

**THE UNIVERSITY OF WESTERN ONTARIO  
DEPARTMENT OF CIVIL AND  
ENVIRONMENTAL ENGINEERING**

**Water Resources Research Report**

**Computerized Tool for the Development of  
Intensity-Duration-Frequency Curves Under a  
Changing Climate**

**User's Manual v.2.1**

**By:  
Andre Schardong  
Slobodan P. Simonovic  
and  
Dan Sandink**

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# **Computerized Tool for the Development of Intensity-Duration-Frequency-Curves Under a Changing Climate**

[www.idf-cc-uwo.ca](http://www.idf-cc-uwo.ca)

## **User's Manual**

Version 2.1

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By

Andre Schardong

Slobodan P. Simonovic

and

Dan Sandink

Department of Civil and Environmental Engineering and

Institute for Catastrophic Loss Reduction

The University of Western Ontario

London, Ontario, Canada

## Executive Summary

Municipal water management in Canada is heavily dependent on the use of IDF curves in planning, design, and operation of municipal water infrastructure. Many watershed management activities related to water supply, water quality management, flood control, and similar rely on the use of IDF curves. This manual documents version 2 of the web based tool for updating Intensity-Duration-Frequency (IDF) curves under a changing climate.

While there is a need in almost every Canadian municipality to adapt to changing climatic conditions, there is a lack of necessary expertise within municipalities for implementing current research related to the impact of climatic change on IDF curves. Thus, one of the primary objectives of the tool is to standardize the IDF updating process and make the results of current research on climate change impacts accessible to practitioners. The authors and supporting agencies believe that a freely available, computerized IDF updating tool aids in the selection of effective climate change adaptation options at the local level, advancing the decision-making capabilities of municipalities and watershed management authorities. The tool also provides a direct link between Canadian municipalities and the research community, creating opportunities for further research and innovation.

This manual describes the major functionalities of version 2 of the web-based IDF\_CC tool. The tool is designed to assist users in developing and updating IDF curves using precipitation data from Environment Canada or user provided hydro-meteorological stations. Available precipitation data is integrated with projections obtained from Global Circulation Models to assess the impacts of climate change on IDF curves. The accompanying document, “*Computerized Tool for the Development of Intensity-Duration-Frequency-Curves under a Changing Climate, Technical Manual Version 2*” referred to as *TechMan*., presents the methodological background of the web-based IDF\_CC tool version 2.

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# 1 Introduction

Changes in climate observed over recent decades are considered to be the cause of dramatic modifications of magnitude and frequency of extreme events. The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2013) has indicated a global surface temperature increase of 0.3 to 4.8 °C by the year 2100 compared to the reference period 1986-2005, with larger changes in the tropics and subtropics than in the mid-latitudes. It is expected that rising temperatures will have a major impact on the magnitude and frequency of extreme precipitation events in some regions (Barnett et al., 2006; Wilcox et al., 2007; Allan et al., 2008, Solaiman et al. 2011).

Assessment of climate change impacts and the implementation of the contemporary climate change research remains a challenge for many stakeholders and policymakers. The most likely reasons are: 1) complexity of the methods based on heavy analytical procedures and difficulties in their implementation; 2) a focus on publishing research findings under the rigorous peer review process with limited attention given to practical implementation; 3) political dimensions of climate change issues; and 4) a high level of uncertainty involved with future climate projections in presence of multiple climate models and emission scenarios. The implementation of a generic and simple web-based tool that allows users to easily consider the impacts of climate change in the form of updated IDF curves for storm water design and management is considered an effective strategy to increase climate change adaptation capacity in Canada (Sandink et al., 2016). To accomplish this task, the IDF\_CC tool has been developed and has been in public use since March 2015 (Simonovic et al., 2016). This tool combines a friendly web-based user interface with a powerful database system, and applies an efficient, sophisticated methodology for the update of IDF curves.<sup>1</sup>

Intensity duration frequency (IDFs) curves are typically developed by fitting a theoretical probability distribution to the annual maximum precipitation (AMP) time series. The AMP data is fitted using extreme value distributions including Gumbel, Generalized Extreme Value (GEV), Log Pearson, Log Normal, among other methods. IDF curves provide precipitation accumulation depths for various return periods (T) and different durations, typically, 5, 10, 15, 20 30 minutes, 1, 2, 6, 12, 18 and 24 hours. Longer durations may also be obtained, depending on the use of IDF curves. Hydrologic design

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<sup>1</sup> For more information on the methodology applied by the IDF\_CC, see the accompanying document entitled “*Computerized Tool for the Development of Intensity-Duration-Frequency-Curves under a Changing Climate, Technical Manual Version 2*,” referred to as *TechMan*.

of storm sewers, culverts, detention basins and other elements of storm water management systems are typically performed based on specified design storms derived from IDF curves (Solaiman and Simonovic, 2010).

The web based IDF\_CC tool version 2 developed for IDF update under changing climatic conditions is implemented in the form of a Decisions Support System (DSS) with three main components (Figure 1). The user interface is built as a GIS based component using Leaflet™, allowing clear geographical representation of hydro-meteorological stations. User information, station data, and Global Circulation Model (GCM) outputs are stored in the IDF\_CC tool's database system. Mathematical models and algorithms populate the tool's model base.<sup>2</sup>

The major objectives of the IDF\_CC tool version 2 are: (i) to automate; and (ii) facilitate the IDF update procedure using historical observed precipitation data and precipitation predictions from available GCM models. A repository of stations from Environment Canada is available through the user interface with complete records of historical yearly maximums. The tool also allows users to provide their own historical hydro-meteorological data, which can be used to generate locally relevant updated IDF curves. The tool interface presents the IDF results in the form of tables and interactive graphs. Version 2 of the tool utilizes data from GCMs produced for Coupled Model Intercomparison Project Phase 5 - CMPI5 (IPCC, 2013) and statistically downscaled daily Canada-wide climate scenarios, at a gridded resolution of 300 arc-seconds (0.0833 degrees, or roughly 10 km) for the simulated period of 1950-2100 (PCIC, 2013) for various Representative Concentration Pathways (RCPs) (representative concentration pathways). For more information on GCMs and RCPs used with the tool, see Section 3.2 and *TechMan* Sections 2.3 and 2.4.

## 1.1 System Components

This section provides a brief description of the three major DSS components of the IDF\_CC tool version 2. These components include: 1) the user interface (UI); 2) mathematical models and 3) the database and GCM file repository (Figure 1).

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<sup>2</sup> For more information, see *TechMan*

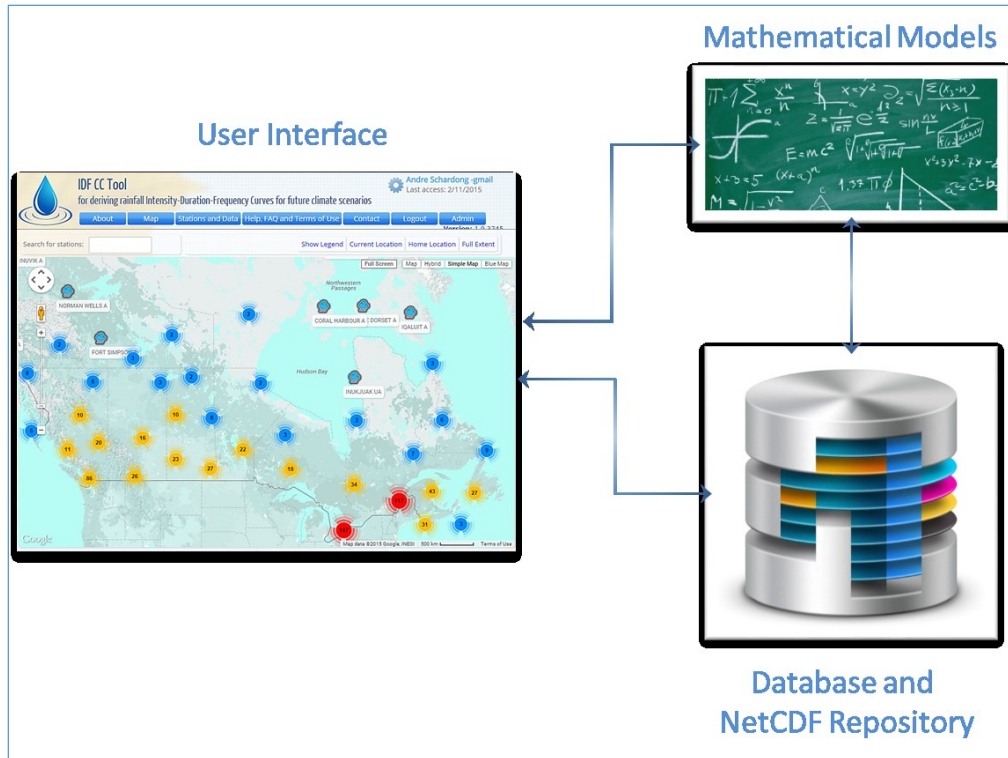


Figure 1. Major system components: user interface, mathematical models and database

## 1.2 Database

The database stores user data, information related to stations and station data, and information from Global Circulation Models (GCMs). The following information is stored in the database:

- User information: to access the IDF\_CC tool's functionalities, users must create an account and provide data that are stored in the database, including their name, email, institution/municipality, intent of use and password.
- IDF repository of Environment Canada data: the IDF\_CC tool's database stores the latest hydro-meteorological station information available from the Environment Canada stations across the country. There are approximately 700 stations throughout the country and roughly 500 of these have at least 10 years of data, which is the minimum length of time series used by Environment Canada to develop IDF curves for a specific station.

- User provided stations and data: any registered user can create stations and provide data for them. The type of data and input options are discussed in section 2.5.5 of this manual. User-created stations can be shared among other users registered with the IDF\_CC tool.
- Original CMIP5 (raw) GCMs and downscaled GCM output files: original and downscaled GCM outputs provided by IPCC PCIC (2013, refer to *TechMan* section 2.4) are available in the netCDF format that is widely used for storing climate data. The direct use of netCDF with the web-based IDF\_CC tool is not computationally efficient and would require huge storage space. Therefore, the netCDF files are converted into more efficient to use format. This converted climate data files are stored in the IDF\_CC tool's database.
- Miscellaneous files: users can upload files that are related to a specific station. The files are also stored within the database and can be of type: text documents, spreadsheets and pdf files.

### 1.3 User Interface

The user interface (Figure 2) provides for management of user actions and inputs and link with the other two DSS components: Mathematical Models and Database. The major parts of the user interface are:

- Leaflet™: the GIS component responsible for map operations;
- Data manipulation: functionalities that allow users to manipulate stations and data;
- Results visualization: functionalities that present the results to the user (tables, equations, interactive graphs).

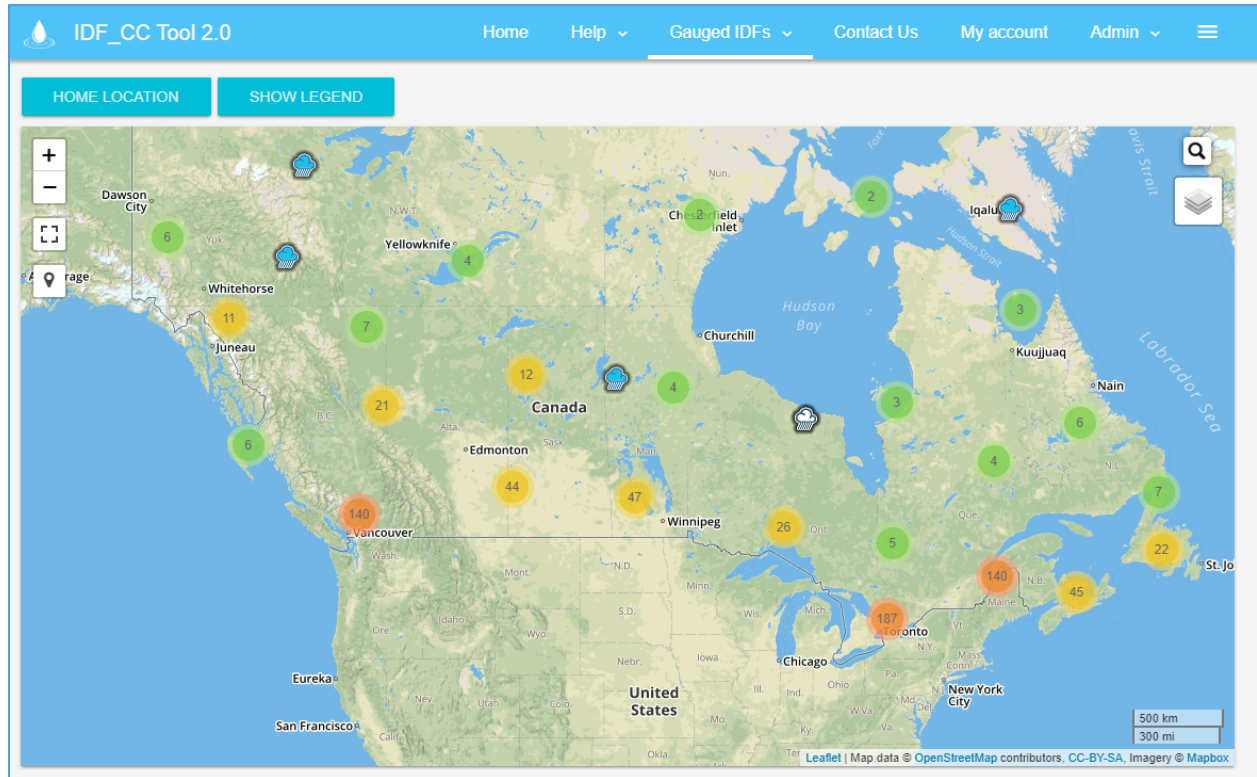


Figure 2. Screenshot of the IDF\_CC tool version 2 user interface

## 1.4 Mathematical Models

The IDF\_CC tool mathematical models are responsible for the calculations required to develop IDF curves based on historical data and incorporating GCM output data into IDF curves. Models listed below are used with the IDF\_CC tool:

- **Statistical analysis algorithms:** statistical analysis is applied to fit the selected theoretical distribution to both historical and future precipitation data. The distribution applied by the tool for fitting historical data is Gumbel, which is fitted using method of moments. For future IDF's and historical data the Generalized Extreme Value (GEV) distribution is used and parameters are fitted using L-moments method. Please refer to *TechMan* section 3.1 for detailed description of the Gumbel and GEV distributions.
- **Optimization algorithm:** an algorithm used to fit the analytical relationships (equations) to the IDF curves. For each return period ( $T$ ) an equation is fitted using “Differential Evolution” optimization algorithm that is described in Storn and Price (1997) and Vasani (2008) (Appendix

A). This algorithm is used to find the coefficients of the equation by minimizing the sum of the root square error of the IDF curve and calculated by the equation.

- IDF update algorithm: the Equidistant Quantile Matching (EQM) algorithm is applied to the IDF updating procedure. This algorithm combines historical observed precipitation data with data from the GCM models to develop the IDF for future periods. A detailed description of this algorithm is presented in the *TechMan* section 3.2.

## **2 The IDF\_CC tool Use**

This section describes in detail use of the IDF\_CC tool version 2. Two case studies are presented to illustrate all functionalities of the tool. The first example uses one Environment Canada station. The second case study exemplifies use of the tool for locations where Environment Canada data are not available. In this case, the user creates a station and inputs their own hydro-meteorological data into the tool.

### **2.1 Creating an Account**

The user must create an account before accessing all IDF\_CC tool functionalities. The account is necessary in order to allow user to customize map locations, create stations and provide data, visualize and export IDF curves fitted by the IDF\_CC tool using historical data and updated IDF curves developed using future climate data. The following information is required from the user to create an account (Figure 3): Full Name, Email address, Affiliation, Occupation, Intent of Use and Password.

Once information is provided an email will be sent to the user with the activation code and/or activation link as shown in Figure 4 (please be sure to check the spam folder for the email sent by the tool). By clicking on the link provided, the user will activate their account. If for some reason the link does not work, the user will be required to provide an activation code when they first access the tool (Figure 5 and Figure 6).

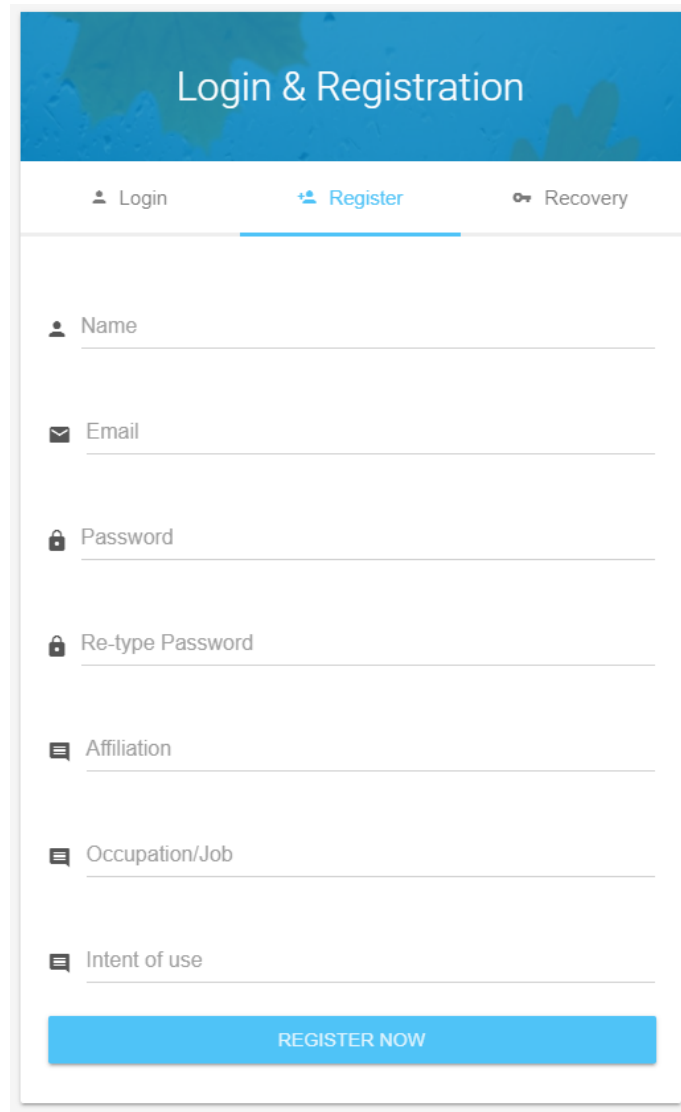
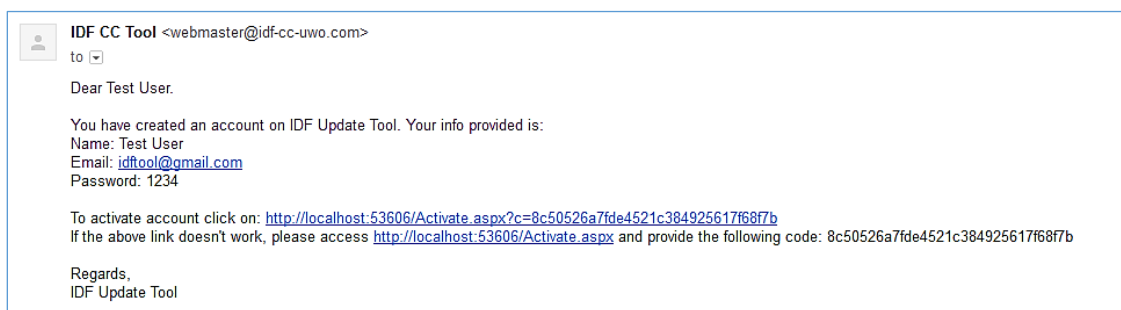


Figure 3. Screenshot of the user account creation page



**IDF CC Tool** <webmaster@idf-cc-uwo.com>  
to ▾  
Dear Test User.  
You have created an account on IDF Update Tool. Your info provided is:  
Name: Test User  
Email: [idftool@gmail.com](mailto:idftool@gmail.com)  
Password: 1234  
To activate account click on: <http://localhost:53606/Activate.aspx?c=8c50526a7fde4521c384925617f687b>  
If the above link doesn't work, please access <http://localhost:53606/Activate.aspx> and provide the following code: 8c50526a7fde4521c384925617f687b  
Regards,  
IDF Update Tool

Figure 4. An example of activation email message



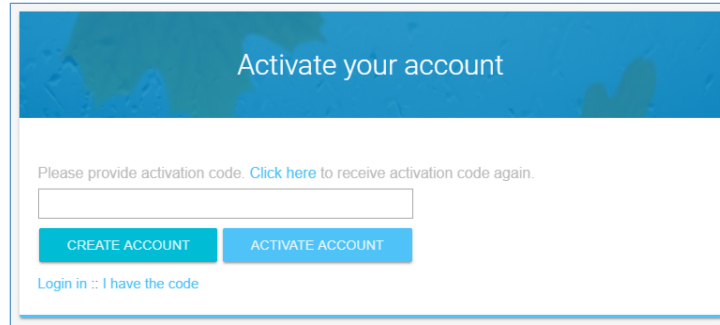


Figure 5. Activation page of the IDF\_CC tool

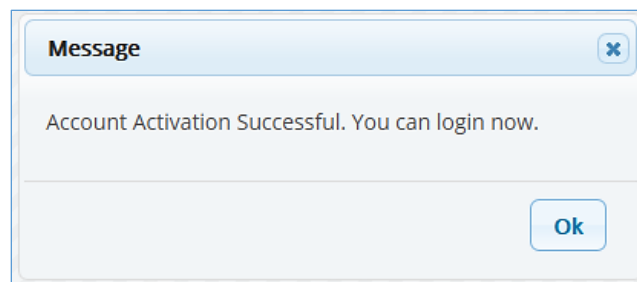


Figure 6. Message of account successfully activated and ready to use

## 2.2 Login and Password

After the account is created and activated, the user will be able to login using the email and password previously provided (Figure 7). The user can recover their password by using the “Recovery” option. A new password will be provided to the user by email as illustrated in Figure 8.

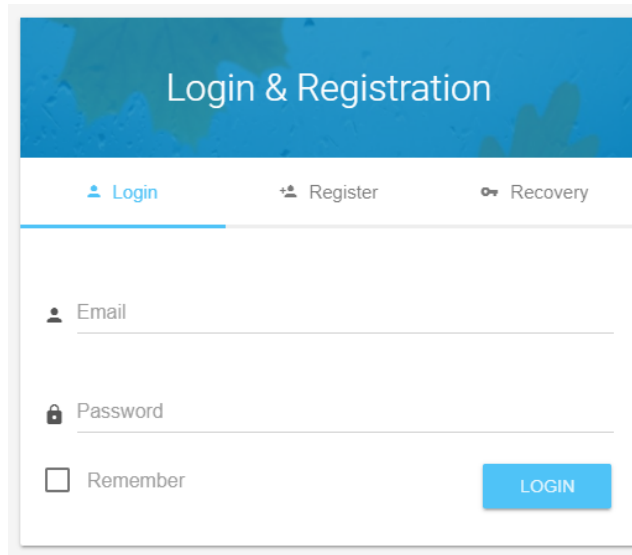
The image shows a web form titled "Login & Registration" with a blue header. Below the header is a navigation bar with three links: "Login" (with a person icon), "Register" (with a person icon), and "Recovery" (with a key icon). The "Login" link is underlined. The main form area contains three input fields: "Email" (with a person icon), "Password" (with a lock icon), and "Remember" (with a checkbox icon). A blue "LOGIN" button is positioned to the right of the "Remember" field.

Figure 7. Login page

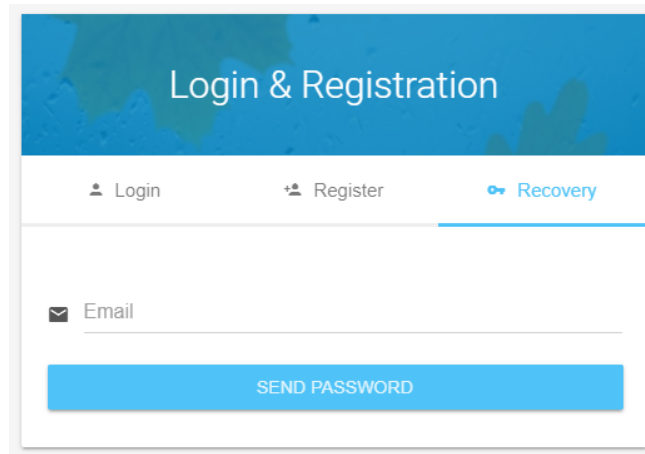
The image shows a web form titled "Login & Registration" with a blue header. Below the header is a navigation bar with three links: "Login" (with a person icon), "Register" (with a person icon), and "Recovery" (with a key icon). The "Recovery" link is underlined. The main form area contains one input field: "Email" (with an envelope icon). A blue "SEND PASSWORD" button is positioned below the "Email" field.

Figure 8. "Recover Password" screen

## 2.3 Main Page Description

After login, the main page is presented to the user (Figure 9). At the top portion, or header, a logo, the name of the tool, menu items, and user name are presented. The middle section is where information and maps are displayed. These functions will be described throughout this manual. The lower part, or footer, presents information and logo from the institutions involved in the development of the IDF\_CC tool.

On the top left of the header, the name of the user is presented, as shown in Figure 10. By clicking on the user's name, the user is able to update account information as shown in Figure 11 and change password as shown in Figure 12.



Figure 9. Main page screenshot

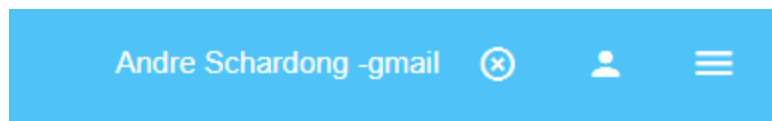




Figure 10. Logged user information


# Update Password and Account

 Update password

 Update account


---

Name

 Andre Schardong -gmail


---

Affiliation

 UWO


---

Occupation/Job

 Student

---

Intent of use

 Resarch

---

UPDATE ACCOUNT

Figure 11. Updating user information

Update Password and Account

Update password Update account

Current Password

New Password

Re-type New Password

UPDATE PASSWORD

Figure 12. Updating password

## 2.4 Menu Options

The menu options, as presented in Figure 13, are briefly described bellow:

- Home: description of the tool and home screen.
- Help: user manuals and additional resources.
- Gauged IDFs: this option presents the map and stations from Environment Canada and those created by the user (Figure 13).
- Stations and Data: this item opens a list of stations created by the user and allows them to select data, upload companion files, share with other users, delete and create stations. This page also allows users to see all stations from Environment Canada, as well as open the IDF screen.

- Help, FAQ and Terms of Use: provides access to help documents including the User Manual, *TechMan*, and other references, frequently ask question section – FAQ and terms of use of the IDF\_CC tool.
- Contact us: contact form of the tool to send comments, report bugs and other issues.
- Admin Menu: this item is only available to IDF\_CC tool’s administrator(s).



Figure 13. Main menu items

## 2.5 Exploring Map Functionalities

The IDF\_CC tool uses a GIS based map tool (Leaflet) to assist the user in locating stations and performing other map related operations (Figure 14). This map shows all stations available from Environment Canada and additional user-created stations. Regions with higher station coverage are grouped (depending on the zoom level) and shown as dots. The number inside the dot is the number of stations in that region. The colours indicate station density (green for lower density, to orange for high density). As users zoom in on a specific region of the map, stations are shown individually, as presented in Figure 15. Stations created by the user are presented with an icon in green while those from Environment Canada are shown in blue, and station with less than 10 years of data in grey (Figure 15).

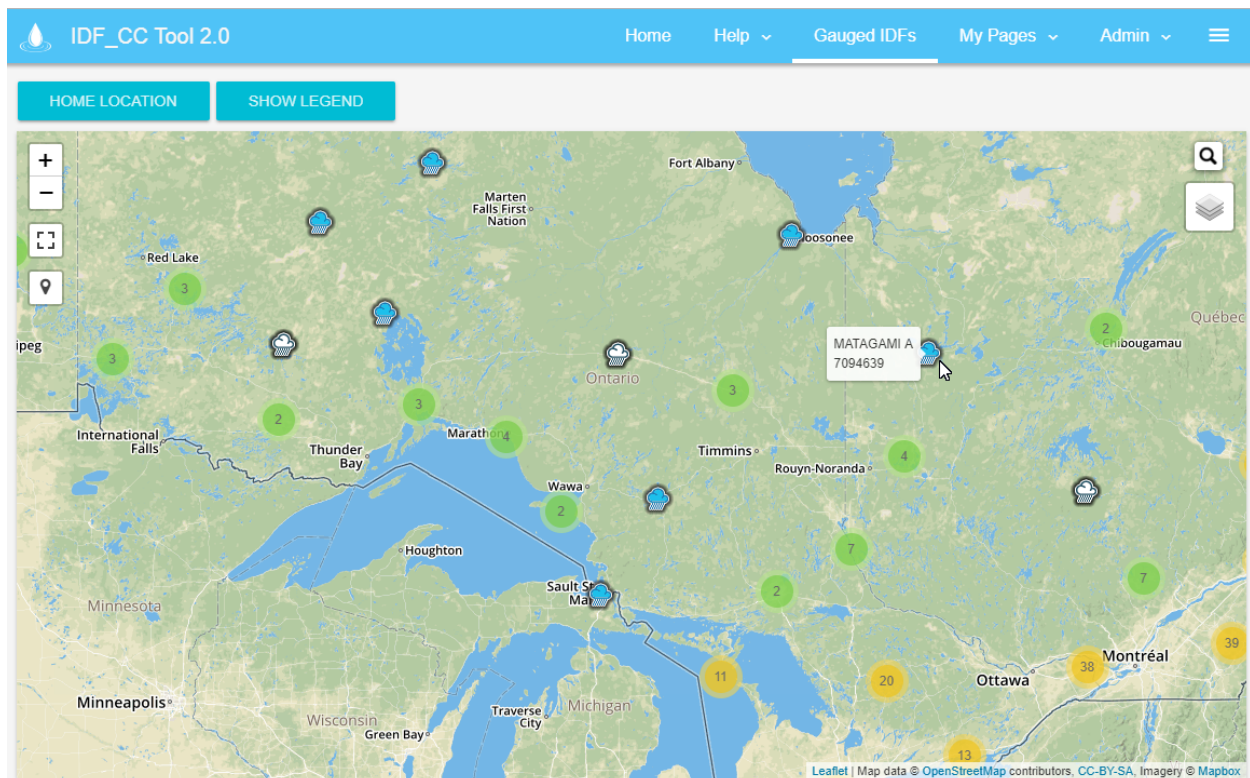


Figure 14. Screenshot with map of Canada showing stations from Environment Canada and/or user provided stations



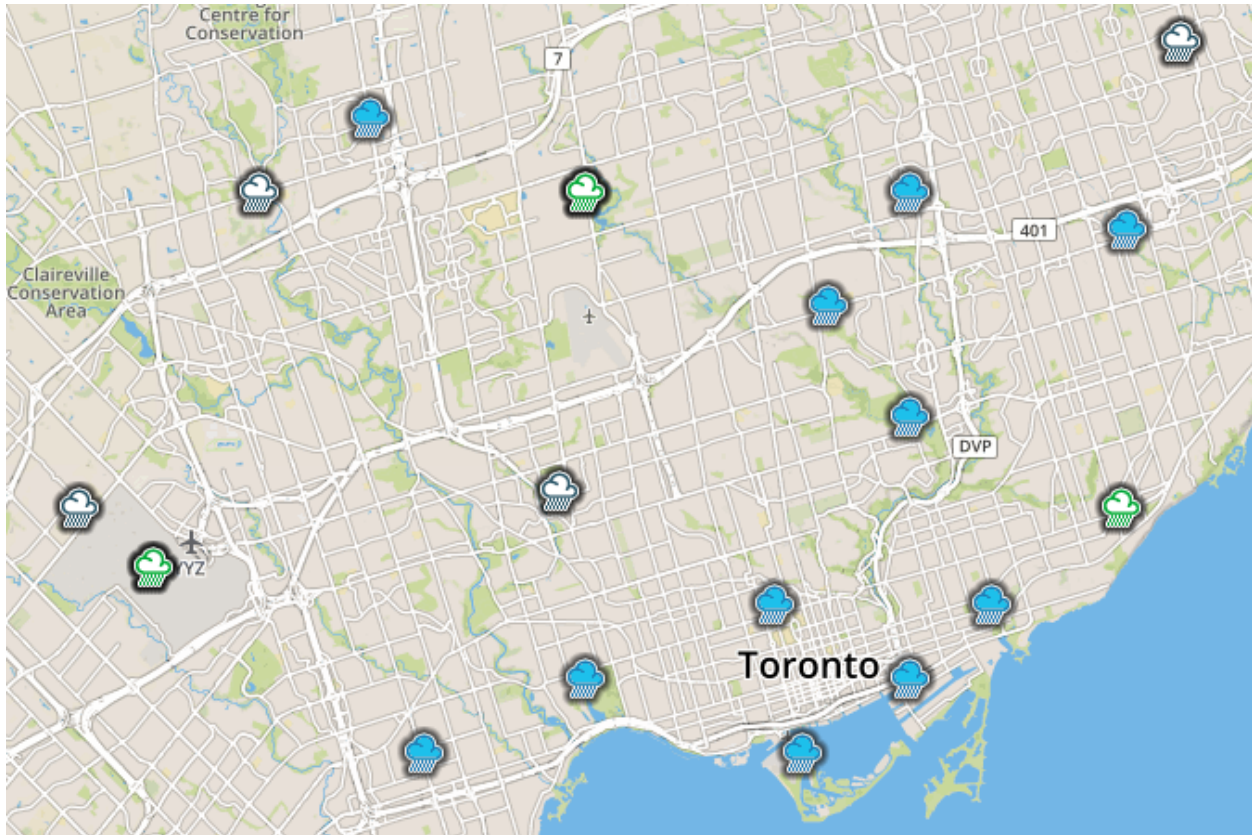


Figure 15. Stations map: Environment Canada (blue), user provided (green), and stations with less than 10 years of data (grey).

### 2.5.1 Locating an Existing Station on the Map

The stations can be visually located on the map or the user can search for stations using the search icon located in the top right corner of the map screen. As the user types in the box, the list of station names is searched and filtered based on the text provided, as in Figure 16. If one of the filtered stations is selected by the user, the map is zoomed-in and centered on the selected station (Figure 16).



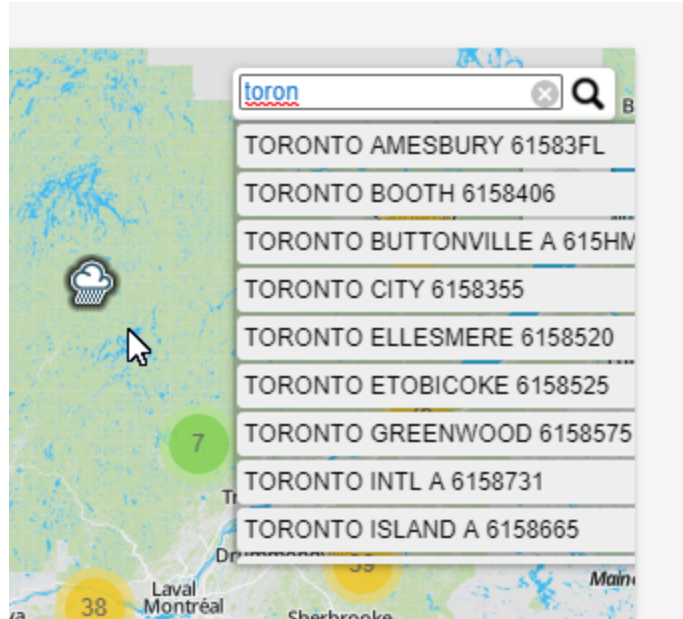


Figure 16. Additional options of the IDF\_CC tool map

In the top right corner over the map screen, some additional functions are available, as shown in Figure 17 and Figure 18. These functions include:



- Show/Hide Legend
- Home Location: the IDF\_CC tool allows user to set a home location by right clicking on a specific location on the map and selecting option “Set as Home Location” as shown in Figure 19. Home location is also where the map will open after login, once it is set.
- Current Location : the IDF\_CC tool will try to obtain the user’s current location using “Geo Location.” A blue dot is placed on the location if found as in Figure 18. The user will also be asked to allow this operation (the web browser will present this request and the message may vary depending on the browser).
- Full Extent : shows the entire map of Canada as in Figure 18.



Figure 17. Additional options on the IDF\_CC tool map

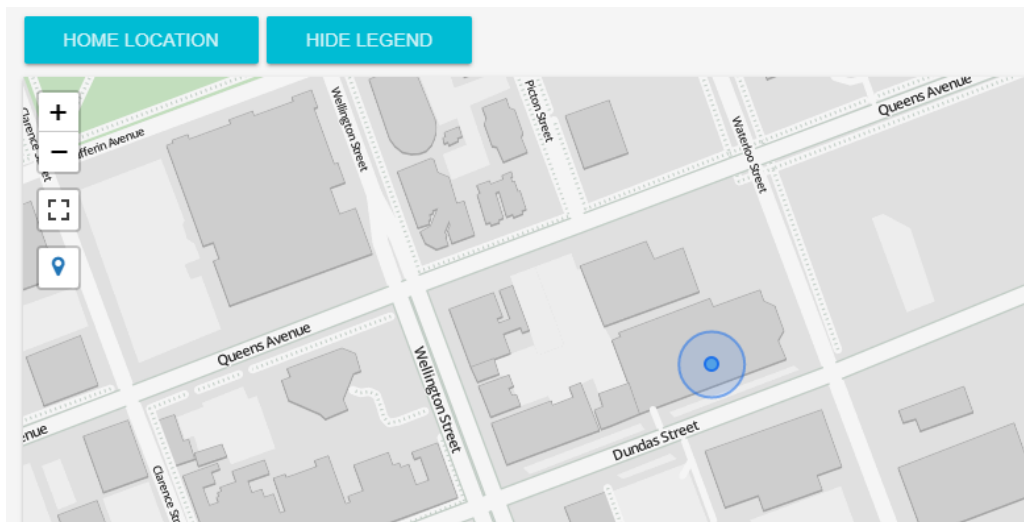


Figure 18. Current location

By right-clicking on the map a context menu will be presented as in Figure 19. One of the options is “set as home location” that will store this location as the “home location” for the logged user. “Center map here” centres the map on the selected location. “Show coordinates” will present the coordinates of the point on the map selected, “Create station here” will open the pop-up window for creating a new station. This option will be explained later in the manual. The advantage of creating a station from the map is that it will automatically provide the coordinates and location (city and province) of the station on the map.

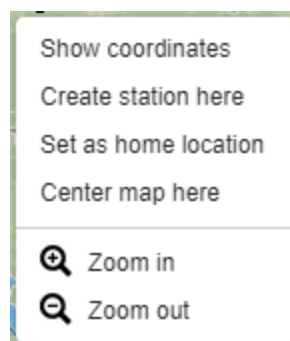


Figure 19. Context menu option on the map

## 2.5.2 Background Options for Maps

The tool provides eight different options for the map backgrounds that differ in the level of detail.

The options are:

- No map: no background map is shown when this option is activated.
- OpenStreetMap: the tool's default base map. Presents details like street names and points of interest. The example map is presented in Figure 20.
- Clean: simplified map with only major points of interest and no labels are shown. The example map is presented in Figure 21.
- Simplified: simplified map with only major roads and major points of interest. The example map is presented in Figure 22.
- Image: satellite images (arterial view) from ESRI © (Figure 23).
- Water colour: simplified map, with minimal details - roads and points of interest. Water bodies are presented in blue and land as light brown (Figure 24).
- Grey: Light grey map with minimum details (Figure 25).
- OpenTopoMap: combines topology and OpenStreetMap (Figure 26).

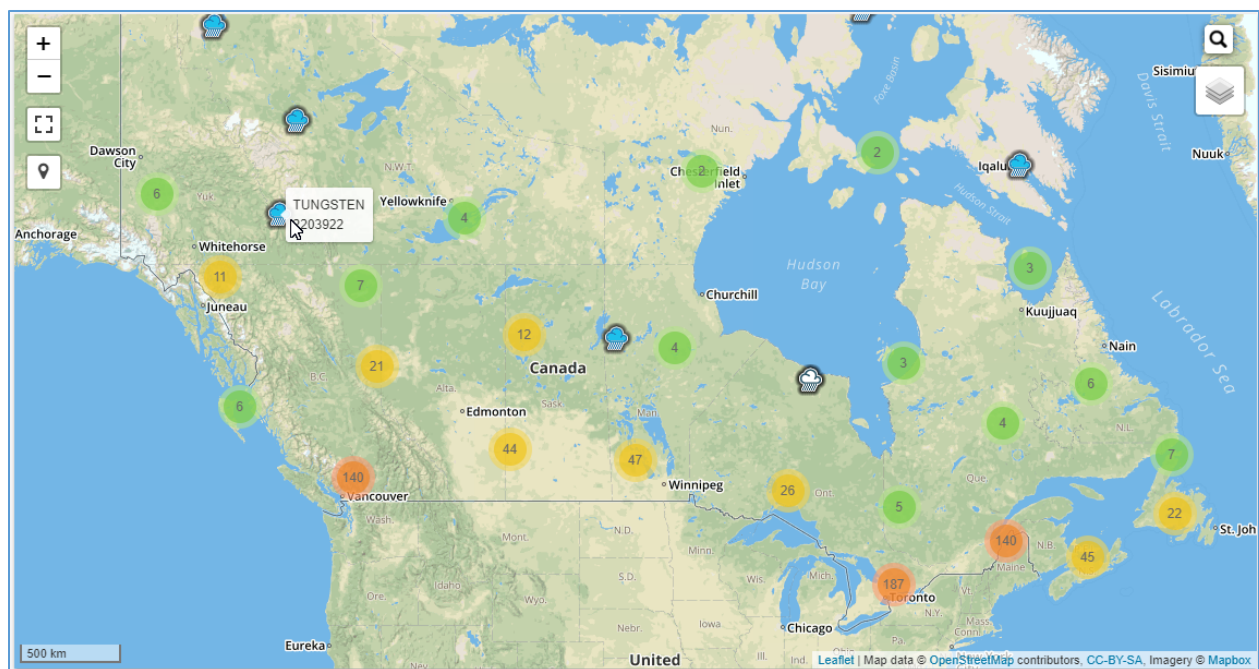
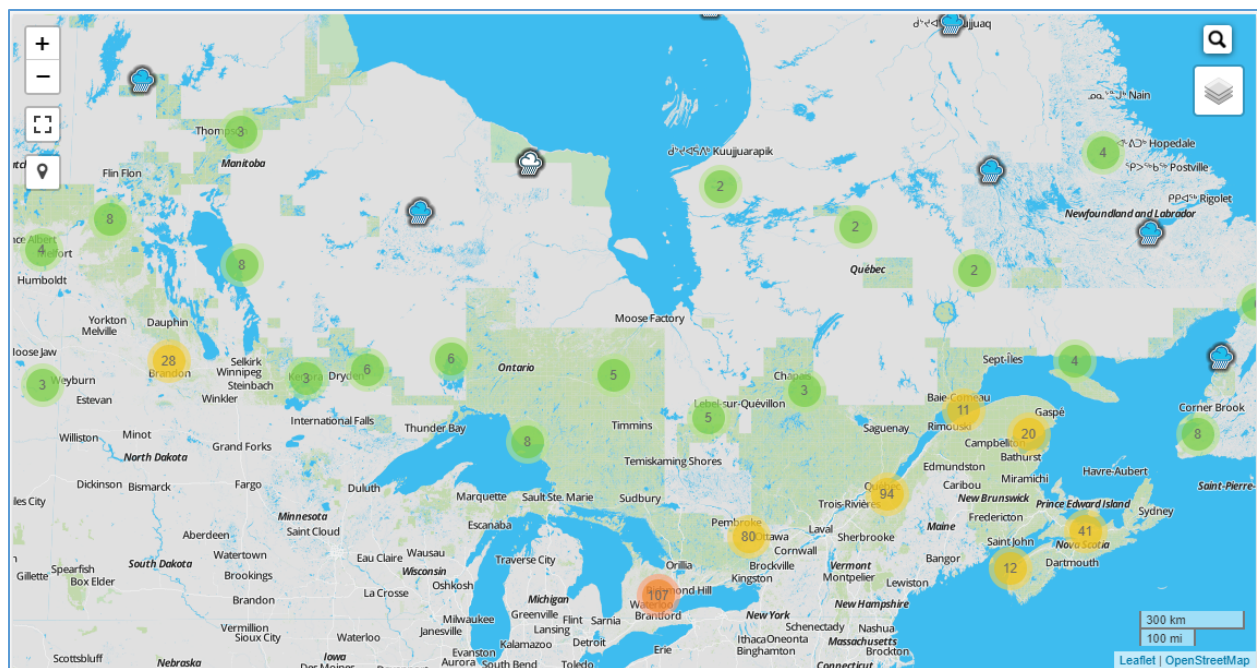
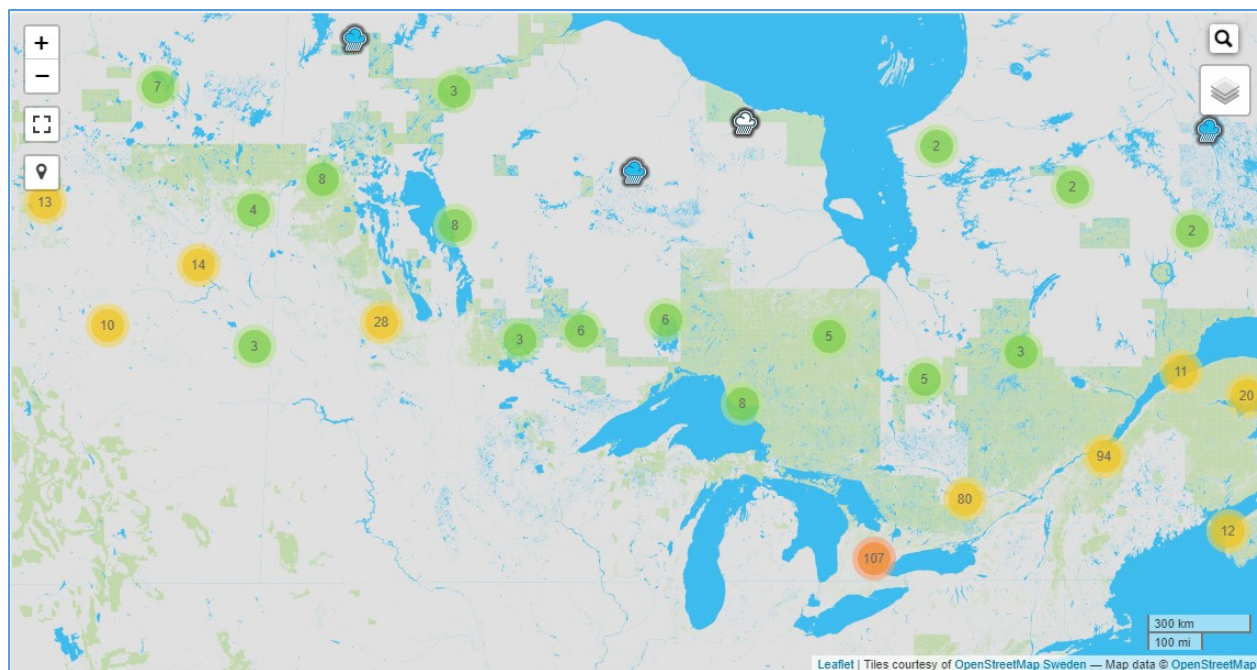


Figure 20. OpenStreetMap (IDF\_CC tool's default)





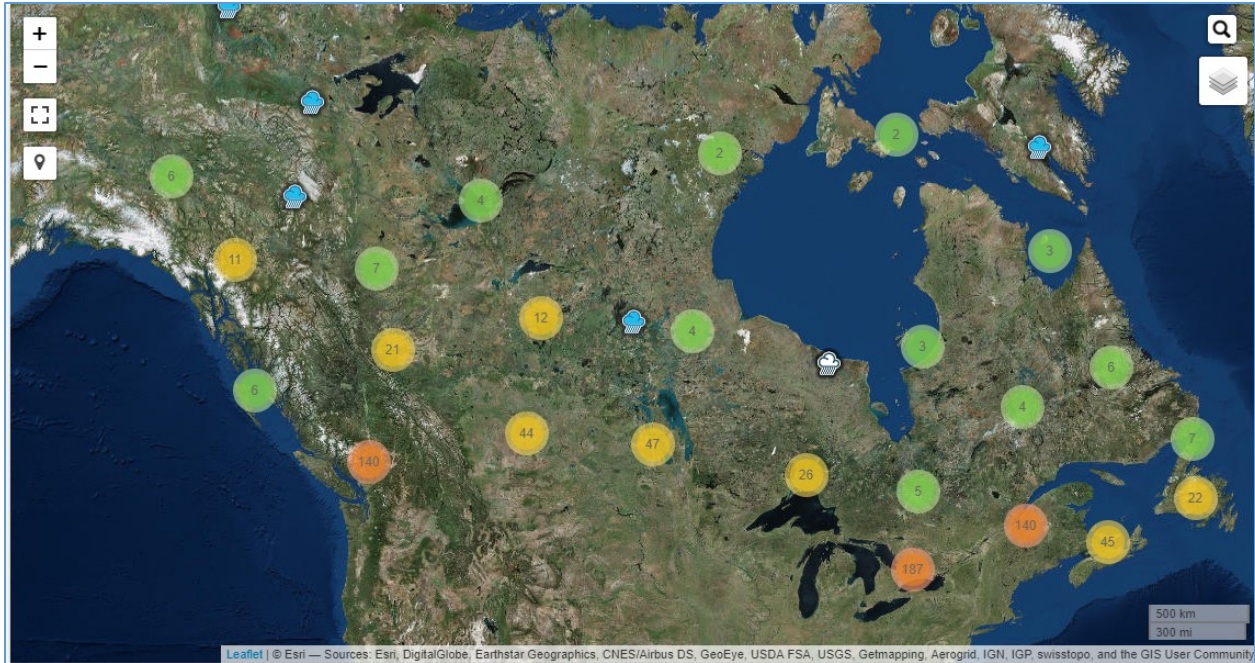


Figure 23. Arterial view background map – ESRI imagery

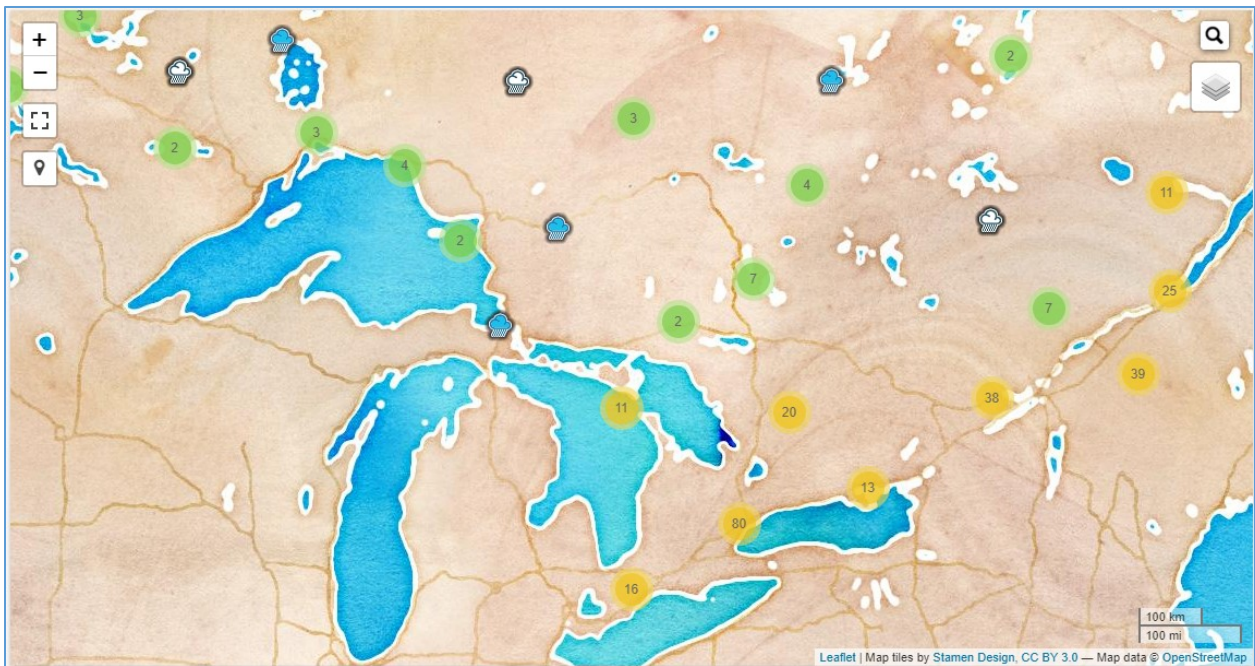


Figure 24. Water colour background map – ESRI imagery

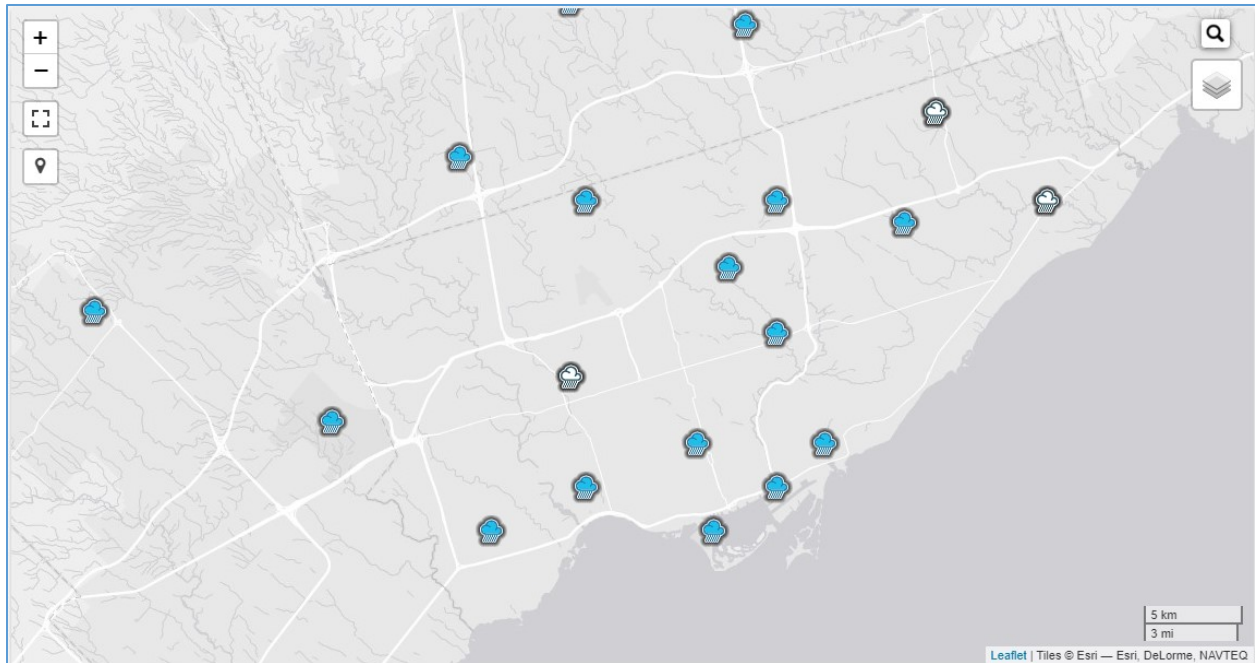


Figure 25. Grey background map – ESRI imagery

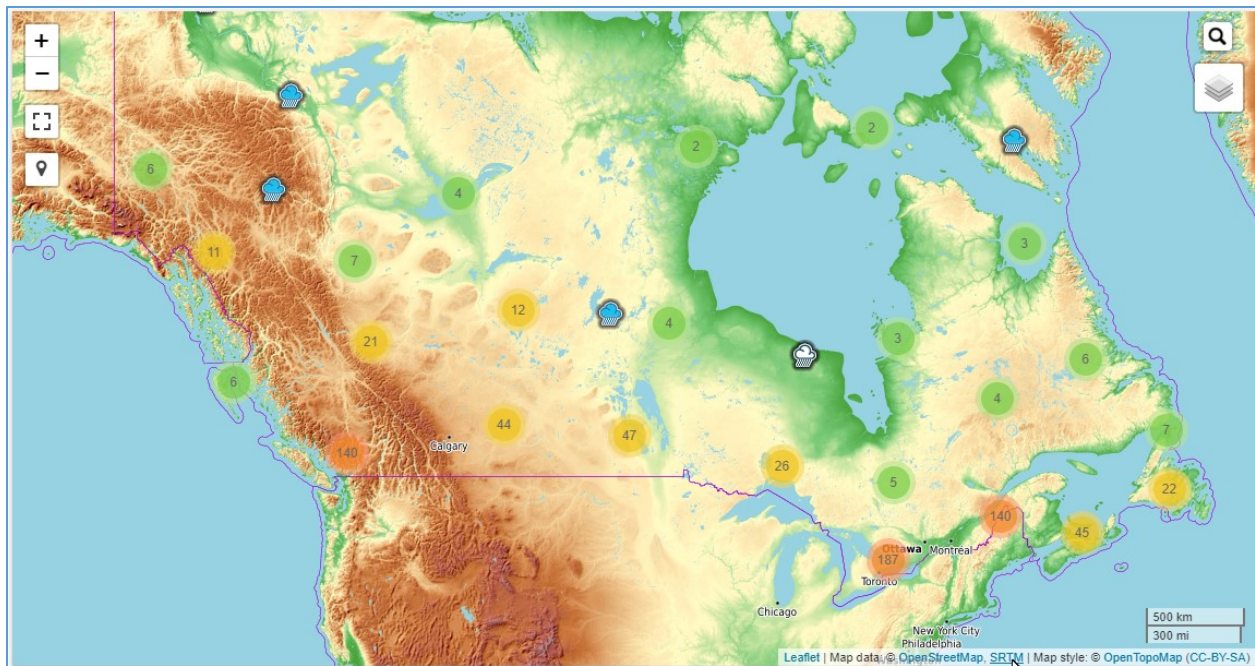


Figure 26. OpenTopoMap background map

The map also presents the source of the background map in use and the scale of the map, as shown in Figure 27.





Figure 27. Map source and map scale

### 2.5.3 Creating Stations on the Map

Another function on the context menu (activated by right click on the map) is “create station here” that can be used to create a station at the selected location. This option will open a new popup window with the new station page as presented in Figure 28. Using this function, some information will be automatically filled in for the user: latitude and longitude (in degrees), city and province (Figure 28).

Other information to be provided by the user to create a station includes:

- Name (required): station name.
- Station ID (required): unique ID has to be provided. The IDF\_CC tool will check if provided ID is already in use.
- Description (optional): a description of the station.
- Sub-daily Maximums (required): the sub-daily precipitation maximums used or considered in the analysis. The defaults selected are: 5, 10, 15, 30 minutes, 1, 2, 6, 12, 24 hours.
- Additional Information (optional): any other relevant additional information about the station.
- City and Province (optional): city and province of the station location.

## Create a new station

### General information

Station name\*

ID\*

Province

Ontario ▼

City

London

Description

Create station

### Location

Latitude (Ex: 40.70 for 40°42' N)\*

42.99761672705504

Longitude (Ex: -80.30 for 80°18' W)\*

-81.22982025146484

Elevation (in m, ex: 100.25)

Additional location information

Select sub-daily maximums for this station

☒ 5 min
☒ 10 min
☒ 15 min
☐ 20 min
☒ 30 min
☒ 1 hr
☒ 2 hr
☐ 3 hr
☒ 6 hr
☒ 12 hr
☐ 18 hr
☒ 24 hr

Figure 28. Creating a station on the map

## Create a new station

### General information

Station name\*

Name is required ✕

ID\*

ID is required ✕

### Location

Latitude (Ex: 40.70 for 40°42' N)\*

Latitude is required ✕

Longitude (Ex: -80.30 for 80°18' W)\*

Longitude is required ✕

Figure 29. Required input for creating a station

The user created station will be plotted on the map based on the provided coordinates. The coordinate system used is the World Geodetic System (WGS) also known as WGS 84 or EPSG 4326. Stations










created by users are visible only to the creators. The creator can share and make the station accessible to other users within the tool. Please see Section 2.6 for more detail.

The next section explains how to provide data for a station, generate the IDFs for historical and future periods, share stations and upload files.

#### 2.5.4 Legend

The legend helps the user identify elements on the map. The elements are quickly described below. The legend becomes visible on the screen by selection “Show legend” option, as presented in Figure 30. The list of items are:

-  Regions with low density of stations (between 1 and 9)
-  Regions with medium density of stations (between 9 and 99)
-  Regions with high density of stations (above 100)
-  Stations created by the user
-  Stations from Environment Canada
-  Stations with less than 10 years of data
-  Stations shared with the user

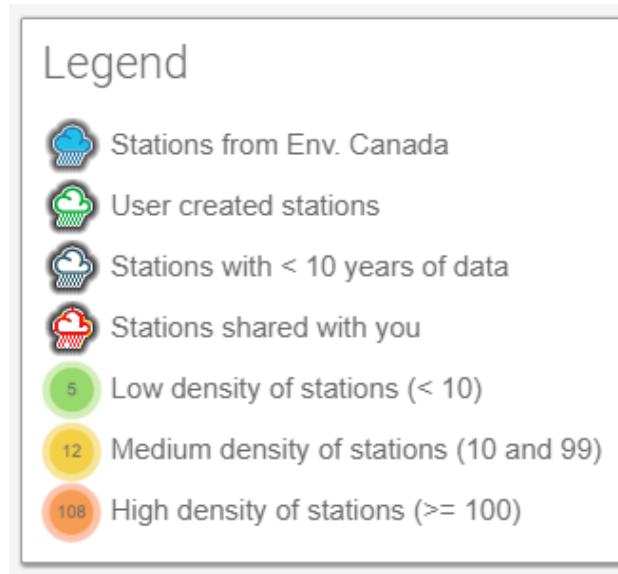


Figure 30. Legend

## 2.6 Managing Stations and Data

The user can access stations from the tool's map view. Additionally, the "Stations and Data" option from the main menu will open a station page as shown in Figure 31. This page will show all stations created by the user and allow (i) precipitation data editing, (ii) uploading files, and (iii) sharing the station with other users. These options are presented as tabs in Figure 31.

Figure 31. Station page: precipitation data editing, uploading files and sharing

The station list will only include stations created by the logged-in user and those shared with the user by other users, as in Figure 32. The user can search the list of stations by typing text within the search textbox above the list. A checkbox “Show Env. Canada Stations” allows user to see all stations in the database from Environment Canada, as shown in Figure 33. Stations that are shared as full access with the logged-in user will be identified with “(full access)” after the station’s name, as in Figure 32. If the other user shares the station as read-only, the “(read-only)” will be added instead of “(full access)”. For more information on sharing user generated stations and station data, see Section 2.6.3.

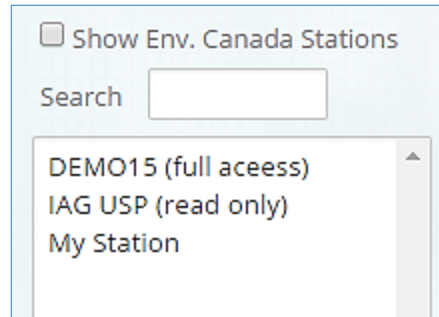


Figure 32. User created stations

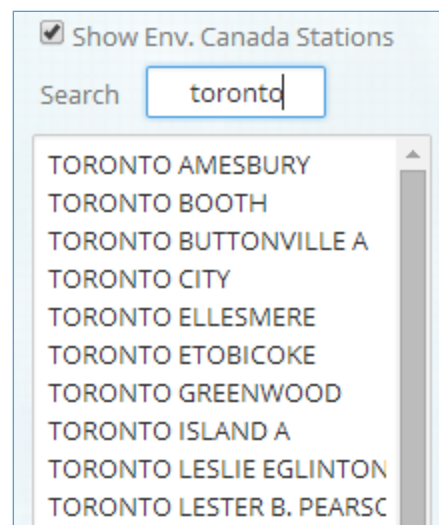


Figure 33. Stations from Environment Canada

Below the list of stations, a few additional functions are available when a specific station has been selected from the list, as illustrated in Figure 34:

- “Generate/Show IDF”: generates and shows the IDF curve and presents the page for updating IDF curves for future climate conditions. The user can also perform these functions by selecting a station on the map.
- “Edit Station”: allows user to edit station’s basic information (location, name, ID, etc.).
- “Create Station”: allows user to create a new station, and serves as an alternative to creating a station by right clicking on the map. When using this approach for creating a new station, no information about coordinates and location (city/province) will be provided and the user will have to provide this information manually.

- “Delete Station”: allows user to delete station and all associated data, and serves as an alternative to deleting the station directly from the map.
- “Create a Copy”: allows user to copy a station to their account. Users can copy stations from Environment Canada and add or modify data. Similar to user created stations, copied stations can be deleted and edited by users.



Figure 34. Options available for a selected station on list

When the selected station is from an official source (e.g., Environment Canada), the “Edit Station” and “Delete Station” options will not be available, as shown in Figure 35.

Figure 35. Users are not able to delete or edit station data for stations from official sources, including Environment Canada

Selecting (clicking) one station from the list will enable the *Tabs* on the right side of the page, as shown in Figure 36. Each *Tab* is described as follows:

- Station Info: basic station information, name, coordinates, ID
- User Data: data provided by the user. This is presented in detail in section 2.6.1.
- Official Data: data from Environment Canada. No editing is possible and the yearly sub-daily precipitation maximums are presented as “read only” data to the user.
- Companion Files: allows user to upload or download supporting files (see Section 2.6.2).
- Share Station: share station with other users registered with the IDF\_CC tool (see Section 2.6.3).

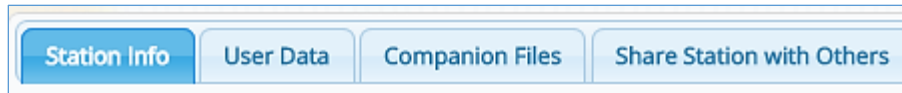


Figure 36. List tabs available on the station data page.

### 2.6.1 Preparing and Providing Data for User-Created Stations

The IDF\_CC tool allows users to provide precipitation data in two formats: daily sub-daily maximums or yearly sub-daily maximums (Figure 37). When selecting the option “Daily Maximums” the starting and ending date for the precipitation series is requested. Once the date range is defined the “Change Dates” button, when selected, will prepare the spreadsheet and allow the user to provide precipitation data within the specified range. As shown in Figure 37 the dates are shown continuously from start to the end date. Days without precipitation events can be left blank (null) or with negative values. In the processing steps the IDF\_CC tool’s algorithms will ignore null or negative values. It is recommended that the user prepare data using a spreadsheet processor, like Microsoft Excel™, and then copy data into the IDF\_CC tool by using Ctrl + C (to copy) from Excel and Ctrl + V (to paste) into the IDF\_CC tool’s spreadsheet. After the data is pasted into the spreadsheet, it can be saved to the database by selecting “Save Daily Data”. Other data formats can also be used, such as formatted text files. Excel spreadsheets and text files (Figure 38) should be organized in columns, where each column represents a sub-daily maximum following the order in the IDF\_CC tool’s spreadsheet (Figure 37). The user will need to provide data for sub-daily durations specified in station information (i.e., 5min, 10min ... 1hr, 2hr ... 24h), otherwise the IDF\_CC tool will neither be able to fit the IDF curves nor to update them.

Select the type of data you would like to use for IDF generation:

☒ Daily maximums ☐ Yearly maximums

**Daily maximums** Yearly maximums

Starting date  Ending date  **Apply** (use dd/mm/yyyy format)

**Save Daily Data**

Date (yyyy-mm-dd)	5 min	10 min	15 min	30 min	1 hr	2 hr	6 hr	12 hr	24 hr
2015-02-01									
2015-02-02									
2015-02-03									
2015-02-04									
2015-02-05									
2015-02-06									
2015-02-07									
2015-02-08									
2015-02-09									
2015-02-10									
2015-02-11									
2015-02-12									
2015-02-13									
2015-02-14									

Figure 37. Editing/saving sub-daily daily maximums

**Data.txt - Notepad**

File	Edit	Format	View	Help
7.6	11.7	15.2	18.5	21.3
10.4	16	21.8	24.6	25.9
9.4	11.7	14.5	22.9	31.2
7.1	11.7	15.7	20.3	20.6
11.9	17.8	21.1	24.4	24.6
7.4	10.2	13	17.8	21.3
5.8	6.1	6.1	8.1	8.9
7.1	8.4	8.6	9.9	10.4
6.1	11.2	13.5	17.8	27.2
9.4	10.7	11.2	17	19.6
17	20.8	23.4	31.5	32.5
10.7	14.2	19.8	21.8	22.4

Figure 38. Formatting data in text files to paste on the IDF\_CC tool's website



When yearly sub-daily maximums are available, they can be entered into the system instead of daily data (see Figure 39). Starting and ending year are required for yearly sub-daily maximums. After defining the range and applying changes with the “Change Years” menu button, the spreadsheet will be ready to receive data. Data can also be copied using Microsoft Excel™ or formatted text files. Each column represents one sub-daily duration. Users are requested to provide data for sub-daily durations (i.e., 5 min, 10 min, 15 min, 30 min, 1hr ... 24hr) specified in the station information otherwise the IDF\_CC tool will neither be able to fit the IDF curves nor update them.

Select the type of data you would like to be used for IDF generation:  
☐ Daily Maximums ☒ Yearly Maximums

Starting Year (yyyy)  Ending Year (yyyy)

Year	10 min	20 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr
1931	10.1	17.7	25.0	37.5	68.4	90.4	116.6	116.6	116.6
1932	11.7	21.7	26.5	32.1	32.1	32.1	35.6	35.6	35.6
1933	11.7	16.5	16.6	27.0	32.9	36.6	45.1	45.7	65.4
1934	16.9	19.3	21.6	29.0	35.9	38.7	38.7	38.7	58.6
1935	15.0	23.0	26.3	31.0	36.2	36.5	44.5	54.7	56.4
1936	11.3	17.9	20.2	23.4	29.6	35.5	43.9	60.5	60.5
1937	22.0	39.0	50.7	55.9	56.4	56.4	56.6	56.6	83.0
1938	8.3	16.6	19.8	24.7	42.2	47.9	54.2	72.2	86.6
1939	16.9	17.1	18.5	28.7	28.9	29.0	39.5	50.2	51.5
1940	12.1	21.7	27.8	44.8	55.3	57.4	61.2	61.2	79.4
1941	14.1	23.5	29.4	39.3	54.0	55.2	55.5	55.5	59.0
1942	12.0	19.6	25.1	39.7	46.4	49.0	50.7	66.3	67.3

Figure 39. Saving/editing sub-daily yearly maximums

## 2.6.2 Companion Files

Additional files can be uploaded and downloaded for each station using the “Companion Files” tab. The types of files that can be uploaded include documents, spreadsheets, text and PDF files. These files will be available for download by the user who created the station and users with which the user

has shared the station. Shared users will have either full access or read only access as specified by the user who created and shared the station (Figure 40). The file name, file size, and file type (icon) are also presented in the *Tab*. Users may delete uploaded documents by selecting the red “x” in the last column, if authorized to do so.

This section is reserved to upload and download files (documents, spreadsheets, text, data) that may support the data and IDF for this station

Select Files to Upload








File Name	Size	Type	Action
<a href="#">idf_v2-2_2012_02_09_614_ON_6144478_LONDON_CS.pdf</a>	46.0 KB		✖
<a href="#">idf_v2-2_2012_02_09_614_ON_6144478_LONDON_CS.png</a>	159.0 KB		✖
<a href="#">idf_v2-2_2012_02_09_614_ON_6144478_LONDON_CS.txt</a>	11.0 KB		✖
<a href="#">idf_v2-2_2012_02_09_614_ON_6144478_LONDON_CS_qq.pdf</a>	70.0 KB		✖
<a href="#">idf_v2-2_2012_02_09_614_ON_6144478_LONDON_CS_qq.png</a>	187.0 KB		✖
<a href="#">idf_v2-2_2012_02_09_614_ON_6144478_LONDON_CS_r.pdf</a>	72.0 KB		✖
<a href="#">idf_v2-2_2012_02_09_614_ON_6144478_LONDON_CS_r.png</a>	242.0 KB		✖

Figure 40. Uploading files

### 2.6.3 Sharing User Created Stations

The “Share Station” *Tab* allows the user to share their user created stations with other users as illustrated in the Figure 41. There are two different levels of access: 1) “Full Access” allows the user to change data and information and view historical and updated IDFs; and 2) “Read Only” allows read only access to the specific station. This type of access will allow users who have been granted access to the station to view and generate updated IDFs, but will not allow these users to edit or delete station data. The station is shared providing the email of the person with whom the user would like to share the station. If the email is associated with an account already registered within the Tool’s database, the user will only receive an email with an invitation to view the station. If the email is not registered, a temporary account will be created and on the first access the user will need to complete their registration for an account (requiring Name, Email, Affiliation, etc.). The creator of the station

can also change editing/viewing permissions for users with which they have shared stations using the “Remove shared” option.

Please type the email of the person with which you would like to share this station.  
You may make the station available as “read only” preventing the shared user from editing the data, or you may grant the user “full access” so they may view and edit the station data.

Email:

[Share as Full Access](#) [Share as Read Only](#)

Station shared with:

Name	Email	Access Level	
[Please Update your name]	abcde@gmail.com	Read Only	<a href="#">Remove Shared</a>
Test User	schardongandre@gmail.com	Read Only	<a href="#">Remove Shared</a>
[Please Update your name]	acdfsadfa@gmail.com	Read Only	<a href="#">Remove Shared</a>
[Please Update your name]	acdfsadfadfa@gmail.com	Read Only	<a href="#">Remove Shared</a>
Andre Schardong -uwo	aschardo@uwo.ca	Read Only	<a href="#">Remove Shared</a>
[Please Update your name]	fadskfjsadkf@gmail.com	Full Access	<a href="#">Remove Shared</a>

Figure 41. Sharing stations with other users

### 3 Development and Updating of IDF Curves

The IDF\_CC tool allows users to simply generate and view IDF curves for any hydro-meteorological station. By selecting a station from the map or using the option “Generate/Show IDF” option described in the previous section, a new pop-up window appears (Figure 42). The first tab (“Station Info”) presents the name, ID, location and information and record lengths for the station. The other two tabs, “IDF, historical data” and “IDF under climate change” are described in sections 3.1 and 3.2, respectively.



Figure 42. IDF\_CC tool page with station information, historical and future IDF

#### 3.1 IDF Curves Based on Historical Data

When the user requests to view an IDF for a station, the IDF\_CC tool triggers a calculation process using mathematical models in the background. When the “IDF, historical data” tab is selected, an IDF curve based on the observed historical precipitation data available is presented to the user. The background data analysis steps are as follows:

- 1) Read and organize data from the database for the selected station.
- 2) Data analysis (ignore negative and zero values) and extraction of yearly maximums.

- 3) Calculate statistical distributions parameters for GEV and Gumbel using L-moments and method of moments, respectively. For more details on Gumbel distribution please refer to *TechMan* section 3.1.1 and 3.1.2.
- 4) Calculate IDF (please refer to *TechMan* section 2.1 and 3.1 for more detail).
- 5) Fit interpolated equations to the IDF curve using optimization algorithm (Differential Evolution): refer to Storn and Price (1997) and Vasan (2008) for more details on Differential Evolution optimization (available in Appendix A).
- 6) Organize data for display (tables, plots, and equations).

After the calculation steps are completed the IDF is presented in the form of tables, total precipitation, intensity graphs and the fitted equation. These results are presented by selecting “IDF, historical data” *Tab* as in Figure 43. The IDF is fitted to the historical data using GEV and Gumbel distribution and results are presented in the following forms:

- 1) Tables: the IDFs are presented in traditional tabular format with duration (in minutes and hours) and return period (T) as in Figure 43. Both total precipitation (Figure 43 in mm and intensity (Figure 44) in mm/h are presented and the user can toggle between these two options.

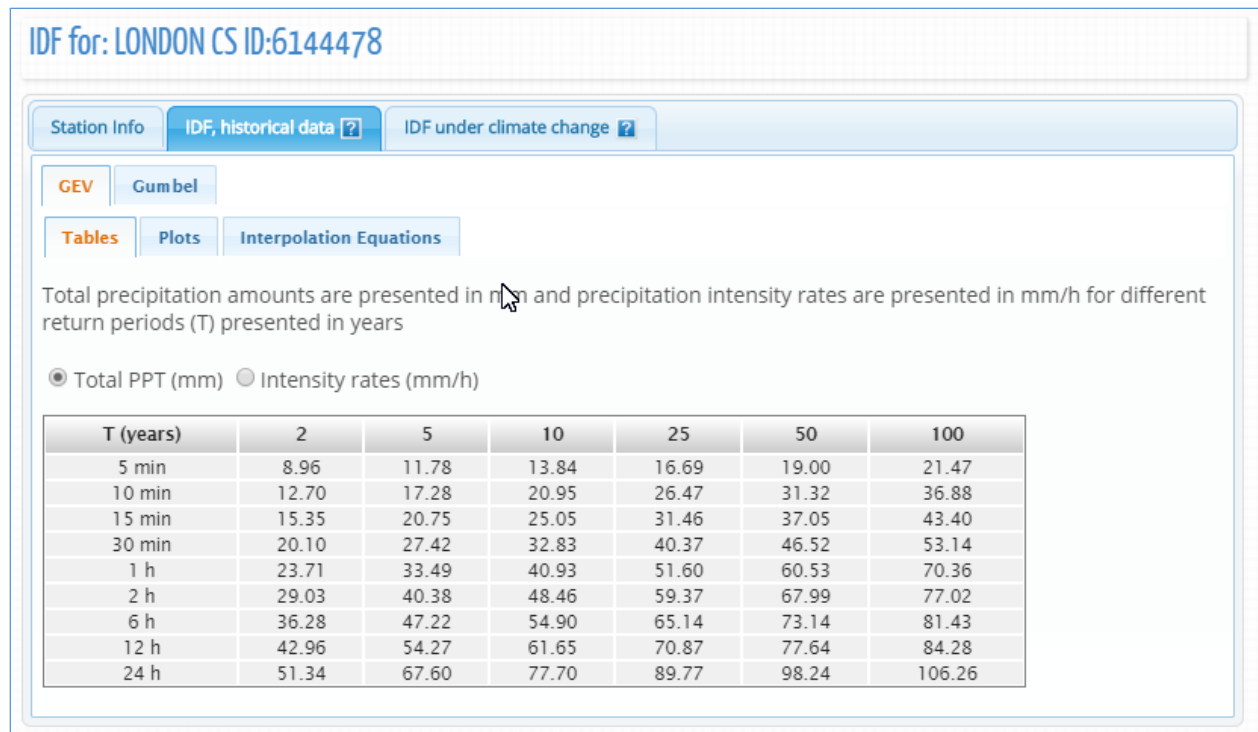


Figure 43. Total precipitation (in mm) IDF table

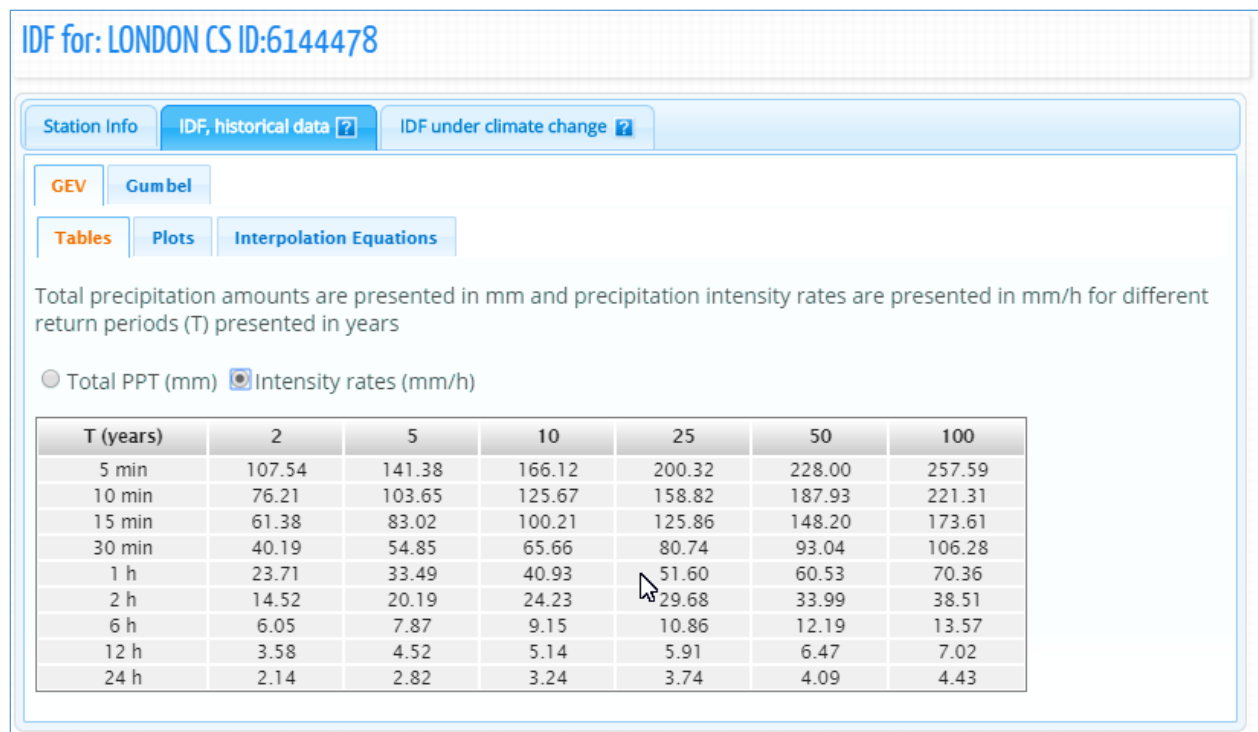



Figure 44. Rainfall intensity (in mm/h) IDF table

2) Plots: the plots or graphs are also presented as *Total Precipitation* (in mm) and *Intensity* (mm/h) as shown in Figure 45 and Figure 46, respectively. The user can hide or show the IDF curve for each return period by clicking on individual return periods in the legend below the graph. Zoom is also available and is performed by dragging out a rectangle in the chart with the mouse pointer. The map will enlarge the selected area (Figure 47) and a “Reset zoom” button is provided. The “Reset zoom” option will revert the initial zoom level (Figure 45). By hovering the mouse pointer over dots, the user can view precipitation, intensity and duration values for each point on the plot. The dots are calculated IDF values and the lines are plotted using the fitted equation that is presented under the “Interpolation Equation” tab. A button on the top left of the plot () allows user to print and export/download the graph to images file (Figure 48).

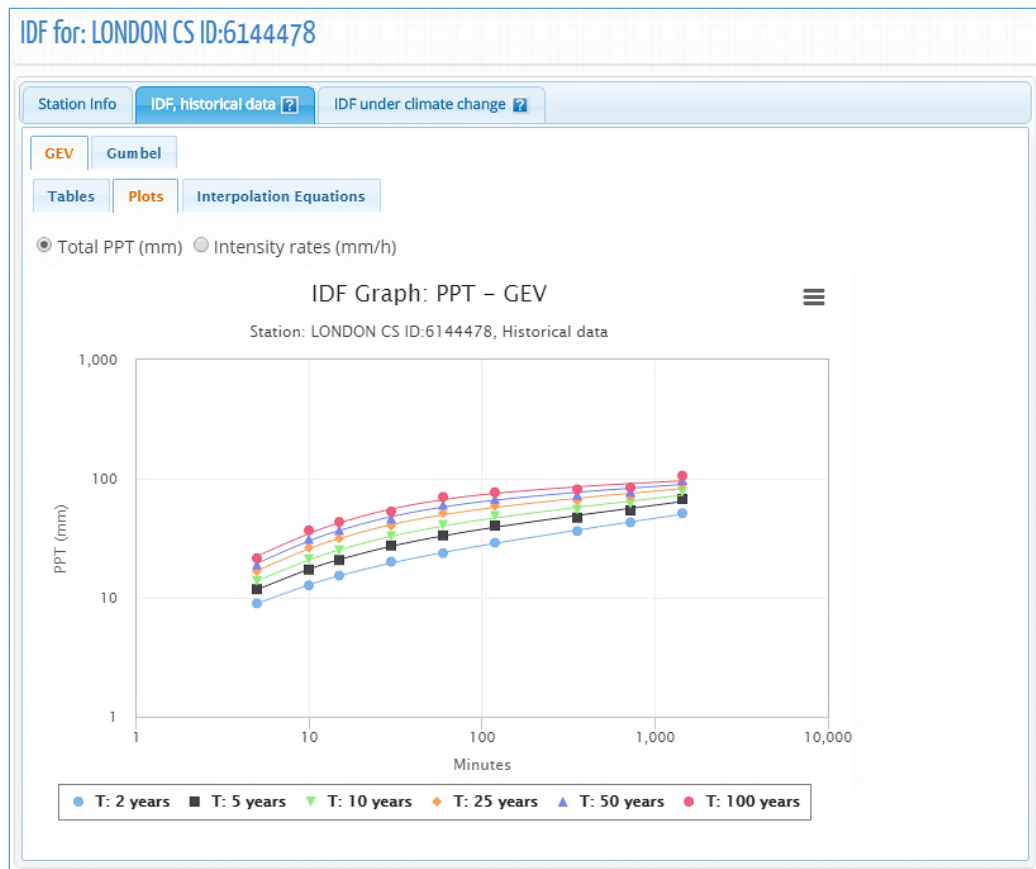


Figure 45. Total precipitation (in mm) IDF graph for different return periods



Figure 46. Rainfall intensity (in mm/h) IDF graph for different return periods

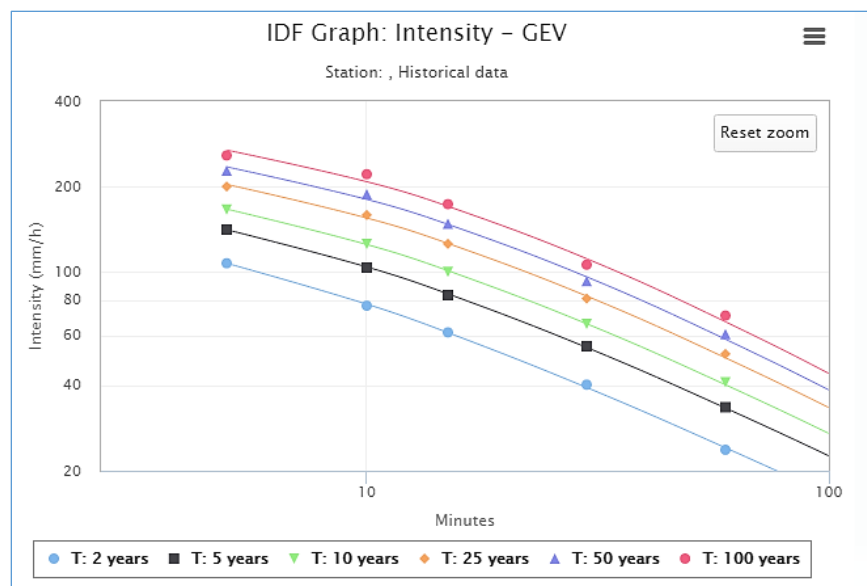


Figure 47. Zooming on a plot and resetting zoom level



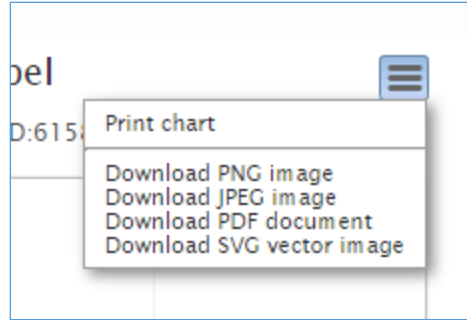


Figure 48. Printing and exporting a plot as image

3) Interpolation Equations: an optimization algorithm is used to fit equations to the calculated IDF values. The equations are presented under the “Interpolation Equations” *Tab* as shown in Figure 49. Three coefficients  $A$ ,  $B$  and  $t_0$  are calculated by the optimization algorithm for each return period ( $T$ ) and presented as a table in Figure 49. This equation can be applied as a fast method for interpolation and calculation of design storms.

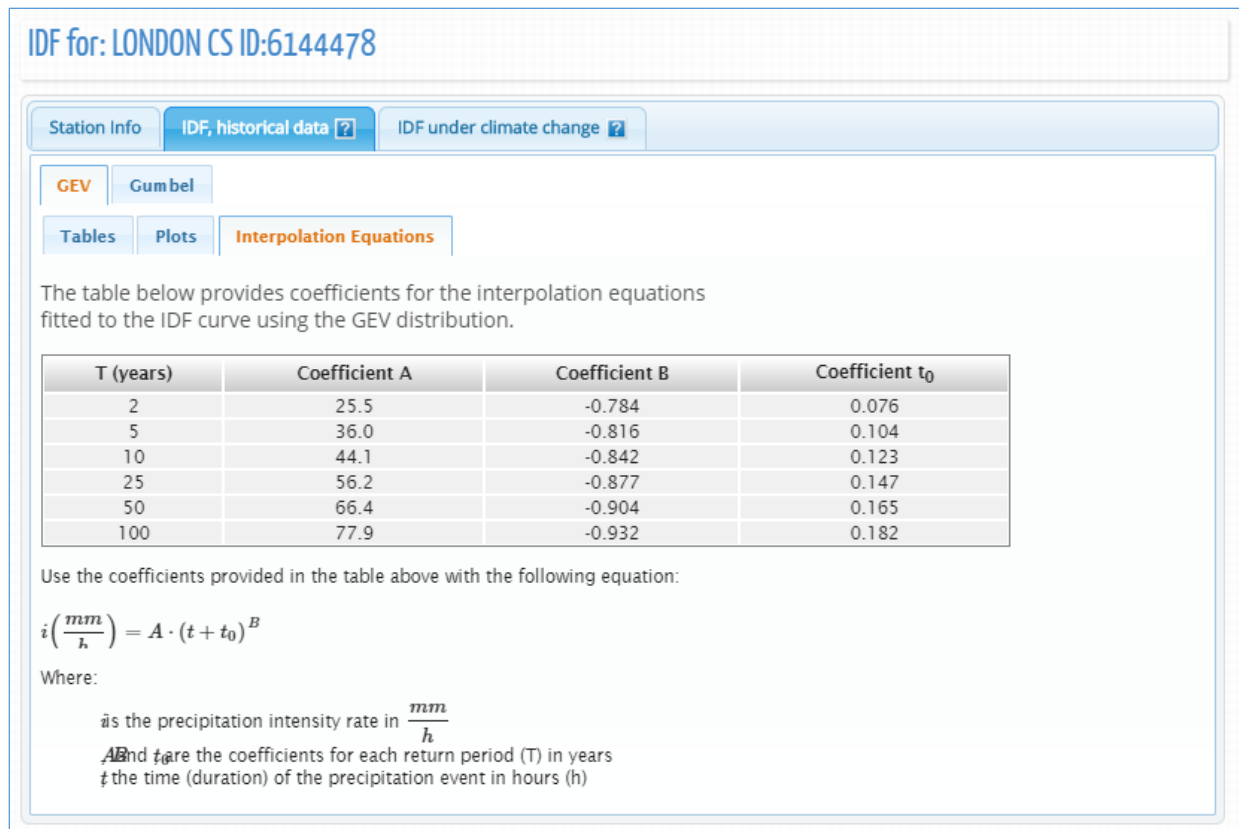


Figure 49. Fitted IDF equation to historical precipitation data

### 3.2 Updated IDF Under Climate Change

By selecting the “IDF under climate change” tab, the user can generate IDF curves that account for future climate conditions. To generate the updated IDFs for future climate, the user can select all models (ensemble option) or individual GCM and projection period as shown in Figure 50. There are 9 bias corrected models (Table 1) and 24 raw GCMs (Table 2) resulting in a total of 33 GCM datasets, available with the IDF\_CC tool. The dataset used for the updating procedure is a choice of the user: “Bias Corrected” or “Raw GCMs”. The available range for the future time period is 2006 to 2100 (Step 1 in Figure 50).

With respect to GCM selection, to generate IDF curves that account for climate change, the user has two options: select all models (ensemble option), or select any model from the list of GCMs provided with the tool (Step 2 in Figure 50). The users are encouraged to test different models due to uncertainty associated with climate modeling. The climate modelling community does not “compare” global

climate models to identify superior/inferior models for specific locations. Thus, users should not that there is no “right” GCM for any given location. Users are provided access all available models in the IDF\_CC tool to allow them to understand uncertainty associated with potential climate change impacts.

The following steps are performed by the IDF\_CC tool to update IDF curves for future climate. Please see *TechMan* section 3.2 for more information on each of the steps:

- 1) Extract precipitation data series from GCM grid points for the selected station (e.g., using BCCAQ with the Canadian CanESM2 model).
- 2) Organize data and extract yearly maximums.
- 3) Apply Equidistant Quantile Matching (EQM) algorithm (refer to *TechMan* section 3.2).
- 4) Estimate distribution parameters and calculate IDFs for each future climate scenario (RCPs).
- 5) Generate median IDF from the results of step 4 for each RCP.
- 6) Organize data for display (tables, plots, and equations, uncertainty range plot).

IDF for: LONDON CS ID:6144478

Station Info | IDF, historical data ? | IDF under climate change ?

Climate Model Selection | Scenario RCP 2.6 ? | Scenario RCP 4.5 ? | Scenario RCP 8.5 ? | Comparison Graphs ?

1. Select the time period to update the IDF curve under climate change. The tool will use Climate Model data for the selected range. The available range is 2006 to 2100. Please select at least a 50 year projection period.

From 2006 to 2100

2. Select a Climate Model to see results. Climate models are listed by name:

☒ Bias Corrected ☐ Raw GCMs

All Models  
Ensemble, Ensemble

Calculate IDF for Future Export all Results

Figure 50. Selection of the CGM model and projection period

The Fifth Assessment Report (AR5) (IPCC, 2013) provides four RCP scenarios: RCP2.6, RCP 4.5, RCP 6.0 and RCP 8.5. The following definitions are directly adopted from AR5 and the RCPs are briefly described below (refer to *TechMan* section 2.3 for more details):

- **RCP 2.6:** pathway where radiative forcing peaks at approximately  $3 \text{ W m}^{-2}$  before 2100 and then declines;
- **RCP 4.5 and RCP6.0:** Two intermediate stabilization pathways in which radiative forcing is stabilized at approximately  $4.5 \text{ W m}^{-2}$  and  $6.0 \text{ W m}^{-2}$  after 2100;
- **RCP 8.5:** high pathway for which radiative forcing reaches greater than  $8.5 \text{ W m}^{-2}$  by 2100 and continues to rise for some time.

The future emission scenarios used in the IDF\_CC tool are RCP 2.6, RCP 4.5 and RCP 8.5. RCP 2.6 represents a low greenhouse gas concentration scenario, followed by RCP 4.5 as an intermediate scenario and RCP 8.5 as a high concentration scenario. RCP 4.5 scenario was selected over RCP 6.0 as an intermediate scenario largely because more GCM models have results for RCP 4.5 than RCP 6.0.

Table 1 – Bias corrected climate models list used with the IDF\_CC Tool – PCIC (2013)

Bias Correction Methods	Model	Country	Centre Name	Original (Lon. vs Lat.)	Bias corrected (Lon. vs Lat.)
BCCAQ	CanESM2	Canada	Canadian Centre for Climate Modeling and Analysis	2.8 x 2.8	0.0833 x 0.0833
BCCAQ	CCSM4	USA	National Center of Atmospheric Research	1.25 x 0.94	
BCCAQ	CNRM-CM5	France	Centre National de Recherches Meteorologiques and Centre Europeen de Recherches et de Formation Avancee en Calcul Scientifique	1.4 x 1.4	
BCCAQ	CSIRO-Mk3-6-0	Australia	Australian Commonwealth Scientific and Industrial Research Organization in collaboration with the Queensland Climate Change Centre of Excellence	1.8 x 1.8	
BCCAQ	GFDL-ESM2G	USA	National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamic Laboratory	2.5 x 2.0	
BCCAQ	HadGEM2-ES	United Kingdom	Met Office Hadley Centre	1.25 x 1.875	
BCCAQ	MIRCO5	Japan	Japan Agency for Marine-Earth Science and Technology	1.4 x 1.41	
BCCAQ	MPI-ESM-LR	Germany	Max Planck Institute for Meteorology	1.88 x 1.87	
BCCAQ	MRI-CGCM3	Japan	Meteorological Research Institute	1.1 x 1.1	

Table 2 – Climate models list used with the IDF\_CC Tool – IPCC (2015)

Country	Centre Acronym	Model	Centre Name	Number of Ensembles (PPI)	GCM Resolutions (Lon. vs Lat.)
China	BCC	bcc_csm1_1	Beijing Climate Center, China Meteorological Administration	1	2.8 x 2.8
China	BCC	bcc_csm1_1 m	Beijing Climate Center, China Meteorological Administration	1	
China	BNU	BNU-ESM	College of Global Change and Earth System Science	1	2.8 x 2.8
Canada	CCCma	CanESM2	Canadian Centre for Climate Modeling and Analysis	5	2.8 x 2.8
USA	CCSM	CCSM4	National Center of Atmospheric Research	1	1.25 x 0.94
France	CNRM	CNRM-CM5	Centre National de Recherches Meteorologiques and Centre Europeen de Recherches et de Formation Avancee en Calcul Scientifique	1	1.4 x 1.4
Australia	CSIRO3.6	CSIRO-Mk3-6-0	Australian Commonwealth Scientific and Industrial Research Organization in collaboration with the Queensland Climate Change Centre of Excellence	10	1.8 x 1.8
USA	CESM	CESM1-CAM5	National Center of Atmospheric Research	1	1.25 x 0.94
E.U.	EC-EARTH	EC-EARTH	EC-EARTH	1	1.125 x 1.125
China	LASG-CESS	FGOALS_g2	IAP (Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China) and THU (Tsinghua University)	1	2.55 x 2.48
USA	NOAA GFDL	GFDL-CM3	National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamic Laboratory	1	2.5 x 2.0
USA	NOAA GFDL	GFDL-ESM2G	National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamic Laboratory	1	2.5 x 2.0
USA	NOAA GFDL	GFDL-ESM2M	National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamic Laboratory		2.5 x 2.0
United Kingdom	MOHC	HadGEM2-AO	Met Office Hadley Centre	1	1.25 x 1.875
United Kingdom	MOHC	HadGEM2-ES	Met Office Hadley Centre	2	1.25 x 1.875
France	IPSL	IPSL-CM5A-LR	Institut Pierre Simon Laplace	4	3.75 x 1.8
France	IPSL	IPSL-CM5A-MR	Institut Pierre Simon Laplace	4	3.75 x 1.8
Japan	MIROC	MIROC5	Japan Agency for Marine-Earth Science and Technology	3	1.4 x 1.41
Japan	MIROC	MIROC-ESM	Japan Agency for Marine-Earth Science and Technology	1	2.8 x 2.8
Japan	MIROC	MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology	1	2.8 x 2.8
Germany	MPI-M	MPI-ESM-LR	Max Planck Institute for Meteorology	3	1.88 x 1.87
Germany	MPI-M	MPI-ESM-MR	Max Planck Institute for Meteorology	3	1.88 x 1.87

Country	Centre Acronym	Model	Centre Name	Number of Ensembles (PPT)	GCM Resolutions (Lon. vs Lat.)
Japan	MRI	MRI-CGCM3	Meteorological Research Institute	1	1.1 x 1.1
Norway	NOR	NorESM1-M	Norwegian Climate Center	3	2.5 x 1.9

### 3.3 Viewing and Exploring Results

Upon completion of the IDF update calculations, the results are presented in the form of tables, total precipitation, rainfall intensity graphs and uncertainty range graphs. These results are presented for each RCP future scenario: 2.6, 4.5 and 8.5. Each RCP scenario is displayed as a set of *Tabs* as shown in Figure 51.

Updated IDF curves for future climate conditions for all three RCPs are presented as tables, plots and uncertainty ranges, as described here:

- 1) Tables: the IDF is presented in the traditional table format for all durations (in minutes and hours) and return periods (T) as illustrated in Figure 51. Both total precipitation in mm (Figure 51) and rainfall intensity in mm/h (Figure 52) are available and the user can toggle between these two options using the available radio buttons. The IDF curves presented in Figure 51 and Figure 52 are a median from all models selected for each emission scenario (see *TechMan* section 2.3).

## IDF for: LONDON CS ID:6144478

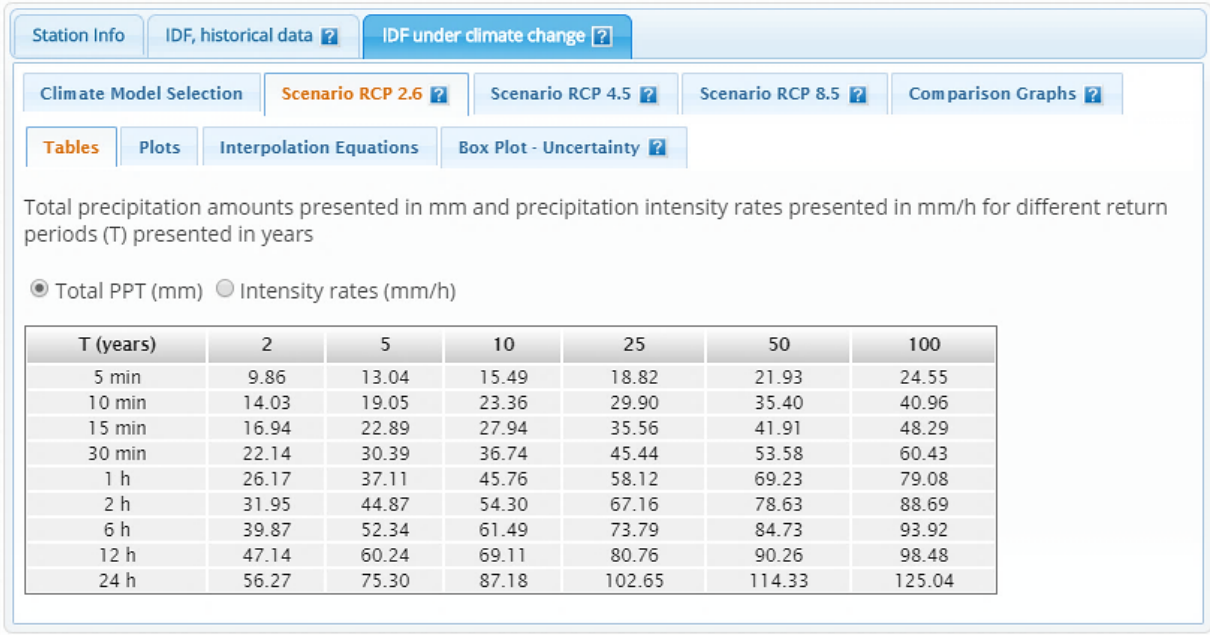


Figure 51. Updated IDF tables for future climate conditions – total precipitation in mm

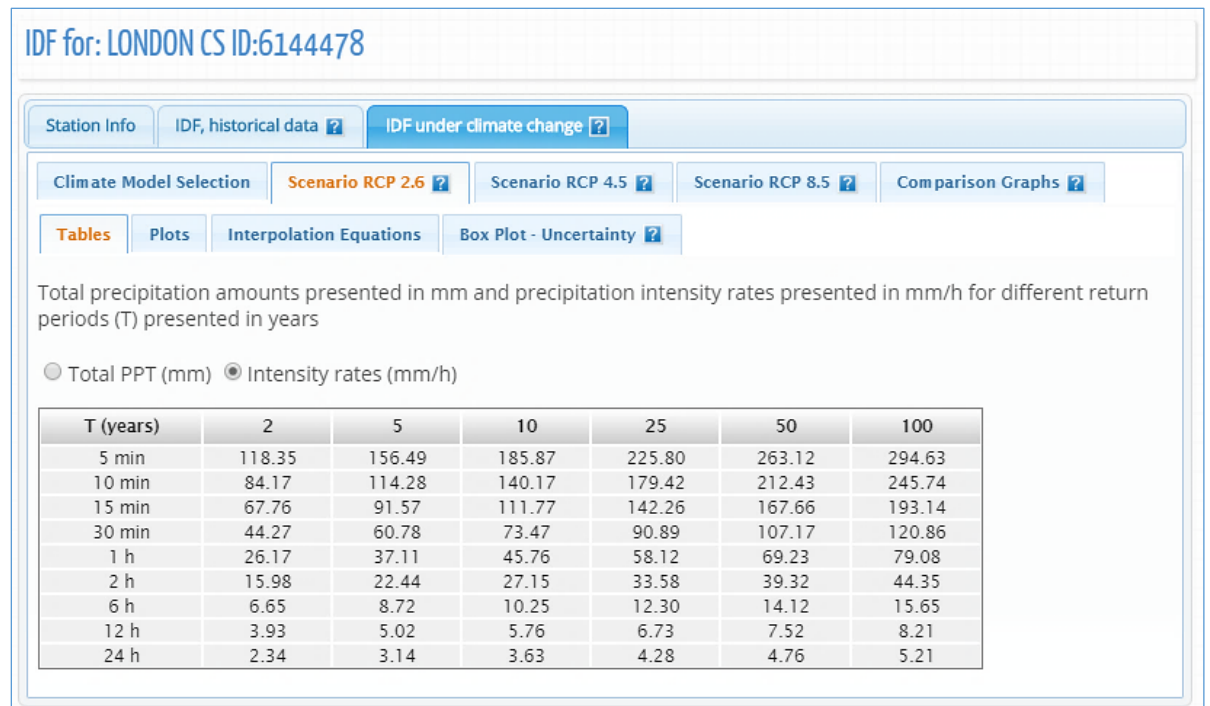


Figure 52. Updated IDF tables for future climate conditions – rainfall intensity in mm/h

2) Plots: the plots or graphs are also available for total precipitation (in mm) and rainfall intensity (mm/h) as presented in Figure 53 and Figure 54, respectively. The user can hide or show the IDF curve for each return period by clicking on individual return periods in the legend below the graph. Zoom is also available and is performed by dragging out a rectangle in the chart with the mouse pointer. The area selected is zoomed-in (Figure 47) and a “Reset zoom” button will be visible. The “Reset zoom” option will revert the zoom level to the original state. By hovering the mouse pointer over dots, the user can view precipitation, intensity and duration values for each point on the plot. The dots are calculated IDF values and the lines are plotted using the fitted equation that is presented under “Interpolation Equations” tab.

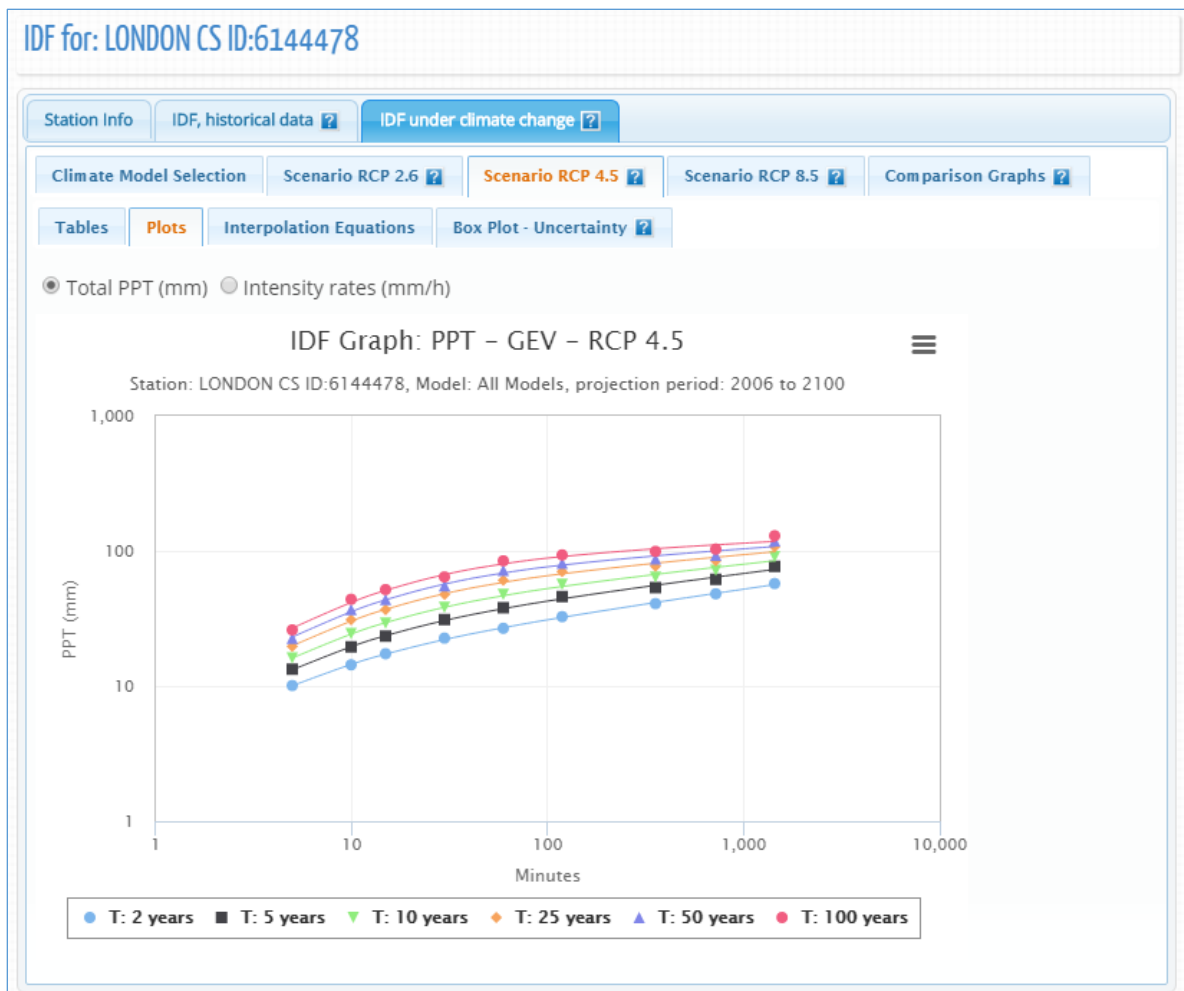




Figure 53. Total precipitation (in mm) updated IDF graph for different return periods



Figure 54. Rainfall intensity (in mm/h) updated IDF graph for different return periods

3) “Interpolation Equations”: an optimization algorithm is used to fit equations to the calculated IDF values. The equations are presented under the “Interpolation Equations” *Tab* as shown in Figure 55. Three coefficients  $A$ ,  $B$  and  $t_0$  are calculated by the optimization algorithm for each return period ( $T$ ) and presented as a table in Figure 55. This equation can be applied as an expedite method for interpolation and calculation for design storms.

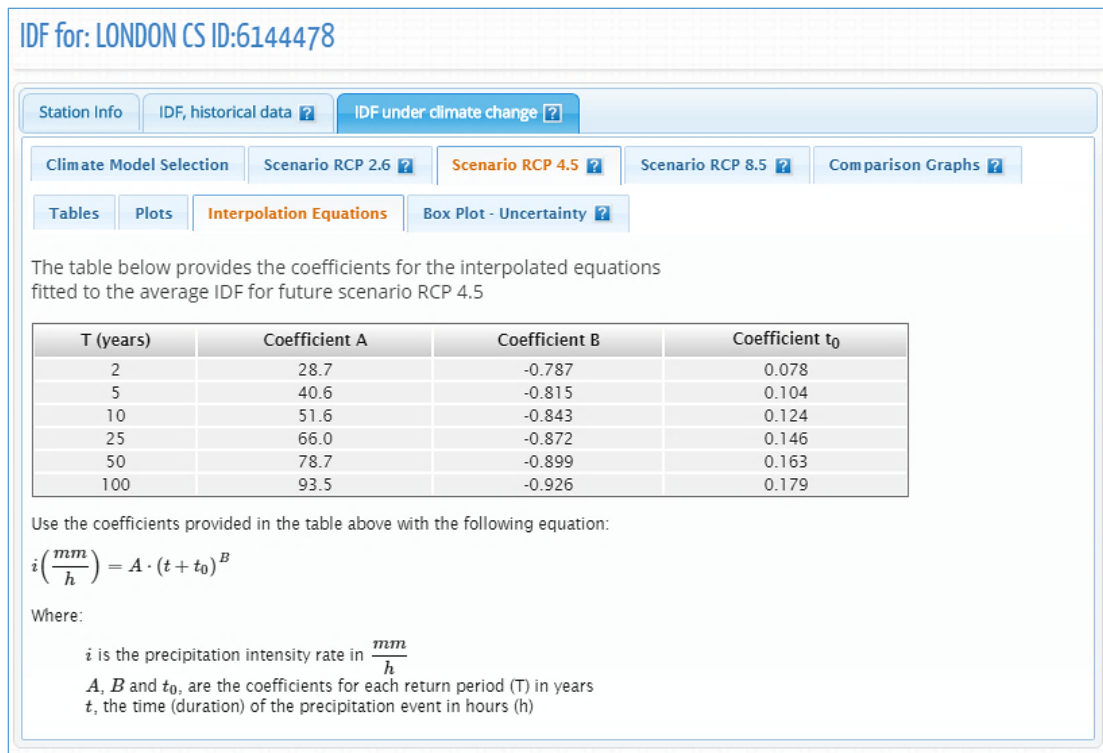


Figure 55. Fitted IDF equation for future scenario

4) Box Plot Uncertainty: Users can quickly view the distribution of results produced by each of the GCMs available within the tool by selecting the “Box Plot – Uncertainty” tab when generating future IDF curves using the “All Models” GCM option. Figure 56 provides an example of an uncertainty plot output. The plot was generated for the London CS rain station, using the “All Models” GCM option for the period 2006-2100, RCP 2.6. The plot indicates the range of values generated for each of the GCM datasets for this future scenario. See the Figure 57 for illustration of how to read the Box Plots.



Figure 56. Box Plot – Uncertainty

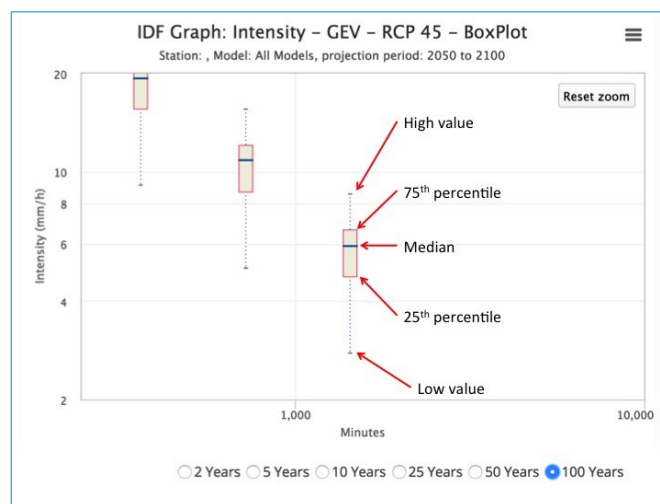


Figure 57. Reading Box Plots

5) Comparison Graphs: this option presents the summary and comparison between the IDF based on historical data and the median IDF for future periods (RCP 2.6, 4.5 and 8.5) as shown in Figure 58. The graphs are presented for each return period, i.e.: 2, 5, 10, 25, 50 and 100 years. The dots in Figure 58 represent the IDF table and the lines are plotted from the Interpolation Equations.

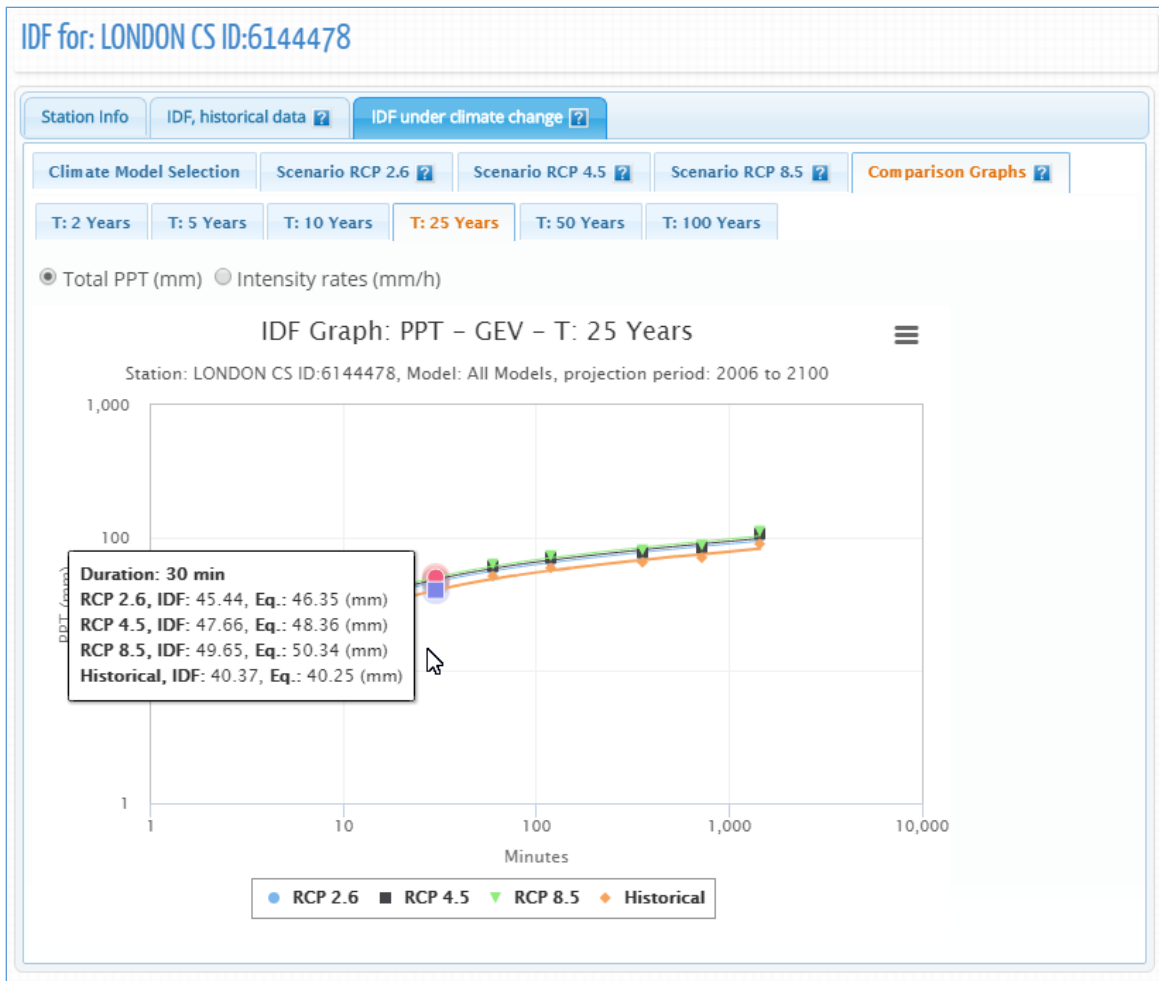


Figure 58. IDF comparison graphs

## 4 Review of IDF Updating Procedures

The IDF\_CC tool version 2 offers two ways to obtain the updated IDF's for future climatic conditions based on the selected GCM models. The first and more direct way is to use an existing station from the Environment Canada stations. The user should follow the three easy steps to update the IDF for future climatic conditions as illustrated in Figure 59: 1) select one station, either from the map or from the list of stations; 2) calculate the IDF curves using the historical data (intermediate step) that can be used for comparison with the updated IDF for the future climatic conditions; and 3) select the GCM model and projection period and generate updated IDF curves for future climatic conditions.

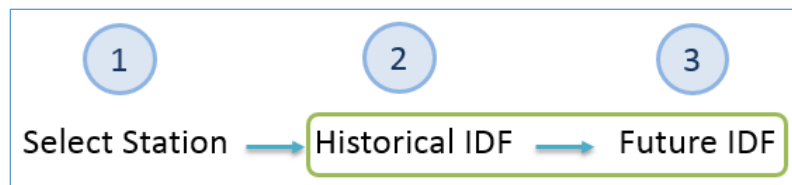


Figure 59. Updating IDF's for future climatic conditions for an Environment Canada station

The second option includes one additional step where the user creates their own station by providing information and data as shown in Figure 60. The remaining steps are the same as in the previous option.

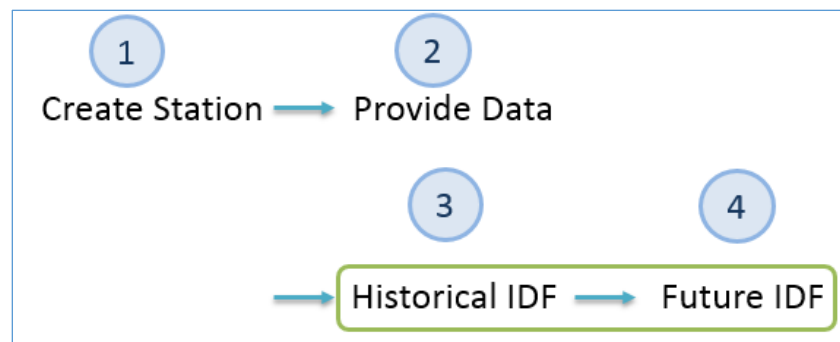


Figure 60. Updating IDF for future climatic conditions for a user provided station

## 5 Final Comments

This report presents the User's Manual for the *Computerized IDF\_CC tool for the Development of Intensity-Duration-Frequency-Curves Under a Changing Climate Version 2*. It aims to assist in the updating of IDF curves for future climatic conditions. The IDF\_CC tool uses a sophisticated though efficient methodology that incorporates changes in the distributional characteristics of GCMs between the baseline period and the projection period. The IDF\_CC tool is easy to use and radically simplifies the IDF update process by automating very demanding procedures like downloading, extracting and manipulating data from various GCM models. The IDF\_CC tool's website [www.idf-cc-uwo.ca](http://www.idf-cc-uwo.ca) should be regularly visited for the latest updates of the IDF\_CC tool, new functionalities and updated documentation.

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## **Appendix - A: Papers/Reports on Differential Evolution - DE**

Vasan A. (2008) - Optimization Using Differential Evolution. *Water Resources Research Report no. 060*, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 38 pp:

<http://www.eng.uwo.ca/research/iclr/fids/publications/products/60.pdf>

Storn, R. and Price, K. (1997), 'Differential Evolution - A Simple and Efficient Heuristic for Global Optimization over Continuous Spaces', *Journal of Global Optimization*, 11, pp. 341–359.

<http://link.springer.com/article/10.1023%2FA%3A1008202821328>

## Appendix - B: Previous reports in the Series

ISSN: (Print) 1913-3200; (online) 1913-3219

[In addition to 78 previous reports \(No. 01 – No. 78\) prior to 2012](#)

Samiran Das and Slobodan P. Simonovic (2012). [Assessment of Uncertainty in Flood Flows under Climate Change](#). Water Resources Research Report no. 079, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 67 pages. ISBN: (print) 978-0-7714-2960-6; (online) 978-0-7714-2961-3.

Rubaiya Sarwar, Sarah E. Irwin, Leanna King and Slobodan P. Simonovic (2012). [Assessment of Climatic Vulnerability in the Upper Thames River basin: Downscaling with SDSM](#). Water Resources Research Report no. 080, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 65 pages. ISBN: (print) 978-0-7714-2962-0; (online) 978-0-7714-2963-7.

Sarah E. Irwin, Rubaiya Sarwar, Leanna King and Slobodan P. Simonovic (2012). [Assessment of Climatic Vulnerability in the Upper Thames River basin: Downscaling with LARS-WG](#). Water Resources Research Report no. 081, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 80 pages. ISBN: (print) 978-0-7714-2964-4; (online) 978-0-7714-2965-1.

Samiran Das and Slobodan P. Simonovic (2012). [Guidelines for Flood Frequency Estimation under Climate Change](#). Water Resources Research Report no. 082, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 44 pages. ISBN: (print) 978-0-7714-2973-6; (online) 978-0-7714-2974-3.

Angela Peck and Slobodan P. Simonovic (2013). [Coastal Cities at Risk \(CCaR\): Generic System Dynamics Simulation Models for Use with City Resilience Simulator](#). Water Resources Research Report no. 083, Facility for Intelligent Decision Support, Department of Civil and Environmental

Engineering, London, Ontario, Canada, 55 pages. ISBN: (print) 978-0-7714-3024-4; (online) 978-0-7714-3025-1.

Roshan Srivastav and Slobodan P. Simonovic (2014). [Generic Framework for Computation of Spatial Dynamic Resilience](#). Water Resources Research Report no. 085, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 81 pages. ISBN: (print) 978-0-7714-3067-1; (online) 978-0-7714-3068-8.

Angela Peck and Slobodan P. Simonovic (2014). [Coupling System Dynamics with Geographic Information Systems: CCaR Project Report](#). Water Resources Research Report no. 086, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 60 pages. ISBN: (print) 978-0-7714-3069-5; (online) 978-0-7714-3070-1.

Sarah Irwin, Roshan Srivastav and Slobodan P. Simonovic (2014). [Instruction for Watershed Delineation in an ArcGIS Environment for Regionalization Studies](#). Water Resources Research Report no. 087, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 45 pages. ISBN: (print) 978-0-7714-3071-8; (online) 978-0-7714-3072-5.

Andre Schardong, Roshan K. Srivastav and Slobodan P. Simonovic (2014). [Computerized Tool for the Development of Intensity-Duration-Frequency Curves under a Changing Climate: Users Manual v.1](#). Water Resources Research Report no. 088, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 68 pages. ISBN: (print) 978-0-7714-3085-5; (online) 978-0-7714-3086-2.

Roshan K. Srivastav, Andre Schardong and Slobodan P. Simonovic (2014). [Computerized Tool for the Development of Intensity-Duration-Frequency Curves under a Changing Climate: Technical Manual v.1](#). Water Resources Research Report no. 089, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 62 pages. ISBN: (print) 978-0-7714-3087-9; (online) 978-0-7714-3088-6.

Roshan K. Srivastav and Slobodan P. Simonovic (2014). [Simulation of Dynamic Resilience: A Railway Case Study](#). Water Resources Research Report no. 090, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 91 pages. ISBN: (print) 978-0-7714-3089-3; (online) 978-0-7714-3090-9.

Nick Agam and Slobodan P. Simonovic (2015). [Development of Inundation Maps for the Vancouver Coastline Incorporating the Effects of Sea Level Rise and Extreme Events](#). Water Resources Research Report no. 091, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 107 pages. ISBN: (print) 978-0-7714-3092-3; (online) 978-0-7714-3094-7.

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Bogdan Pavlovic and Slobodan P. Simonovic (2016). [Automated Control Flow Generation Procedure: Cheakamus Dam Case Study](#). Water Resources Research Report no. 093, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 78 pages. ISBN: (print) 978-0-7714-3113-5; (online) 978-0-7714-3114-2.

Sarah Irwin, Slobodan P. Simonovic and Niru Nirupama (2016). [Introduction to ResilSIM: A Decision Support Tool for Estimating Disaster Resilience to Hydro-Meteorological Events](#). Water Resources Research Report no. 094, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 66 pages. ISBN: (print) 978-0-7714-3115-9; (online) 978-0-7714-3116-6.

Tommy Kokas, Slobodan P. Simonovic (2016). [Flood Risk Management in Canadian Urban Environments: A Comprehensive Framework for Water Resources Modeling and Decision-Making](#). Water Resources Research Report no. 095. Facility for Intelligent Decision Support, Department of

Civil and Environmental Engineering, London, Ontario, Canada, 66 pages. ISBN: (print) 978-0-7714-3117-3; (online) 978-0-7714-3118-0.

Jingjing Kong and Slobodan P. Simonovic (2016). [Interdependent Infrastructure Network Resilience Model with Joint Restoration Strategy](#). Water Resources Research Report no. 096, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 83 pages. ISBN: (print) 978-0-7714-3132-6; (online) 978-0-7714-3133-3.

Sohom Mandal, Patrick A. Breach and Slobodan P. Simonovic (2017). [Tools for Downscaling Climate Variables: A Technical Manual](#). Water Resources Research Report no. 097, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 95 pages. ISBN: (print) 978-0-7714-3135-7; (online) 978-0-7714-3136-4.

Andre Schardong, Slobodan P. Simonovic and Dan Sandink (2017). [Computerized Tool for the Development of Intensity-Duration-Frequency Curves Under a Changing Climate: Technical Manual v.2.0](#). Water Resources Research Report no. 098, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 58 pages. ISBN: (print) 978-0-7714-3144-9; (online) 978-0-7714-3145-6.