**	**27.0**	**28**	**28.0**
Average	26.5	27.1	28	28.0
Maximum	59	31.9	36	33.2

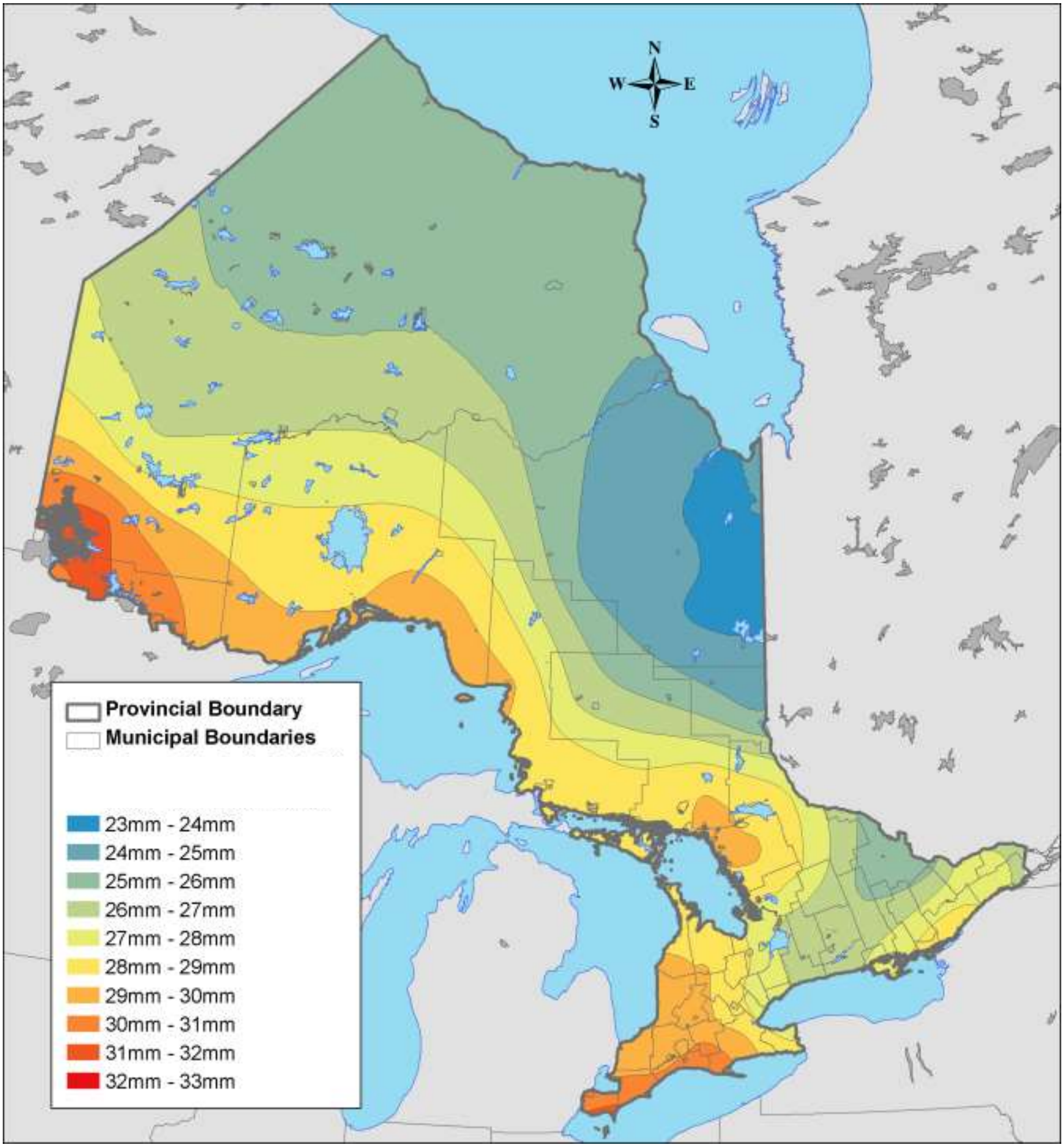


Figure 3.67 – Recommended Regional 90% Percentile Volume Targets for Ontario
(represented by the 95th percentile daily rainfall contours April - October, where daily volume exceeds 2 mm).

4 RECOMMENDED VOLUME TARGETS FOR ONTARIO

The following section outlines the recommended Runoff Volume Control Targets (RVC_T) for Ontario to be applied as part of new development, redevelopment, reurbanization and residential intensification, linear projects as well as part of stormwater retrofits.

In all cases, the RVC_T for Ontario shall be considered a minimum target, and should not preclude the proponent from achieving the required stormwater quantity, quality, erosion control and water balance requirements as identified through watershed, subwatershed, master drainage plans, Environmental Impact Statement (EIS), Provincial Policy and Guidelines or other area-specific studies; nor does it preclude the proponent from the requirement to prepare appropriate pollution prevention plans per the Canadian Environmental Protection Act, and/or Risk Management Plans per the relevant Source Protection Policies pursuant to the Clean Water Act. In all cases, the most stringent policy and/or requirement shall apply.

4.1 Recommendations for the Development of a RVC_T for Ontario

From the review of the sources, methods, and research that were used to determine the runoff volume treatment target for the five (5) selected jurisdictions completed and detailed in **Section 2.0** and the supporting rationale as detailed in **Section 3.1** to **Section 3.5** (Water Balance, Urbanization and Hydromodification, Conventional Stormwater Management and Watershed Impervious Area, and Rationale for the 90th Percentile) the following recommendations are proposed for consideration by the MOECC in the development of the Runoff Volume Control Targets (RVC_T) for Ontario:

- The RVC_T for Ontario be founded upon the principles of maintaining the pre-development water balance and returning precipitation volume to the natural pathways of runoff, evapotranspiration, and infiltration in proportions which are in keeping with the watershed conditions prior to development. **The goal of maintaining the pre-development water balance shall be to ensure the ecosystem function and natural quality and hydrological characteristics of natural features, including aquatic habitat, baseflow, water quality, temperature, storage levels and capacity, and hydroperiods will be maintained and known impacts are avoided.** As such, the appropriate portion of the RVC_T must be returned to natural pathways of the pre-development water balance. Any remaining volume should be controlled per the requirements detailed below.

- The RVC_T for Ontario regard rainwater as a resource which is to be managed as close to the source area as possible (i.e. on-site) using approaches which focus on runoff prevention.

- The RVC_T for Ontario be based on the management of the geographically specific 90th percentile event (**Figure 3.67**). The 90th percentile event is the rainfall event whose precipitation total is less than or equal to 90 percent of all daily rainfall events on an annual basis.

- The goals of the RVC_T for Ontario include:
    - The application of a consistently derived, geographically specific volume control target across the province.
    - The development of a repeatable and scientifically based approach for sizing stormwater practices that can perform efficiently and effectively, which can be administered simply, promote better site design, and be flexible in responding to site specific conditions.
    - Greater consistency and integration of stormwater management among the many cities, watershed organizations and regions within the province.

- The RVC_T should be founded on the following principles:

    - Acknowledgement that land development alters the natural or pre-development water balance.
    - At 10% total watershed imperviousness of watersheds with traditional ditch and pipe systems, about 10% of the total rainfall volume becomes runoff that enters receiving waters; this runoff volume is the root cause of aquatic habitat degradation[45]. As such an appropriate performance target for managing runoff volume is to limit total runoff volume to 10% (or less) of total rainfall volume. This means that 90% of rainfall volume must be controlled and returned to natural hydrologic pathways, through infiltration, evapotranspiration or re-use.
    - That reducing runoff volume at the source is the key to protecting property and infrastructure, habitats, aquatic and terrestrial ecosystems and water quality.
    - That a BMP which is sized to capture and treat the runoff generated from the 90th percentile event will also capture and at least partially treat an equivalent volume during larger rainfall events beyond the 90th percentile. Therefore, treating the runoff generated from the 90th percentile rainfall may result in a capture efficiency of greater than 90% of the annual average rainfall volume.
    - The application of landscaped based volume based stormwater controls, such as Low Impact Development (LID) techniques are a key component of climate change adaption and mitigation strategies.
    - The natural hydrologic cycle should be maintained to the greatest extent possible.
    - Volume based stormwater controls, including Low Impact Development (LID) practices, are relevant for all forms of development.
    - Per the (February 2015) MOECC Interpretation Bulletin – Expectations Re: Stormwater Management - Going forward the Ministry expects that stormwater management plans will reflect the findings of the watershed, subwatershed, and environmental management plans, and will employ LID in order to maintain the natural hydrologic cycle to the greatest extent possible.

- The means to achieve the RVC_T includes:
    a) **Retention** - where the captured volume shall be ultimately infiltrated, evapotranspired or re-used and the specified volume will not later be discharged to sewer networks (with the exception of internal water re-use activities) or surface waters and does not therefore become runoff;
    and,
    b) **Volume Capture and Treatment** - Also referred to as `*treatment and release*`, where the volume capture and treatment directly aims at reducing surface water

impairment through treatment of the specified volume, often referred to as a "water quality volume".

- The RVC_T for Ontario employ a '**mandatory control hierarchy'** whereby stormwater management practices are preferentially selected which:
    - Begin with better site design through the minimization of land stripping and grading, the preservation of existing vegetation and the use of erosion control practices in combination with sediment control measures.
    - Utilize natural systems and preserve existing natural systems,
    - Create multifunctional landscapes that achieve goals and objectives beyond stormwater management to include broader community goals of livability and sustainably as well as environmental protection objectives,
    - Contribute to water sustainability across the watershed to reduce the use of resources including potable water.
    - Provides climate change co-benefits. A co-benefit is an action or a technology that is designed to both reduce greenhouse gas (GHG) emissions and reduce vulnerability to climate impacts in the future. When something contributes to both climate change mitigation and adaptation, it is a climate co-benefit.

- The **mandatory control hierarchy** for application as part of the RVC_T for Ontario include the following priorities in keeping with the above noted rationale:

    1. **Control Hierarchy Approach 1 (Retention) –** Low Impact Development retention techniques which utilize the mechanisms of infiltration, evapotranspiration and or re-use to recharge shallow and/or deep groundwater; return collected rainwater to the atmosphere and/or re-use collected rainwater for internal or external uses respectively. The target volume is controlled and not later discharged to the municipal sewer networks (with the exception of internal water re-use activities) or surface waters and does not therefore become runoff.

        Rationale:
        - Reduced runoff volumes
        - Less variable pollution control as <u>pollutant loads</u> to receivers are reduced through runoff volume reductions (infiltration, evapotranspiration and re-use) as compared to approaches which rely on removal efficiencies (i.e. % removal)
        - Urban flood and combined sewer overflow (CSO) prevention by increasing the sewer capacity by reduced volume and peak flows, as well as delayed time-to-peak;
        - Maintenance of pre-development water balance;
        - Contribution to stream baseflow and mitigation of thermal impacts to urban streams; and
        - The preservation of groundwater quantity and levels.

    2. **Control Hierarchy Approach 2 (LID Volume Capture and Release) –** Low Impact Development filtration technologies which utilize filtration to filter runoff using LID techniques with appropriate filter media per the LID Stormwater Planning and Design Guide (2010, v1.0 as amended from time to time). The controlled volume is filtered and released to the municipal sewer networks or

surface waters at a reduced rate and volume (a portion of LID Volume Capture and Release may be infiltrated or evapotranspirated).

Rationale:

- Reduced runoff volumes (LID filtration controls have been demonstrated to provide runoff volume reductions irrespective of the ability to infiltrate through absorption, material wetting and increased depression storage).
- Less variable pollution control as pollutant loads to receivers are reduced through runoff volume reductions as compared to approaches which rely on removal efficiencies (i.e. % removal)
- Additional water quality benefits result from treatment process of filtration which may also include pollution adsorption and sedimentation;

3. **Control Hierarchy Approach 3 (Other Volume Detention and Release)** – Other stormwater technologies which utilize filtration, hydrodynamic separation and or sedimentation (i.e. end-of-pipe facilities) to detain and treat runoff using an appropriate filter media per industry standard verification protocols; separate contaminates from runoff; and/or facilitate the sedimentation and removal of contaminants respectively. The controlled volume is treated and released to the municipal sewer networks or surface waters at a reduced rate.

   Rationale:

   - Additional water quality benefits result from treatment process of filtration (which may also include pollution adsorption and sedimentation), separation of pollutants from runoff, or sedimentation;

The selection process should be documented and justified per the site-specific conditions and environmental objectives to the satisfaction of the MOECC.

- The RVC_T for Ontario should facilitate the implementation of the integrated strategy which includes past MOECC guidance as well as guidance from other agencies for managing the complete geographically specific Rainfall Frequency Spectrum (RFS).

- The RVC_T for Ontario should not only be quantifiable, but also synthesize complex information into a consistent target that is simple to understand and achieve, yet is comprehensive in scope.

- The RVC_T for Ontario should include specific volume control targets for New Development, Redevelopment, Reurbanization, Linear Development and Stormwater Retrofits and include flexible Treatment Options for Sites with Restrictions (i.e. Constraints).

- The RVC_T for Ontario should be such that the detention requirements for flood control will not change significantly, but the focus on water-quality treatment be shifted to a standard of pollutant load reduction through runoff volume reductions, following the mandatory control hierarchy. It is noted that a portion of the detention and/or peak flow requirement may be fulfilled by the volume control practice and that practitioners shall be required to demonstrate through calculations or hydrologic modelling the storage quantity and/or the peak flow reductions associated with incorporating the required volume controls into a development, redevelopment, reurbanization, residential intensification or linear infrastructure project.

- The RVC_T for Ontario should consider the requirements of nutrient limited watersheds (i.e. phosphorous and nitrogen) by following other jurisdictions (see **Section 2.4.2**) by requiring the control of runoff from the entire site, not exclusively the impervious surfaces.

- The RVC_T for Ontario should recognize that runoff is generated from all surfaces (not exclusively from impervious surfaces).

4.2 Key Terminologies

For the purpose of this report the following terminology shall be applied.

Stormwater refers to rainwater and melted snow that flows over roads, parking lots, lawn and other sites in rural and urban areas.

Stormwater Management refers to practices which aim to reduce runoff volumes, minimize the impact of polluted runoff flowing into watercourses, control the rate at which runoff is discharged, prevent flooding from occurring, and reduce the strain that stormwater places on stormwater infrastructure.

Infiltration is the downward entry of water into the site soils, as contrasted with percolation which is movement of water through soil layers. For the purpose of this document, infiltration volume shall correspond to the volume which recharges shallow and deep aquifers. Irrigation water which enters the surface of the soil shall not be considered infiltration (see Re-use).

Impervious Area or Surface are hardened surfaces which do not significantly absorb rainwater and/or are not specifically designed to permit the entry of water. For the purpose of this document, impervious areas and/or surfaces shall include, but shall not be limited to, compacted urban soils and gravels, impermeable roof tops and paved surfaces (non-permeable concrete, asphalt and pavers).

Filtration refers to the interception and removal fine particulate material and pollutants from runoff as it passes through an engineered filter media, synthetic filter cells and/or cartridges. Filters shall consist of an appropriate filter media per the LID Stormwater Planning and Design Guide (2010, v1.0 as amended from time to time) or a third party verified manufactured or proprietary product. Filtered runoff may be collected and returned to the conveyance system or allowed to partially infiltrate.

Evaporation is the the process by which water changes from a liquid to a gas (e.g. from rivers and other water bodies into the atmosphere). It does not incorporate transpiration losses from plants.

Transpiration is the portion of precipitation, surface or groundwater runoff absorbed by plants and animals and released in vapor form back to the atmosphere.

Evapotranspiration is the combination of evaporation and transpiration. For the purpose of this document, the evapotranspiration volume shall correspond to free-standing water lost to the atmosphere as well as soil and plant moisture lost to the atmosphere. Harvested rainwater which is used for irrigation and lost to the atmosphere will not be considered evapotranspiration, but rather volume retention through capture during the respective rainfall event. Irrigated volumes will instead be treated as a demand on the rainwater harvesting system which is intended to ensure sufficient capture volume is available for subsequent rainfall events to achieve the required target (see Re-use).

Water Balance of an area over a period of time represents the way in which precipitation falling within that time period is partitioned between the processes of evaporation, transpiration, infiltration, and runoff, taking account of changes in water storage.

Re-use includes storing stormwater runoff and then using it as a source of water for internal and/or external uses. Re-use is also referred to as rainwater harvesting. For the purpose of this document, the runoff collected will be treated as the retained volume and the volume utilized for internal and/or external uses will be treated as a demand on the rainwater harvesting system which is intended to ensure sufficient capture volume is available for subsequent rainfall events to achieve the required target.

Pre-development - is defined as follows for the various development conditions:

- For New Development (i.e. Greenfield Development and or agricultural conversion to urban) - the pre-development impervious condition shall correspond to the current conditions present in the field at the project onset or to an undisturbed forested condition with a maximum runoff-coefficient of 0.15, whichever is most stringent.

- For Redevelopment, Reurbanization and Intensification the (existing urban areas) – the pre-development impervious condition shall correspond to the current conditions present in the field at the project onset, or the least urbanized condition (i.e. lowest total impervious percentage for the site) prior to the project onset to a maximum runoff-coefficient of 0.30, whichever is most stringent.

- For Linear Development and retrofits - the pre-development impervious condition shall correspond to the current conditions present in at the project onset.

New Development means the creation of a new lot, a change in land use, or the construction of buildings and structures requiring approval under the Planning Act, but does not include:

a) Activities that create or maintain infrastructure authorized under an environmental assessment process; and,
b) Works subject to the Drainage Act

Redevelopment - the creation of new units, uses or lots on previously developed land in existing communities, including brownfield and greyfield sites. It may also involve the partial or full demolition of a building and/or structure and the assembly of lands for development.

- Brownfield means undeveloped or previously developed properties that may be contaminated. They are usually, but not exclusively, former industrial or commercial properties that may be underutilized, derelict or vacant
- Greyfield are previously developed sites that are not contaminated.

Intensification – intensification of a property, site or area which results in a net increase in residential or employment density, units or accommodation and can occur in the context of redevelopment and reurbanization. It includes:

a) redevelopment, including the redevelopment of brownfield sites;
b) the development of vacant or underutilized lots within previously developed areas;
c) infill development - new development on formerly vacant land;
d) the conversion or expansion of existing industrial, commercial and institutional buildings for residential use; and
e) the conversion or expansion of an existing residential building or buildings to create new residential units or accommodation, including accessory apartments, second dwelling units and rooming houses.

Reurbanization - describes four (4) distinct types of activity, all of which serve to increase the residential or employment density on sites located within the existing urbanized area of a community. The four types of activity captured under the definition of reurbanization include:

a) infill: new development on formerly vacant land;
b) intensification: an expansion in the use of an existing structure or structures that serves to increase the density on a site
c) adaptive re-use: a change in the use of a building or structure, typically from commercial/industrial to residential, that results in greater density; and,
d) redevelopment: the wholesale change or conversion of an area, often involving some form of land assembly and/or demolition, which results in significantly higher density than existed previously (see above)

Linear Projects - Construction or reconstruction of roads, trails, sidewalks, rail lines and transit infrastructure that are not part of a common plan of development or sale.

Stormwater Retrofit – voluntary construction and/or reconstruction of new municipal stormwater infrastructure and services within an existing area, already serviced or inadequately serviced by stormwater infrastructure which provides a net environmental benefit. A stormwater retrofit:

- cannot be part of a common plan of development (e.g. subdivision, site plan, plan of condominium etc.)
- cannot be described as new development, redevelopment, intensification and reurbanization; and
- does not require approval under the Planning Act.

4.3 Recommended Runoff Volume Control Targets (RVC_T) for Ontario

Based on the jurisdiction reviews completed as part of the **Jurisdictional Scan of Canadian, US and International Stormwater Management Volume Control Criteria Report** and per the recommendations developed as a result of the study of the selected five (5) jurisdictions (**Section 2.0**), the supporting rationale as detailed in **Section 3.1** to **Section 3.5** (Water Balance, Urbanization and Hydromodification, Conventional Stormwater Management and Watershed Impervious Area, and Rationale for the 90th Percentile) and the rainfall analysis for Ontario (**Section 3.6**), a **Runoff Volume Control Target (RVC_T) for Ontario of the 90th percentile event as determined through the hourly rainfall analysis using a 12-hour MIT and excluding events smaller than 2 mm is proposed.** The average 90th percentile of 27 mm was calculated for the Province, with regional variation in the 90th percentile of 23 mm to 33.2 mm.

The volume control target should not preclude the proponent from achieving the required stormwater quantity, quality, erosion control and water balance requirements as identified through watershed, subwatershed, master drainage plans, Environmental Impact Statement (EIS), Provincial Policy and Guidelines or other area-specific studies; nor does it preclude the proponent from the requirement to prepare appropriate pollution prevention plans per the Canadian Environmental Protection Act, and/or Risk Management Plans per the relevant Source Protection Policies pursuant to the Clean Water Act. In all cases, the most stringent policy and/or requirement shall apply.

4.3.1 Runoff Volume Control Target (RVRT) for Ontario

Any works that result in site disturbance, that result in the creation of impervious surface, or fully reconstructs all or some existing impervious surface must meet all of the following stormwater performance requirements as described below.

The following shall be exempt from the application of the requirements listed below. It is acknowledged that individual municipalities may choose to enact more stringent requirements based on specific needs, policies or environmental goals. In all cases the most stringent requirement shall apply.

The exemptions include:

- Minor building additions which result in the creation of no more than 45 m^2 of additional impervious area(s);
- Construction of sheds, decks, patios and other minor site structure/alterations which result in the creation of no more than 10 m^2 of additional impervious area(s);
- Minor variances from municipal zoning bylaws;
- Changes to legal non-conforming uses which the current zoning does not permit;
- Consent for land severance to divide a parcel of land into more than one lot or as lot additions to abutting properties;
- Subdivision of a lot or a block fronting on existing or dedicated road for the purpose of selling, conveying, leasing or mortgaging;

4.3.1.1 New Development Volume Control

For new, nonlinear developments that results in the creation of impervious surface(s) on sites without restrictions, stormwater runoff volumes will be controlled and the post-construction runoff volume shall be controlled on-site, per the mandatory control hierarchy, for the runoff generated from the geographically specific 90th percentile rainfall event (**Figure 3.67)** from all surfaces on the entire site. The site shall be required to maintain the pre-development water balance.

4.3.1.2 Redevelopment, Reurbanization and Intensification Volume Control

For redevelopment, reurbanization and residential intensification projects that results in the creation of impervious surface (including the expansion of parking surfaces) for sites without restrictions, stormwater runoff volumes will be controlled and the post-construction runoff volume shall be controlled on-site, per the mandatory control hierarchy, for the runoff generated from the geographically specific 90th percentile rainfall event (**Figure 3.67)** from all surfaces on the entire site. The site shall be required to maintain the pre-development water balance.

4.3.1.3 Linear Development Volume Control

a) New linear projects without restrictions and subject to the approved Source Protection Plan, that results in the creation of impervious surface(s) and/or fully reconstructs the existing impervious surfaces, shall control per the mandatory control hierarchy the larger of the following:

    i. The runoff generated from the geographically specific 90th percentile rainfall event (**Figure 3.67)** from the new and/or fully reconstructed impervious surfaces on the site

    Or

    ii. The runoff generated from the geographically specific 90th percentile rainfall event (**Figure 3.67)** from the net increase in impervious area(s) on the site

    The site shall be required to maintain the pre-development water balance.

b) Roadway reconstructions which are primarily mill and overlay and other resurfacing activities are not considered new linear projects and shall achieve volume control to the maximum extent possible (MEP) subject to the approved Source Protection Plan. Maximum extent possible (MEP) shall be defined as the maximum achievable volume control, beyond the water balance requirement, using all known, available and reasonable methods, given the site restriction. Excessive costs alone shall not be considered an acceptable constraint, instead practitioners are encouraged to explore and document alternative and innovative alternatives with a reduced implementation cost.

4.3.1.4 Retrofit Volume Control

For the voluntary construction and/or reconstruction of new municipal stormwater infrastructure within an existing urban area the project shall achieve volume control to the maximum extent possible (MEP) provided the following conditions are met:

- The subject area is already serviced by or is inadequately serviced by stormwater infrastructure,
- The stormwater retrofit can be demonstrated to provide a net environmental benefit,
- The subject project can be implemented and is in compliance with the approved Source Protection Plan

- The subject site or project is not part of a common plan of development as defined by the municipality (e.g. subdivision, site plan, plan of condominium etc.), cannot be described as new development, redevelopment, intensification and reurbanization and cannot require approval under the Planning Act,

Maximum extent possible (MEP) shall be defined as the maximum achievable volume control, beyond the water balance requirement, using all known, available and reasonable methods, given the site restriction.

4.3.1.5 Flexible Treatment Options for Sites with Restrictions

The Runoff Volume Control Target (RVC_T) acknowledges that infiltration (**Control Hierarchy Approach 1)** of the runoff generated from the geographically specific 90th percentile rainfall event may not be feasible for every site as a result of site specific constraints. For all sites, regardless of perceived constraints, the proponent shall fully attempt to comply with the appropriate volume control alternative as described above. The Runoff Volume Control Target (RVC_T) acknowledges that volume control is achievable on these sites via re-use and evapotranspiration practices even when partial or no infiltration is possible.

Should consultation with the subject municipality, conservation authority, the MOECC as part of the Environmental Compliance Approval (ECA) pre-consultation and/or pre-design investigation by the proponent identify that volume targets are not achievable; the proponent must consider and present to the MOECC the merits of relocating project elements to address varying soil conditions and other constraints. Property constraints which may result in the permitting alternatives to the above prescribed volume targets include:

a) Shallow bedrock†,
b) High groundwater†,
c) Swelling clays or unstable sub-soils,
d) Contaminated soils (i.e. Brownfields),
e) High Risk Site Activities including spill prone areas,
f) Prohibitions and or restrictions per the approved Source Protection Plans
g) Surface water dominated or dependant features including but not limited to marshes and/or riparian forest wetlands which derive the majority of their water from surface water, including streams, runoff, and overbank flooding. Surface water dominated or dependant features which are identified through approved site specific hydrologic or hydrogeologic studies, and/or Environmental Impact Statements (EIS) may be considered for a reduced volume control target. Pre-consultation with the MOECC and local agencies is required.
h) Water reuse feasibility study has been completed to determine non-potable reuse of stormwater for onsite or shared use. Potable reuse may be considered on case specific basis.

† May limit infiltration capabilities if bedrock and groundwater is within 1 m of the proposed facility invert per Table 3.4.1 of the LID Stormwater Planning and Design Guide (2010, V1.0 or most recent). Detailed assessment or studies are required to demonstrate infiltration effects and results may permit relaxation of the minimum 1 m offset.

Two (2) alternatives are identified for sites with restrictions (i.e. constraints). The proponent shall document the flexible treatment options sequence starting with Alternative #1 in a hierarchical approach ending with Alternative #2 and submit all documentation to the MOECC and/or appropriate approval authority.

4.3.1.5.1 Alternative #1 – Reduced Runoff Volume Control Target (RVC_T)

Proponent attempts to comply with the following conditions:

a) Achieve at least 75% volume control from all impervious surfaces for the runoff generated by the geographically specific 90th percentile rainfall event (**Figure 3.67)**.
b) Options considered and presented shall examine the merits of relocating project elements to address, varying soil conditions and other constraints across the site.
c) Not applicable for sites which directly discharge to a watercourse less than 500 m from the site boundaries (See **Section 4.3.1.6**)

4.3.1.5.2 Alternative #2 - Maximum Extent Possible (MEP)

Proponent attempts to comply with the following conditions:

a) Achieve volume control to the maximum extent possible (MEP). In regards to Alternative #2, the Maximum extent possible (MEP) shall be defined as the maximum achievable volume control, using all known, available and reasonable methods, given the site restriction. Excessive costs alone shall not be considered an acceptable constraint, instead practitioners are encouraged to explore and document alternative and innovative alternatives with a reduced implementation cost.
b) Options considered and presented shall examine the merits of relocating project elements to address, varying soil conditions and other constraints across the site.
c) Not applicable for sites which are directly discharge to a watercourse less than 500 m from the site boundaries (See **Section 4.3.1.6**)

4.3.1.6 Direct Discharge of Stormwater to Watercourses or Wetlands

Sites which discharge directly to watercourses or wetlands present unique challenges for stormwater practitioners. The reduction of pollutant loads is essential before stormwater is discharged to these features in order to preserve or enhance ecological habitat as proximity to the receiver typically does not provide any alternative off-site or centralized treatment options. The Runoff Volume Control Target (RVC_T) acknowledges that volume control is achievable on these sites via reuse, evapotranspiration and infiltration practices.

It should be noted that surface water dominated or dependant features are acknowledged as potential site restrictions (see **Section 4.3.1.5**) including but not limited to marshes and/or riparian forest wetlands which derive the majority of their water from surface water, including streams, runoff, and overbank flooding. Surface water dominated or dependant features which are identified through approved site specific hydrologic or hydrogeologic studies, and/or Environmental Impact Statements (EIS) may be considered for a reduced volume control target. Pre-consultation with the MOECC and local agencies is required.

For sites that discharge via private or municipal conveyance systems directly to a watercourse or wetland that is within 500 m of the site boundary, the proponent will ensure the site achieves complete volume control of runoff that is generated from the geographically specific 90th percentile rainfall event from all surfaces on the entire site. Alternatives #1, #2, will not be considered.

5 FUTURE CONSIDERATIONS

In the development of this report, the following future considerations have been identified:

Many meteorological stations in Ontario do not collect year-round precipitation data. While not significantly affecting the results presented in this report, the lack of spatially distributed year-round precipitation data did limit the analysis. We recommend that the collection of year-round, quality checked, precipitation data which also captures precipitation form (i.e., rain vs. snow) continue. Where possible, additional stations which capture snowfall and accumulation should be considered or existing stations upgraded. Robust winter precipitation information and snow melt data are required to validate the targets presented herein and in the future, further develop validated four season stormwater management targets for use in design activities. The potential impacts of future climate change only increase the need to collect these data as rigorously as possible across the Province.

APPENDIX A – Ontario Rainfall Analysis (Digital Appendix)

APPENDIX B – Recommended Procedures for Developing a Rainfall Frequency Spectrum

Rainfall Frequency Spectrum Development

Guidance on creating an RFS was obtained from USEPA (2009) and CWP (2008) and is provided below as a seven (7) step process. If a community is large in area or has considerable variation in elevation or aspect, the RFS analysis should be conducted at multiple stations.

1. Obtain a long-term rainfall record from an adjacent weather station (daily precipitation is fine, but try to obtain at least 30 years of daily record). NOAA has several Web sites with long-term rainfall records (see http://www.nesdis.noaa.gov). Local airports, universities, water treatment plants, or other facilities might also maintain rainfall records.
2. Edit out small rainfall events than are 0.1 inch or less, as well as snowfall events that do not immediately melt.
3. Using a spreadsheet or simple statistical package, analyze the rainfall time series and develop a frequency distribution that can be used to determine the percentage of rainfall events less than or equal to a given numerical value (e.g., 0.2 inches (5 mm), 0.5 inches (13 mm), 1.0 inches (25 mm), and 1.5 inches (38 mm)).
4. Construct a curve showing rainfall depth versus frequency, and create a table showing rainfall depth values for 50%, 75% 90%, 95% and 99% frequencies.
5. Use the data to define the Water Quality storm event (90th percentile annual storm rainfall depth). This is the rainfall depth that should be treated through a combination of Runoff Reduction and Water Quality Volume treatment.
6. The data can also be used to develop criteria for Channel Protection. The 1‐year storm (approximated in some areas by the 99% rainfall depth) is a good standard for analyzing downstream channel stability.
7. Other regional and national rainfall analysis such as TP-40 (NOAA) or USGS should be used for rainfall depths or intensity greater than 1 year in return frequency (e.g., 2-, 5-, 10-, 25-, 50-, or 100-year design storm recurrence intervals).

First Flush

Similarly, according to USEPA (1976), during the “first flush” storm, the pollutant concentration in the runoff at the beginning of the rainfall event is relatively high, and as the rainfall continues, the subsequent runoff concentration decreases. The temporal profile of the pollutant concentration during storms is approximated by an exponential decrease, as shown in **Figure B1.** The coefficients “C_0” and “C_p” correspond to the initial and subsequent average pollutant runoff concentrations.

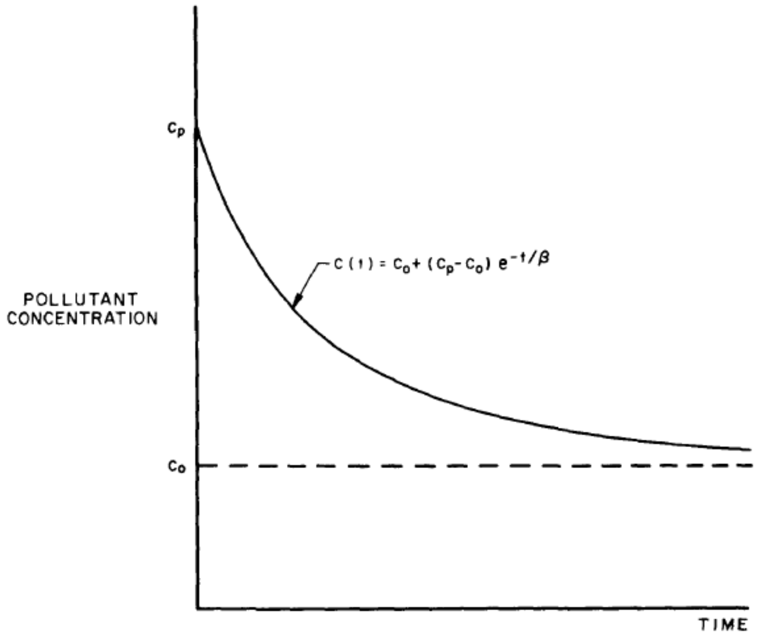


Figure B1 - Exponential decrease in pollutant load during first flush (USEPA, 1979)

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[1] Urban Stormwater Guidelines and Best Management Practices for Protection of Fish and Fish Habitat, Draft Discussion Document, Barry Chilibeck (666-3765) or Megan Sterling (666-2322), Revision 4

[2] Minn. Stat. § 115.03 subd. 5c (2009); this section states: "The agency [MPCA] shall develop performance standards, design standards, or other tools to enable and promote the implementation of low-impact development and other stormwater management techniques. For the purposes of this section, "low-impact development" means an approach to storm water management that mimic's a site's natural hydrology as the landscape is developed. Using low-impact development approach, storm water is managed on-site and the rate and volume of predevelopment stormwater reaching receiving waters is unchanged. The calculation of predevelopment hydrology is based on native soil and vegetation."

[3] US EPA (1989) Analysis of Storm Event Characteristics of Selected Rainfall Gages Throughout the United States (Appendix – Detailed Analysis Results)

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[6] Issued Paper "B" Precipitation Frequency Analysis and Use (EOR and SWMP, Jan 6, 2005).

[7] Barr Engineering, Assessment of MIDS Performance Goal Alternatives: Runoff Volumes, Runoff Rates, and Pollutant Removal Efficiencies, (June 30, 2011) *available at* **http://www.pca.state.mn.us/index.php/view-document.html?gid=15664**.

[8] *Id*.

[9] D.C. Mun. Regs. Tit. 21, § 500 *et seq. avalable at* **http://www.dcregs.dc.gov/Gateway/ChapterHome.aspx?ChapterNumber=21-5**

[10] Much of the description of the D.C. stormwater rule is adapted from various facts sheets available online, including D.C. Dept. of Energy & Envt., *Stormwater Rule Fact Sheet*, **http://sustainable.dc.gov/release/district-establishes-new-river-protecting-stormwater-management-standards**.

[11] According to DDOE (2014), "PROW is defined as the surface, the air space above the surface (including air space immediately adjacent to a private structure located on public space or in a PROW), and the area below the surface of any public street, bridge, tunnel, highway, railway track, lane, path, alley, sidewalk, or boulevard, where a property line is the line delineating the boundaries of public space and private property" (p. B-1)

[12] According to the DDOE (2014), "Maximum extent practicable, or "MEP," is the language of the Clean Water Act that sets the standards to evaluate efforts pursued to achieve pollution reduction to United States waterbodies. MEP

[13] This threshold (disturbance of 5,000 ft^2) has been a trigger for stormwater management BMPs since stormwater management regulations were first established in 1988.

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[14] More information about unified sizing criteria can be found at **http://stormwater.pca.state.mn.us/index.php/Unified_sizing_criteria**.

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