Ontario
Climate Change Data Portal

Technical Report

Developing Future Projected IDF Curves and a Public Climate Change Data Portal for the Province of Ontario

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The projected IDF curves and the up-to-date project results as well as all associated data have been made publicly available at Ontario Climate Change Data Portal (Ontario CCDP): http://ontarioccdp.ca. The Ontario CCDP is developed with care and believed to be reliable, but mechanical or human errors remain a possibility. The IEESC accepts NO responsibility for any inaccuracies or omissions in the data, nor for any loss or damage directly or indirectly caused to any person or body by reason of, or arising out of, any use of Ontario CCDP. All IDF curves presented in the report and posted on this Portal at this time are calculated using the original model outputs of hourly precipitation. While all the revealed changes in the projected precipitation or IDF curves are possible from a physics or climate change science perspective, one should use these curves with extreme caution for practical applications. Further investigation is being undertaken to calibrate these IDF curves using historical data. These IDF curves will be updated once they are calibrated. Alternatively users can always download the hourly precipitation data and calculated their own IDF curves with appropriate corrections.

When referring to the IDF curves and data sets published on Ontario CCDP, the source must be clearly and prominently stated and cited. This report summarizes the development of Ontario CCDP and the main findings in projected IDF curves and maps of temperature and precipitation, and should be referenced as:

Wang, Xiuquan and Gordon Huang (2014), Technical Report: Developing Future Projected IDF Curves and a Public Climate Change Data Portal for the Province of Ontario. IEESC, University of Regina, Canada.

Copies for this report are available to download from: http://ontarioccdp.ca

The Ontario CCDP is developed and maintained by Xiuquan Wang at the University of Regina.
For any questions or comments, please contact Xiuquan Wang at: xander.wang@ontarioccdp.ca.

Executive Summary

It is important for the Province of Ontario to promote the enhancement of knowledge and scientific expertise on the effects of climate change, and the acquisition and dissemination of the best information to support the development of sound, responsible and effective climate change adaptation strategies.

Currently, climate adaptation practitioners have identified a need to refine climate change impacts modeling down to a regional/community level in order to understand the direct and long-term impacts on Ontario's communities. To this end, the Ministry has been building the Province of Ontario's modeling, monitoring and research capacity related to potential climate change at finder resolution over Ontario, by funding projects on high-resolution probabilistic climate projections over the entire Province using the PRECIS model developed at UK Met Office Hadley Centre.

Building upon the results of previous project, "Developing high-resolution probabilistic projections over Ontario", this project will involve the development of IDF curves for all 25-km grid points (approximately 1900) across the entire Province of Ontario.

Climate modeling data generated in the previous projects funded by Ontario Ministry of the Environment is contained in lengthy reports which are not practical for decision-making at the local level. As such, this project will also involve the development of a climate data portal which will ensure technical and non-technical end-users (e.g. municipalities, private sector) have easy and intuitive access to the climate data.

As one of the deliverables of this project, this report summarizes:

- development of projected IDF curves at grid point scale;
- development of the public data portal – Ontario Climate Change Data Portal (Ontario CCDP);
- main findings in IDF curves of selected weather stations and projected maps of temperature and precipitation.

Consistent with many other studies, no apparent trends are found in long-term (annual and seasonal) averages of future projected precipitation. However, significant changes are found in future projected IDF curves which are statistically derived from precipitation events of different durations and intensities. Analysis of IDF curves at 12 selected stations across Ontario show that, in general, high intensity rainfall events would likely to be more frequent across the province in the future); however, substantial spatial variations exist from location to location due to PRECIS's capacity to resolve local geophysical features at high resolution.

Following the submission of this report to Ontario Ministry of the Environment, the Ontario CCDP is officially released to the public at http://ontarioccdp.ca. By being built with a web-based user-friendly interface, Ontario CCDP initially incorporated the high-resolution climate projections developed by the IEESC at the University of Regina. Other modeling results will be potentially integrated into this data portal in the near future. Ontario CCDP can provide both visual representations and data downloading functions of climate scenarios across Ontario using geospatial maps, including typical climate change indicators (e.g. temperature, precipitation) at temporal scales from annual, seasonal, monthly to daily and hourly.

Acknowledgments

This project has received funding support from the Ontario Ministry of the Environment. Such support does not indicate endorsement by the Ministry of the contents of this material.

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1. Introduction

Around the world, including Ontario, the effects of climate change have already been upon us. The Ontario government understands that it has a responsibility to help people adapt to those effects that are already being experienced, as well as the future effects of climate change. It is important that Ontario continues to acquire and enhance knowledge and scientific expertise on the effects of climate change in the province in order to provide the best possible information to policy makers for the development of sound, responsible and effective climate change adaptation strategies.

Based upon the high-resolution probabilistic projections developed in the previous project funded by Ontario Ministry of Environment, this project will initially involve the development of IDF curves at 25-km grid point scale over the entire Province of Ontario. A climate data portal – Ontario CCDP will then be developed for these IDF curves as well as climate data, including typical climate change indicators (e.g. temperature and precipitation) at temporal scales from annual, seasonal, monthly to daily and hourly.

The objective of this project is detailed as follows:

(1) Project IDF Curves: calculate IDF curves at each PRECIS grid cell (25 km x 25 km) over the entire Province of Ontario;

(2) Design and develop a climate data portal with expansion capabilities and with visualization and data downloading functionality;

(3) Incorporate the following variables into the climate data portal and publish it to the public domain.

  a) For visualization and data downloading:

  - Annual mean temperature
  - Annual total precipitation

- Seasonal mean temperature
- Seasonal total precipitation
- Monthly mean temperature
- Monthly total precipitation
- IDF curves

b) For data downloading only (due to huge data volume and associated searching time):

- Daily maximum, minimum, and average temperature
- Daily total precipitation
- Hourly temperature
- Hourly total precipitation
- Hourly surface relative humidity
- Hourly surface solar radiation
- Hourly surface wind speed
- Hourly surface wind direction

The above variables should be available for the following time periods:

- Baseline period (1960-1990)
- 2030s (2015-2045)
- 2050s (2035-2065)
- 2080s (2065-2095)

The data sets of this project are derived from the previous high-resolution probabilistic modeling results produced by the IEESC at the University of Regina using the PRECIS model (IEESC 2012). The Hadley Centre has published 17 sets of boundary data from a perturbed physics ensemble (i.e. HadCM3Q0-Q16, known as 'QUMP'), which is based on Hadley Centre's HadCM3 model under SRES A1B emissions scenario, for use with PRECIS in order to allow users to generate an ensemble of high-resolution regional simulations (McSweeney and Jones 2010, McSweeney, Jones et al. 2012). Downscaling the 17 PPE ensemble with PRECIS would require very large inputs of computing resources, data storage and data analyses. In order to explore the range of uncertainties while minimizing these requirements, we select a sub-set of 5 members (i.e. HadCM3Q0, Q3, Q10, Q13, and Q15) from the QUMP ensemble according to the Hadley Centre's recommendation (see http://www.metoffice.gov.uk/precis/qump). HadCM3Q0 is first selected as it is the standard, unperturbed model using the original parameter settings as applied in the atmospheric component of HadCM3. Selection of the remaining four members is based on a) their performances in simulating key features of the climate over Ontario, and b) their ability of sampling the range of outcomes of future changes simulated by the full 17-member ensemble (Bellprat, Kotlarski et al. 2012). We run five PRECIS experiments driven by boundary conditions from the selected GCM members from 1950 to 2099 at its highest horizontal resolution (i.e. 25 km). This allows us to carry out comprehensive analyses by providing full simulation coverage from present day to future. The PRECIS model outputs are extracted and divided into four 31-yr periods: one baseline period (1960-1990), and three future periods (2015-2045, 2035-2065, and 2065-2095), representing its simulations for the province of Ontario under current and future climate forcings. Based upon the 5-member PRECIS ensemble results, we calculated nine percentiles: 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90% for each variable as listed above for the four 31-yr periods, with the purpose of providing useful information for assessing the possible impacts associated with climatic changes at regional or local scales.

As the major achievement of this project, the Ontario CCDP is developed by integrating web-based technologies, map visualization, as well as a user-friendly interface to ensure technical or non-technical end-users have easy and quick access to the latest climate data over the province of Ontario, Canada. The official website of Ontario CCDP is http://ontarioccdp.ca. Accessing to and downloading the IDF curves and climate data sets published on this data portal are free of charge. The source should be clearly and prominently stated and cited when referring to the maps, IDF curves and climate data sets of Ontario CCDP.

2. Development of IDF Curves

This chapter introduces the methodologies used for developing projected IDF curves at grid point scale over the province of Ontario. It also summarizes the main findings of the IDF curves at selected twelve weather stations under the changing climate.

2.1 Methodology

An IDF (Intensity-Duration-Frequency) curve is produced from an extreme value statistical analysis of at least 10 years of rate-of-rainfall observations (EC 2012). In general, an IDF curve includes the frequency of extreme rainfall rates and amounts corresponding to the following durations: 5 min, 10 min, 15 min, 30 min, 60 min, 2 hr, 6 hr, 12 hr, and 24 hr. Return period is known as recurrence interval because it represents the average time between years having occurrences of a rainfall event of a given magnitude, and it is usually expressed in years: 2 yr, 5 yr, 10 yr, 25 yr, 50 yr and 100 yr.

The IDF curve is widely used to analyze the essential characteristics of point rainfall for shorter durations, thus it can provide a convenient tool to summarize regional rainfall information, and is useful in municipal storm water management practice (Prodanovic and Simonovic 2007). In short, the development of IDF curve starts by gathering time series records of different durations. Annual extremes are then extracted for all durations from the time series. A probability distribution will be selected to fit the annual extreme data, with the purpose of estimating rainfall quantities and standardize the characteristics of point rainfall with widely varying lengths of record (Hogg and Hogg , Nhat, Tachikawa et al. 2006, Mailhot, Duchesne et al. 2007, Prodanovic and Simonovic 2007, Shephard 2011, Solaiman and Simonovic 2011, Peck, Prodanovic et al. 2012, Mirhosseini, Srivastava et al. 2013).

As a common practice by Environment Canada (EC 2012), Gumbel's extreme value distribution is widely accepted and used to fit the annual extremes rainfall data with the method of moments (CSA 2010). The Gumbel probability distribution has the following form (Watt, Lathem et al. 1989):

$$x_T = \mu_z + K_T \sigma_z \tag{1}$$

where x_T represents the magnitude of the *T*-year event, μ_z and σ_z are the mean and standard deviation of the annual maximum series, and K_T is a frequency factor depending on the return period, *T*. The frequency factor is usually obtained using the following relationship:

$$K_T = \frac{-\sqrt{6}}{\pi}\left[0.5772 + \ln\left(\ln\left(\frac{T}{T-1}\right)\right)\right] \tag{2}$$

Meteorological Service of Canada (MSC) uses this method to estimate rainfall frequency for durations of 5, 10, 15 and 30 minutes, as well as for 1, 2, 6, 12 and 24 hours. When data records for durations shorter than 1 hour are not available in the PRECIS modeling outputs, a method from World Meteorological Organization (WMO 1994) will be employed to estimate rainfall-frequency data for those shorter durations.

In order to make the process of IDF data interpolation more efficient, the IDF data derived with above methods is typically fitted to a continuous function. The following three parameter function is recommended by the Ontario Drainage Management Manual (MTO 1997):

$$i = \frac{\mathrm{A}}{(t_d + \mathrm{B})^{\mathrm{C}}} \tag{3}$$

where i is the rainfall intensity (mm/h), t_d is the rainfall duration (h), and A, B, and C are coefficients. Method of least squares can be used to estimate values of these coefficients to achieve the closest possible fit of the data (MTO 1997). Once IDF data is fitted to the above function, plots of rainfall intensity vs. duration for different return periods can be produced.

2.2 Projected IDF Curves

To develop IDF curves based on the PRECIS projections, time series of hourly total precipitation for four 31-yr periods are derived for all 25-km grid points over Ontario. The aforementioned method is then applied to generate IDF curves at grid point scale. Here, we only screened out twelve points which cover twelve weather stations (see Table 1) respectively to further analyze their major characteristics under the changing climate. Four 31-yr periods will be covered but only three typical percentiles (i.e. 10%, 50%, and 90%) will be considered in the following analysis. For more IDF curves, please visit the website of Ontario CCDP: http://ontarioccdp.ca.

Table 1. Twelve weather stations.

ID	Weather Station Name	Latitude	Longitude	Elevation
1	WINDSOR A	42°16'32.000" N	82°57'20.000" W	189.60 m
2	LONDON INT'L AIRPORT	43°01'59.000" N	81°09'04.000" W	278.00 m
3	TORONTO LESTER B. PEARSON INT'L A	43°40'38.000" N	79°37'50.000" W	173.40 m
4	TORONTO ISLAND A	43°37'43.000" N	79°23'42.000" W	76.50 m
5	WIARTON A	44°44'45.000" N	81°06'26.000" W	222.20 m
6	SAULT STE MARIE A	46°29'00.000" N	84°30'34.000" W	192.00 m
7	NORTH BAY A	46°21'49.000" N	79°25'22.000" W	370.30 m
8	OTTAWA MACDONALD-CARTIER INT'L A	45°19'21.000" N	75°40'09.000" W	114.00 m
9	SIOUX LOOKOUT A	50°07'00.000" N	91°54'00.000" W	383.10 m
10	TIMMINS VICTOR POWER A	48°34'11.000" N	81°22'36.000" W	294.70 m
11	MOOSONEE UA	51°16'00.000" N	80°39'00.000" W	10.00 m
12	BIG TROUT LAKE	53°50'00.000" N	89°52'00.000" W	224.10 m

Figure 1 to Figure 3 show the projected IDF curves at WINDSOR A station for 10%, 50%, and 90% percentiles respectively, each percentile covers four 31-yr periods: 1960-1990, 2015-2045, 2035-2065, and 2065-2095. There is a slight increase in the rainfall intensity for the period of 2015-2045 at 10%

percentile relative to the baseline period (i.e. 1960-1990), no apparent changes are projected for the period of 2035-2065 while a slight decrease is projected for the period of 2065-2095. Similar patterns are reported by the IDF curves at 50%. As for the ones of 90% percentile, there are apparent increases for shorter durations ranging from 5 min to 2 hr for three future periods. The shorter the duration the more significant the increase is.

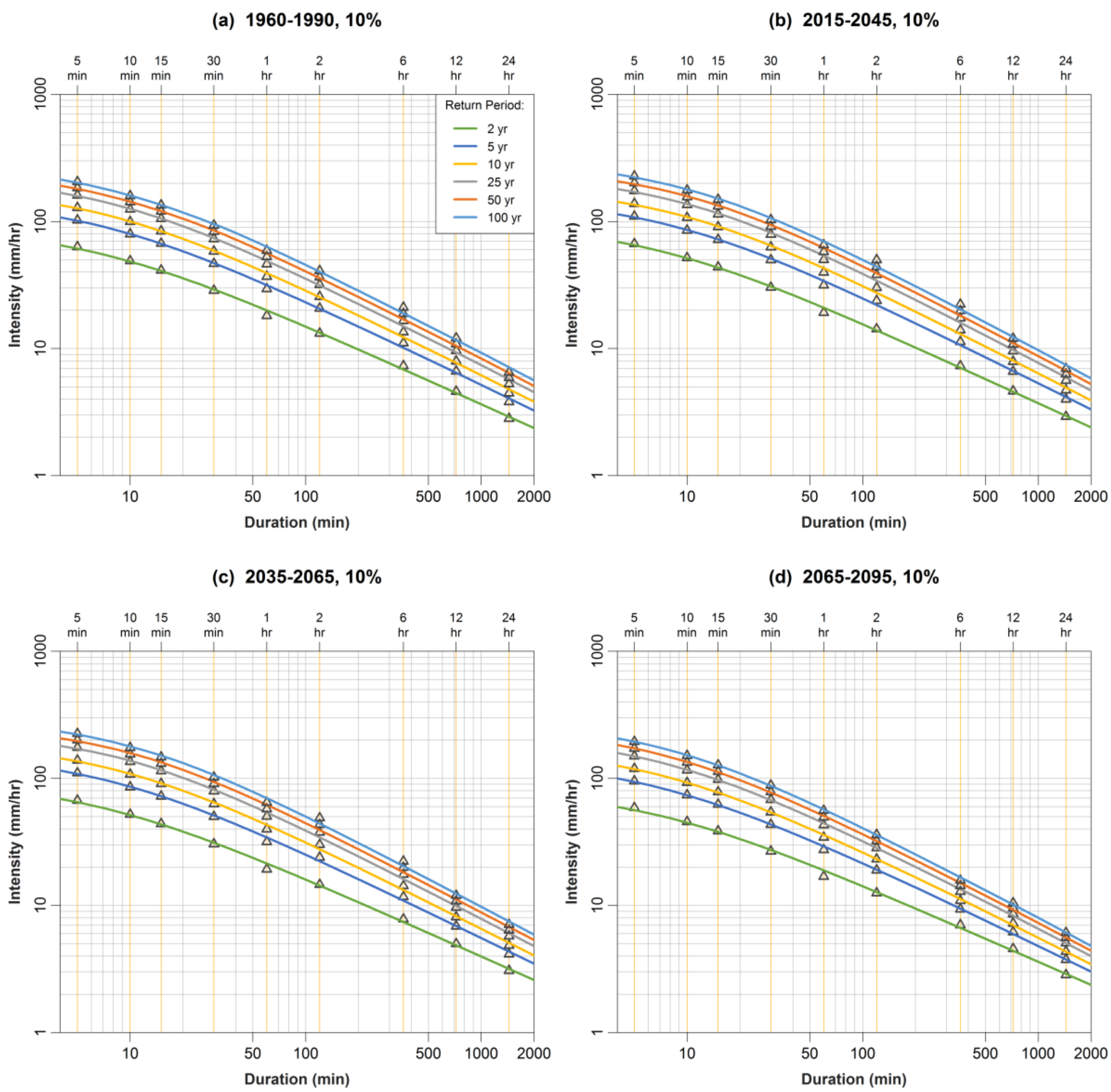

Figure 1. Projected IDF Curves of WINDSOR A at 10% percentile.

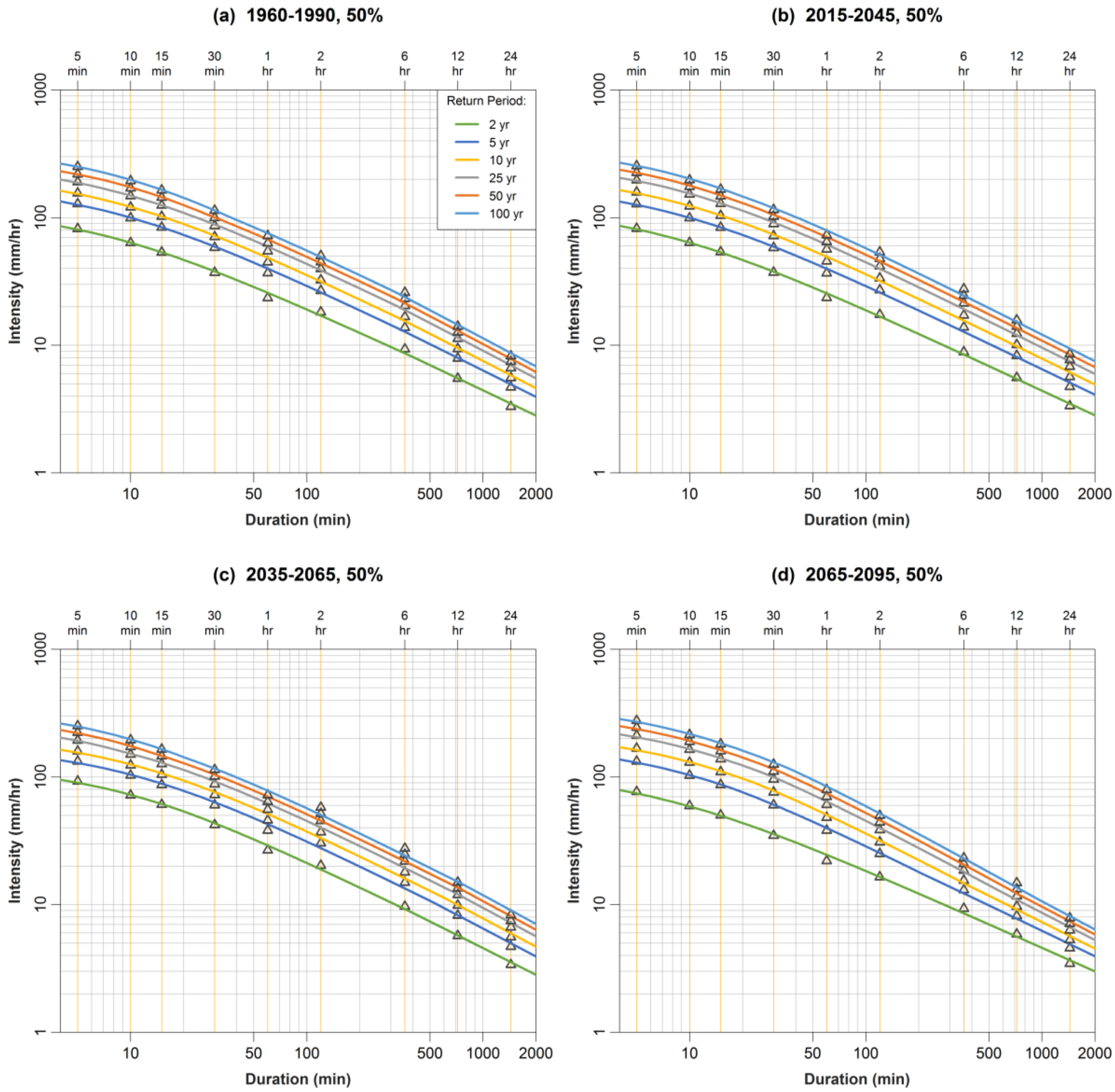

Figure 2. Projected IDF Curves of WINDSOR A at 50% percentile.

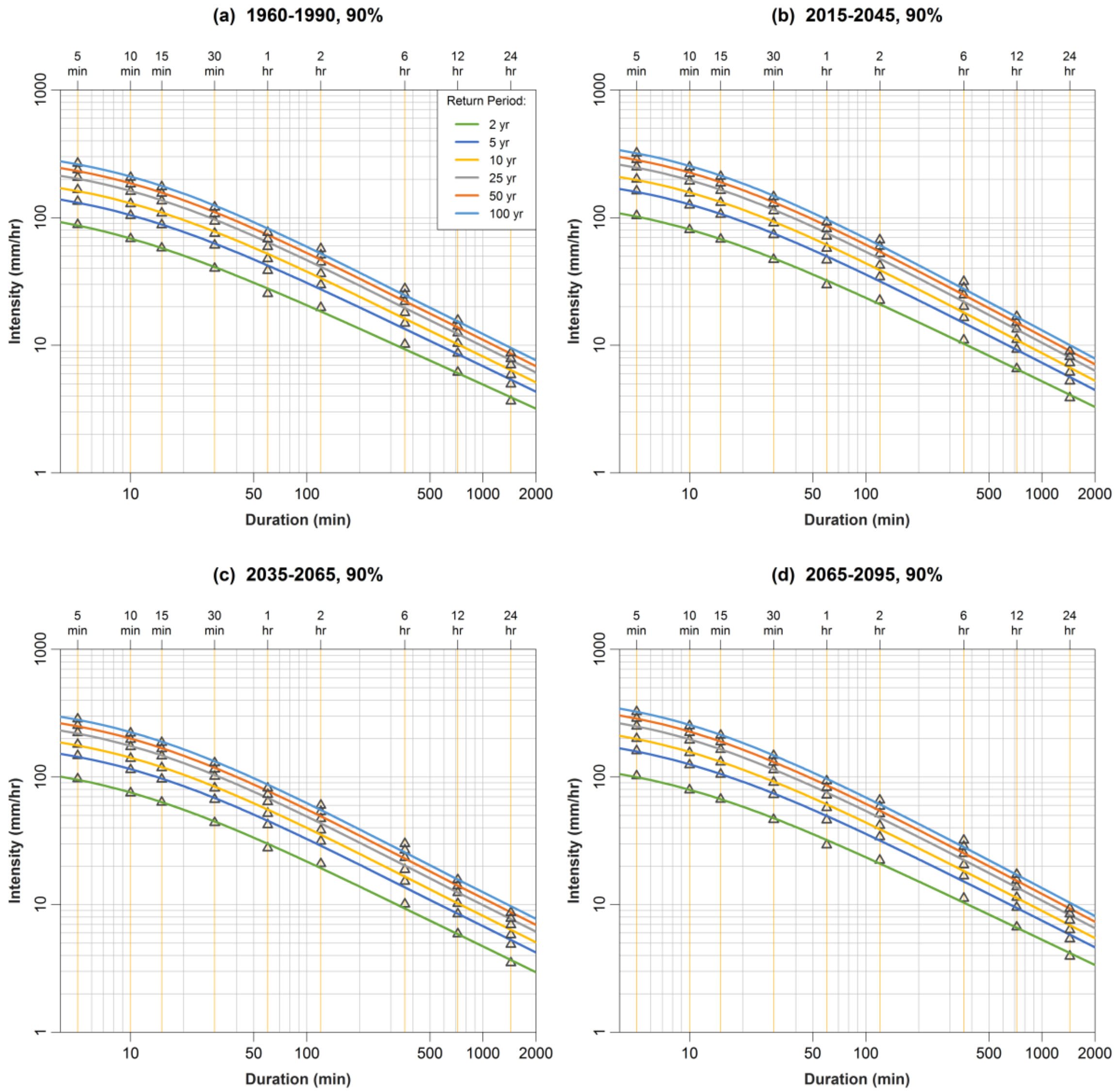

Figure 3. Projected IDF Curves of WINDSOR A at 90% percentile.

Figure 4 to Figure 6 show the projected IDF curves at LONDON INT'L AIRPORT station for 10%, 50%, and 90% percentiles respectively, each percentile covers four 31-yr periods: 1960-1990, 2015-2045, 2035-2065, and 2065-2095. There are apparent increases in the rainfall intensity for the three future periods at 50% percentile relative to the baseline period (i.e. 1960-1990). Similar patterns are reported by the IDF curves at both 10% and 90% percentiles.

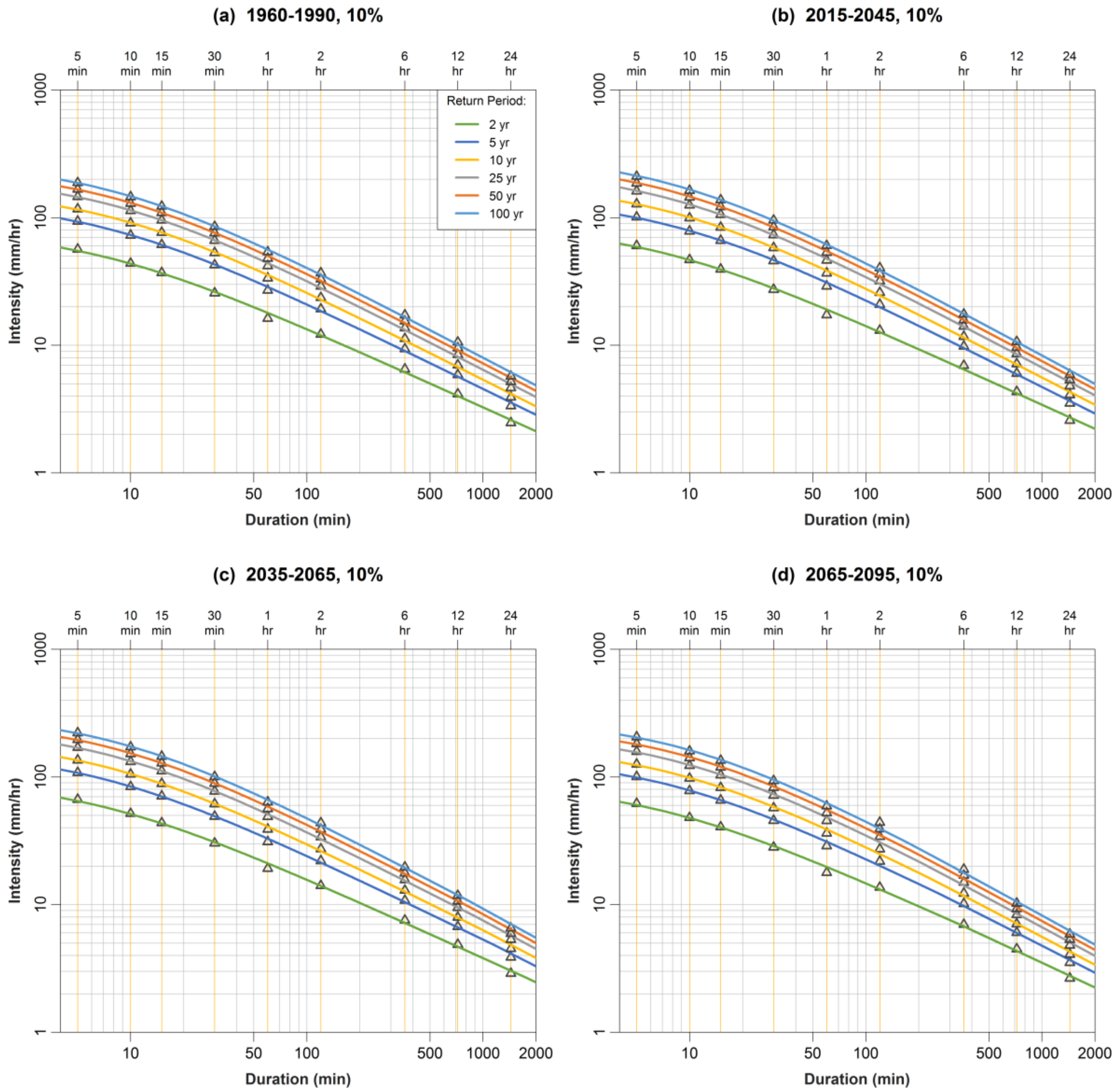

Figure 4. Projected IDF Curves of LONDON INT'L AIRPORT at 10% percentile.

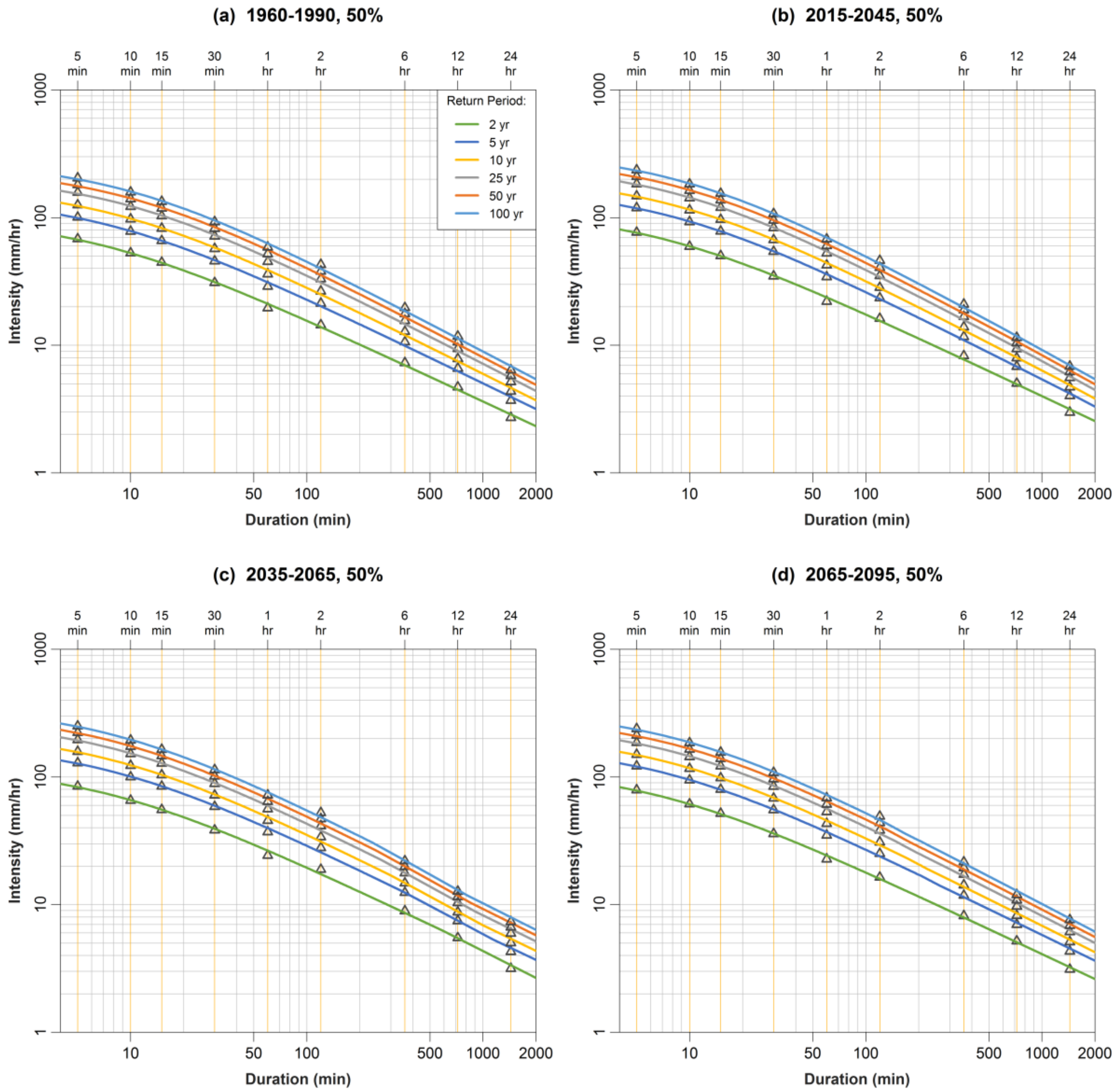

Figure 5. Projected IDF Curves of LONDON INT'L AIRPORT at 50% percentile.

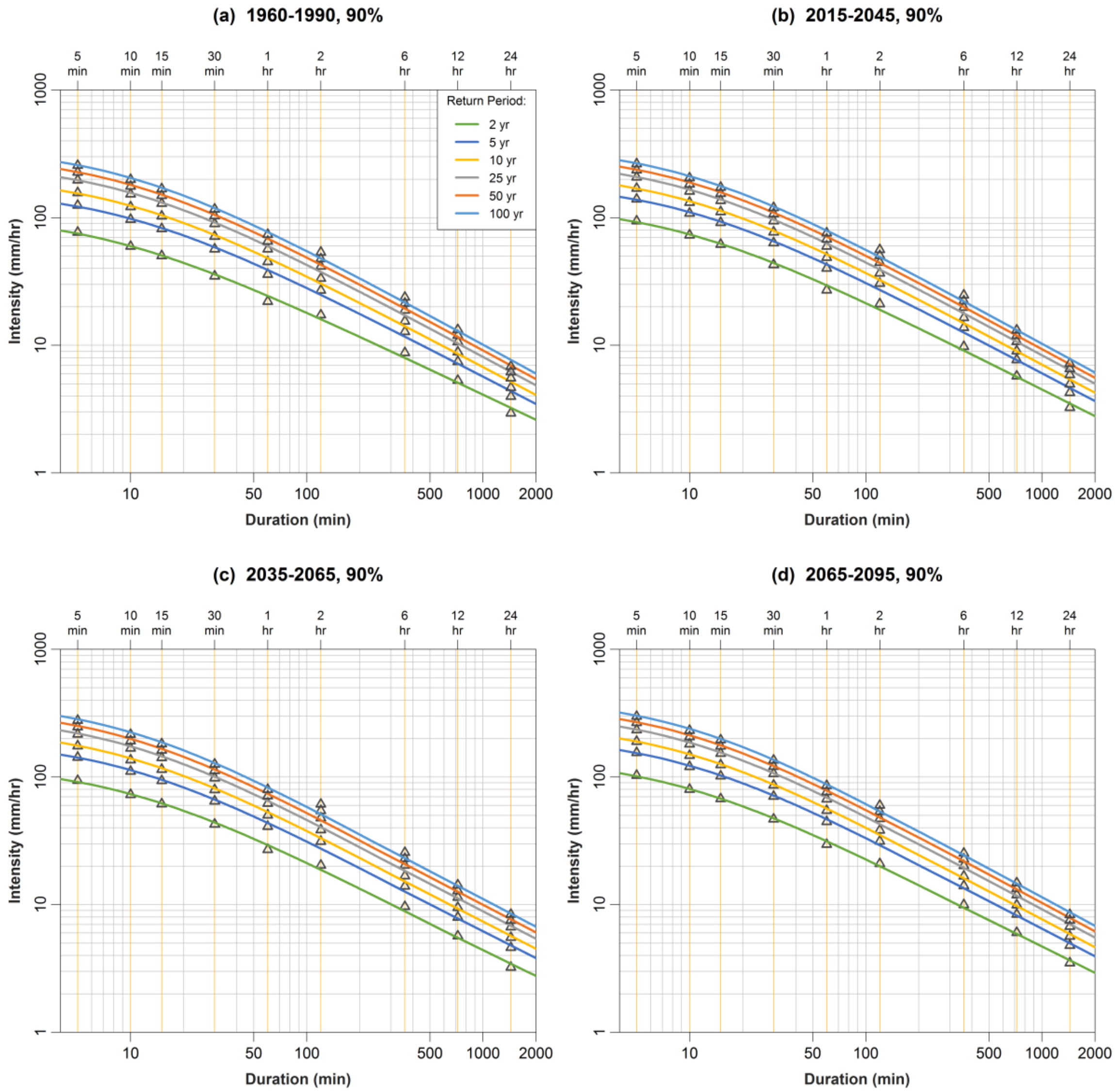

Figure 6. Projected IDF Curves of LONDON INT'L AIRPORT at 90% percentile.

Figure 7 to Figure 9 show the projected IDF curves at TORONTO LESTER B. PEARSON INT'L A station for 10%, 50%, and 90% percentiles respectively, each percentile covers four 31-yr periods: 1960-1990, 2015-2045, 2035-2065, and 2065-2095. There are apparent increases in the rainfall intensity for the three future periods at 10% percentile relative to the baseline period (i.e. 1960-1990). Similar patterns are reported by the IDF curves at 90% percentile. For the ones at 50% percentile, there are significant increases in the rainfall intensity for 2015-2045 and 2065-2095, but no apparent changes are reported for the period of 2035-2065.

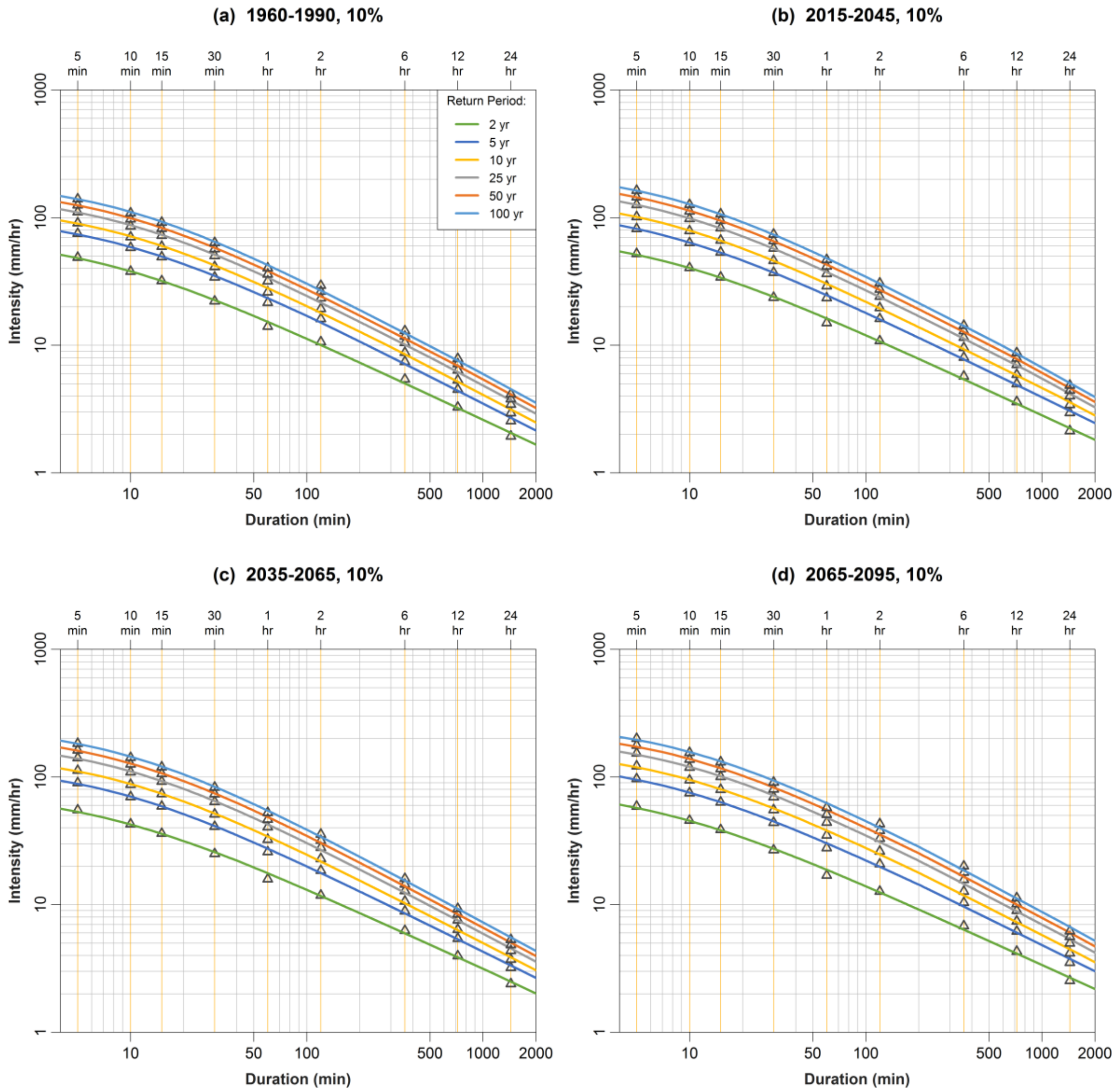

Figure 7. Projected IDF Curves of TORONTO LESTER B. PEARSON INT'L A at 10% percentile.

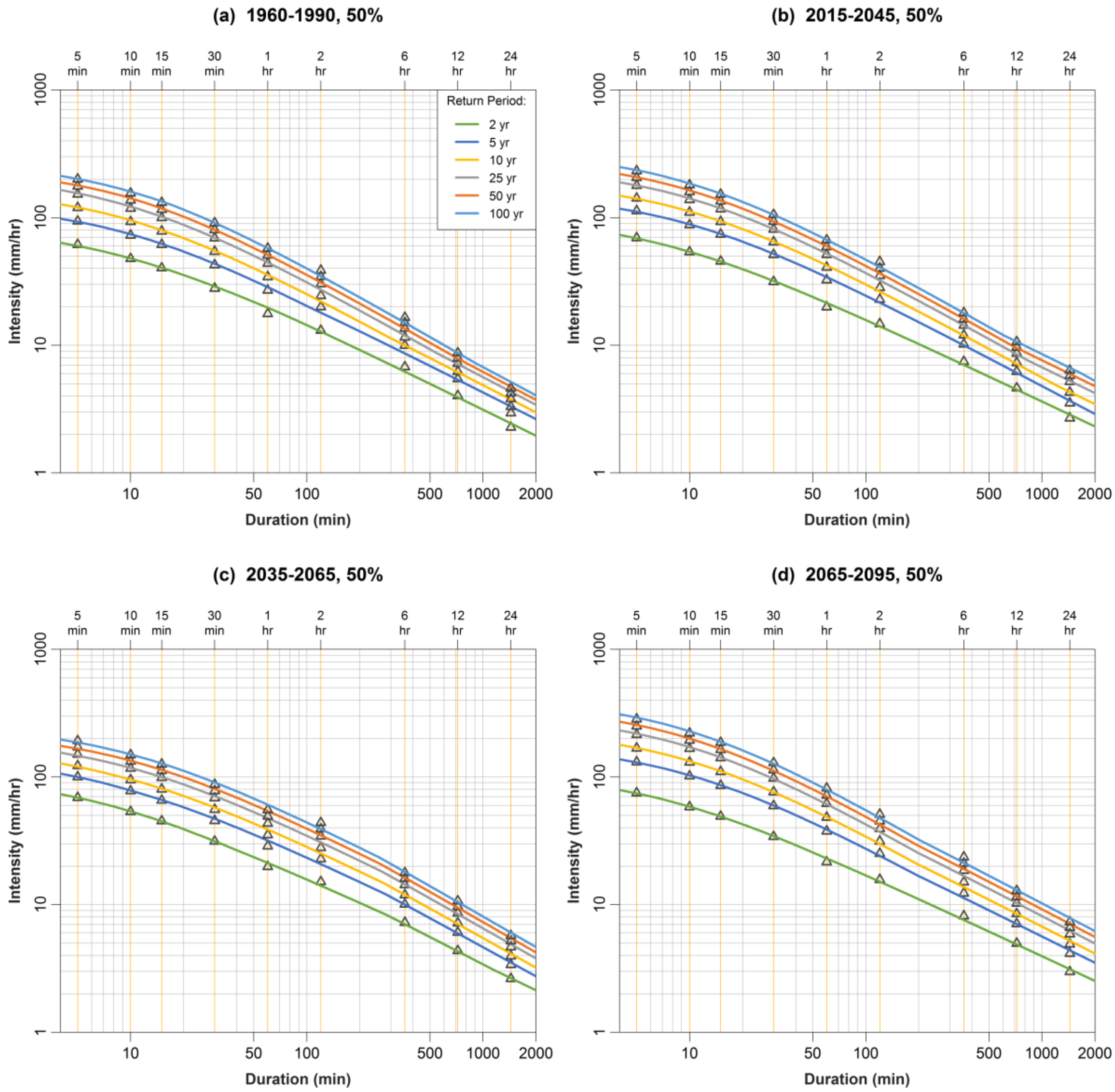

Figure 8. Projected IDF Curves of TORONTO LESTER B. PEARSON INT'L A at 50% percentile.

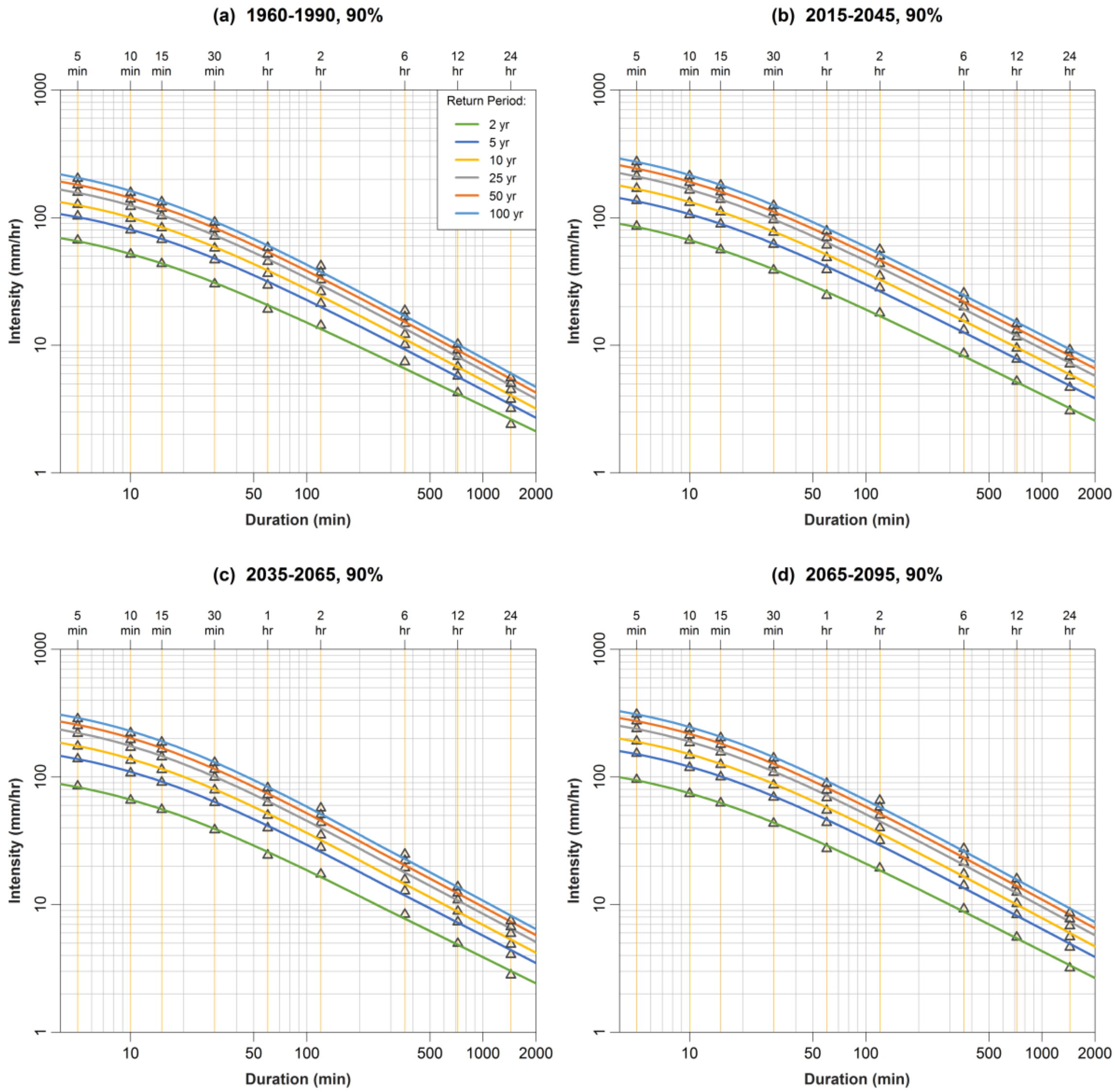

Figure 9. Projected IDF Curves of TORONTO LESTER B. PEARSON INT'L A at 90% percentile.

Figure 10 to Figure 12 show the projected IDF curves at TORONTO ISLAND A station for 10%, 50%, and 90% percentiles respectively, each percentile covers four 31-yr periods: 1960-1990, 2015-2045, 2035-2065, and 2065-2095. There are apparent increases in the rainfall intensity for the three future periods at 50% percentile relative to the baseline period (i.e. 1960-1990). Similar patterns are reported by the IDF curves at both 10% and 90% percentiles.

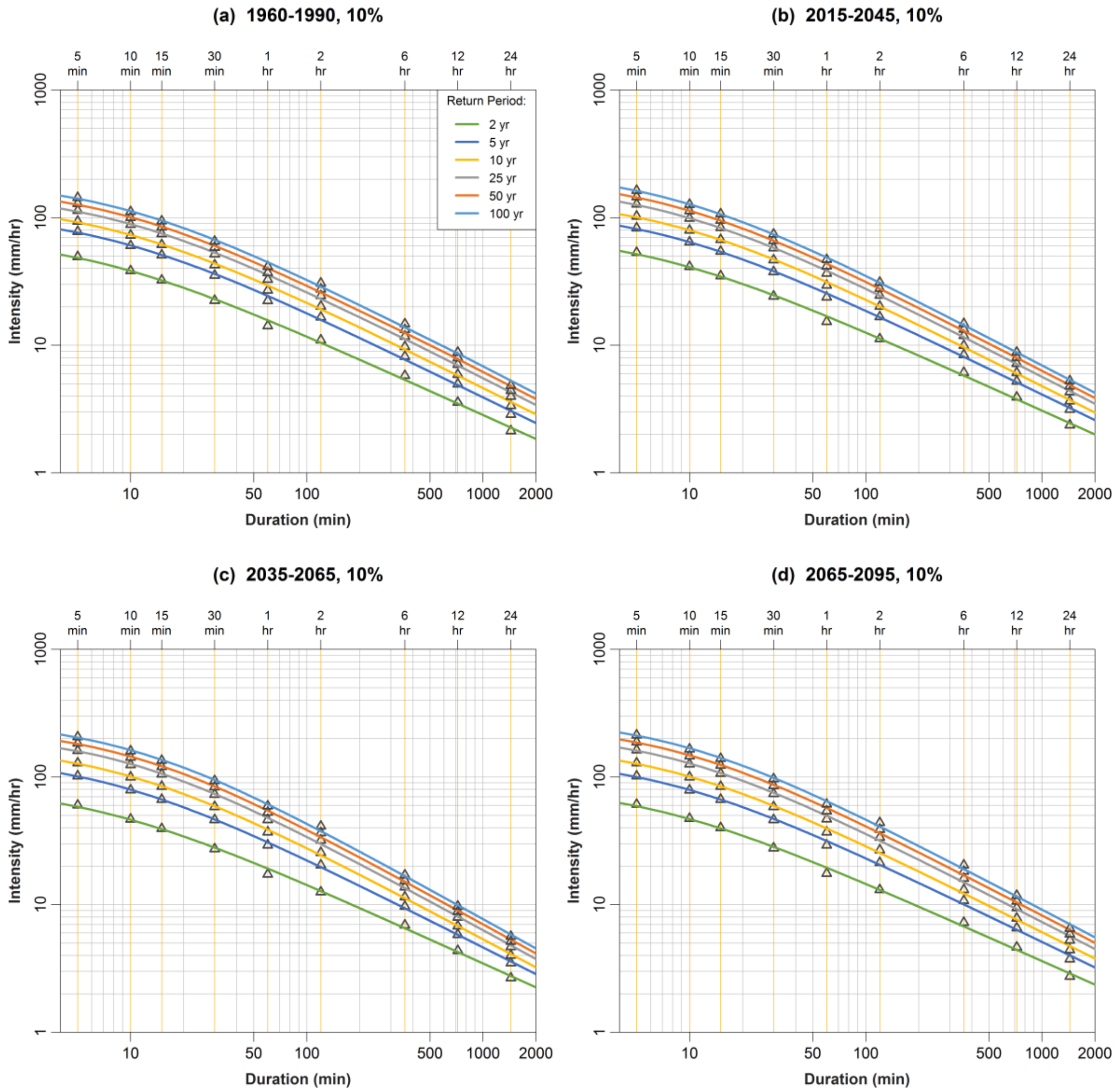

Figure 10. Projected IDF Curves of TORONTO ISLAND A at 10% percentile.

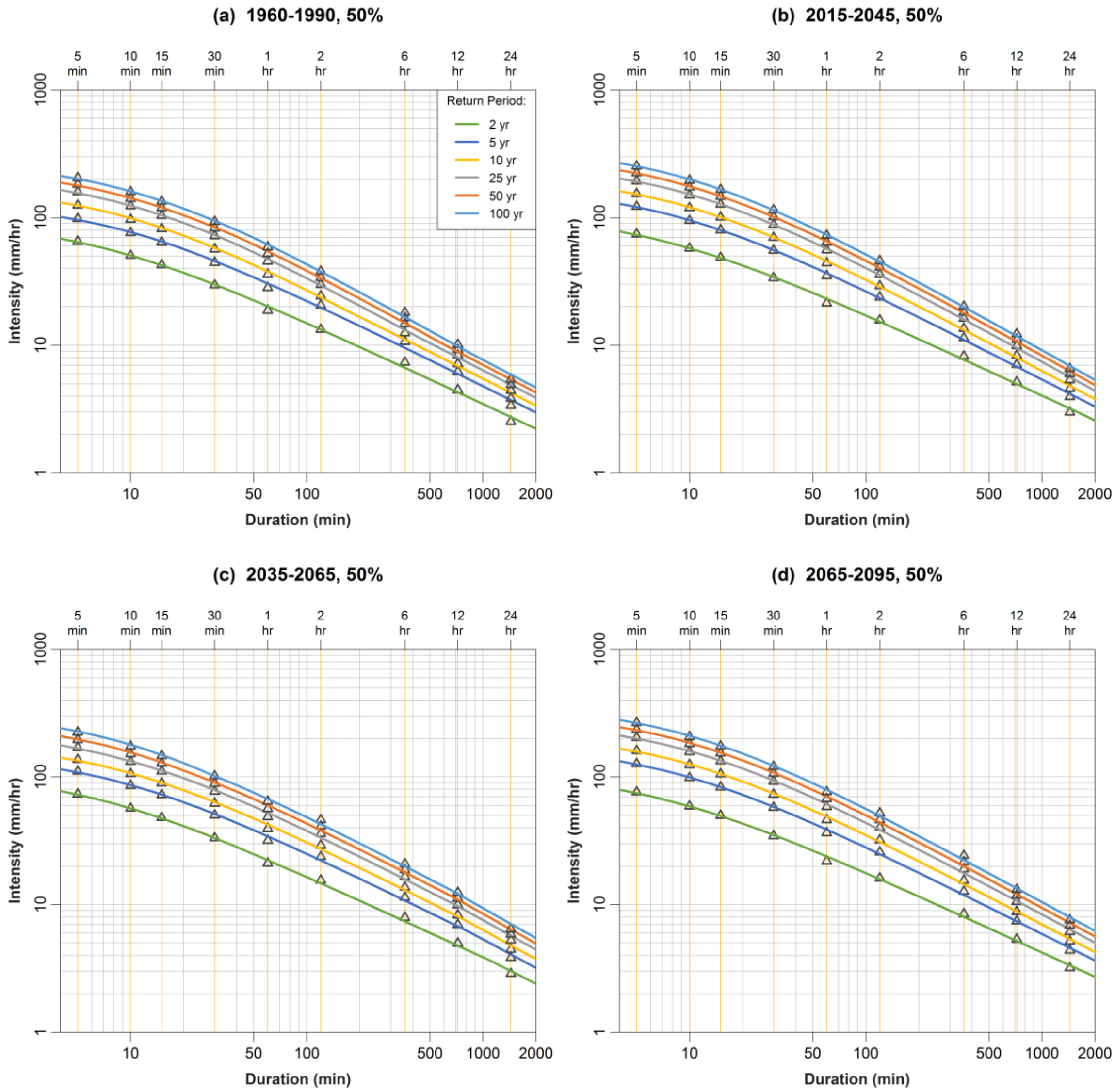

Figure 11. Projected IDF Curves of TORONTO ISLAND A at 50% percentile.

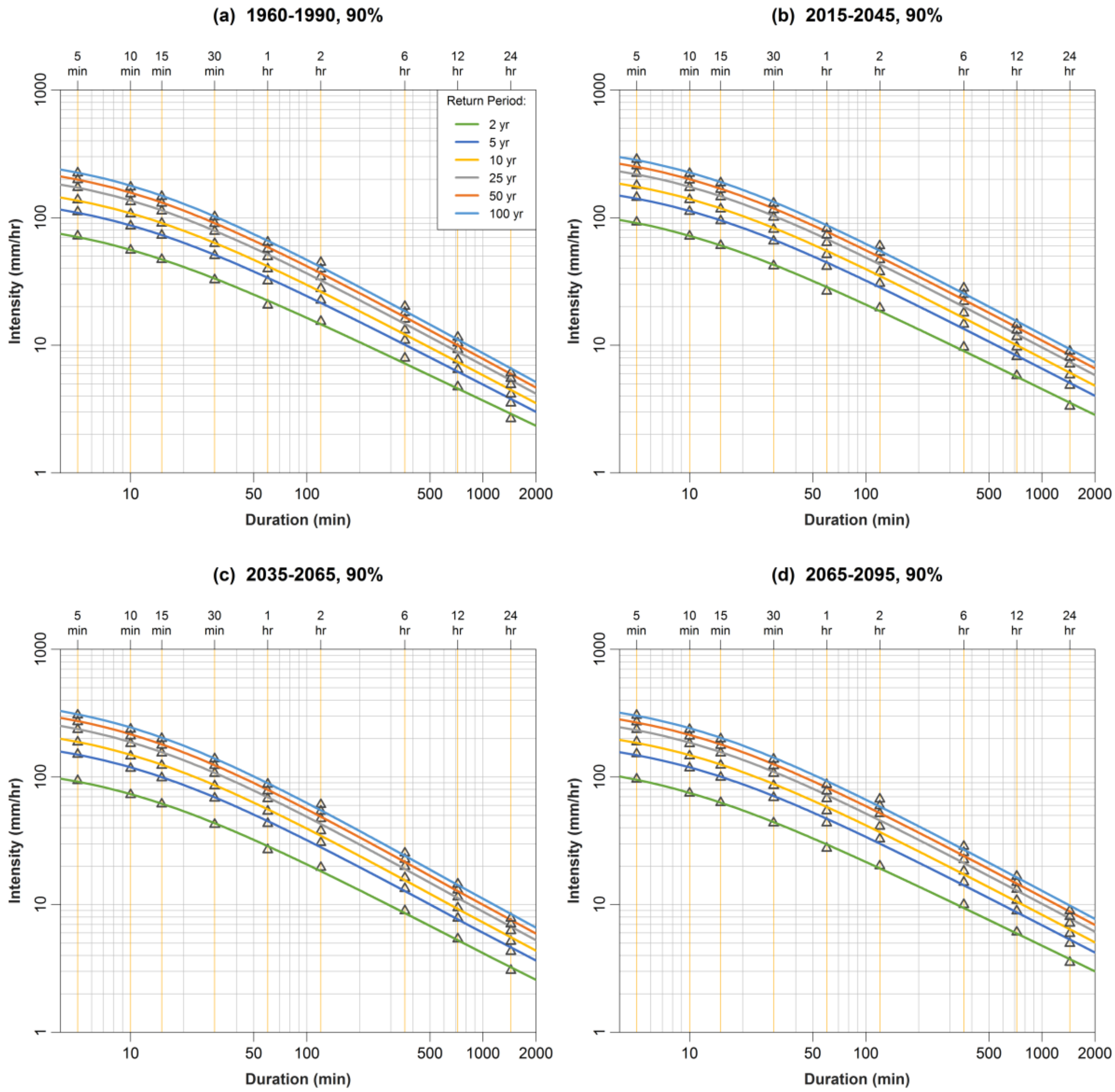

Figure 12. Projected IDF Curves of TORONTO ISLAND A at 90% percentile.

Figure 13 to Figure 15 show the projected IDF curves at WIARTON A station for 10%, 50%, and 90% percentiles respectively, each percentile covers four 31-yr periods: 1960-1990, 2015-2045, 2035-2065, and 2065-2095. There are apparent increases in the rainfall intensity for the three future periods at 10% percentile relative to the baseline period (i.e. 1960-1990). Similar patterns are reported by the IDF curves at 90% percentile. For the ones of 50% percentile, there are significant increases in the rainfall intensity for the periods of 2015-2045 and 2065-2095, while no apparent changes are reported for the period of 2035-2065.

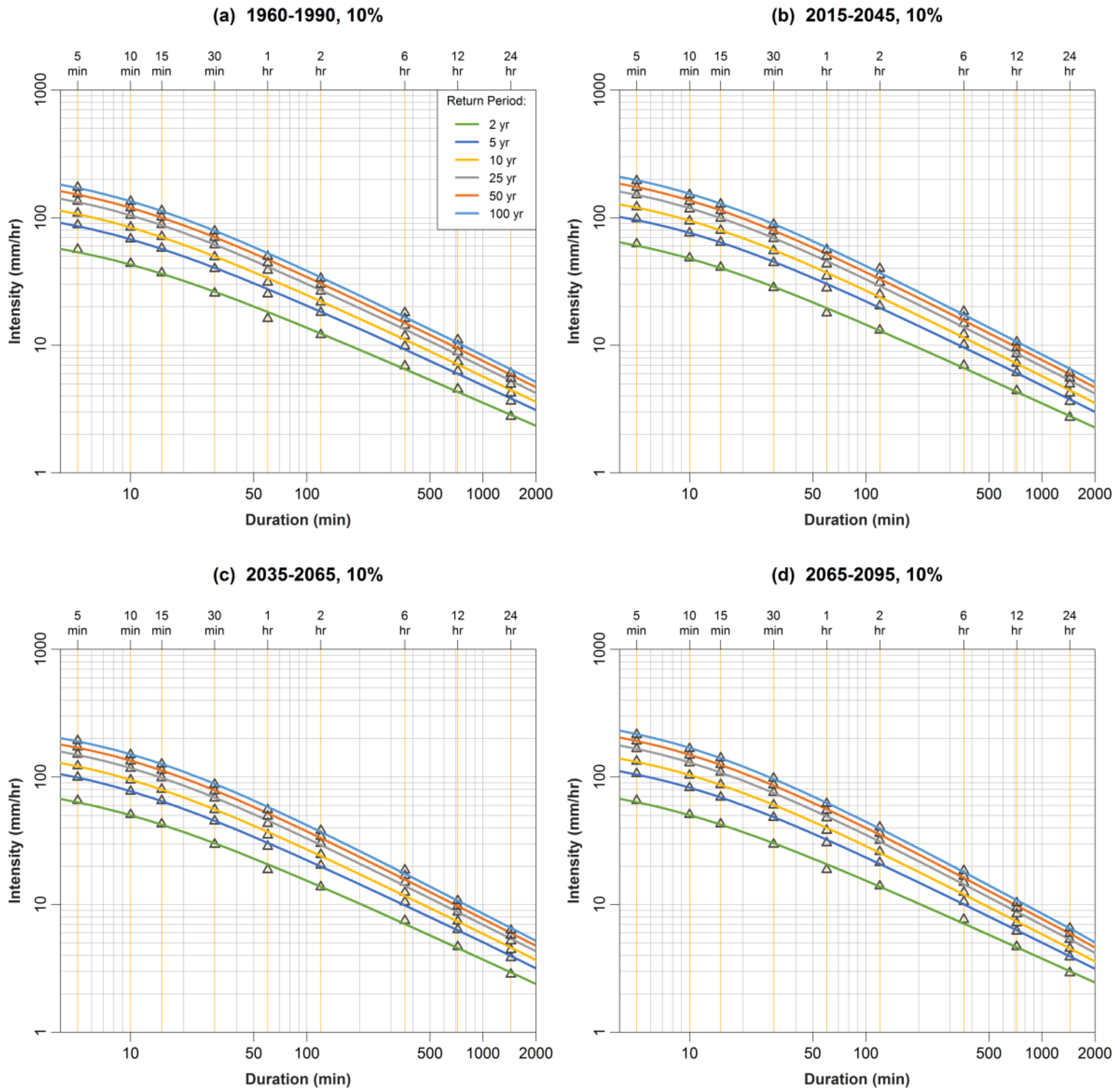

Figure 13. Projected IDF Curves of WIARTON A at 10% percentile.

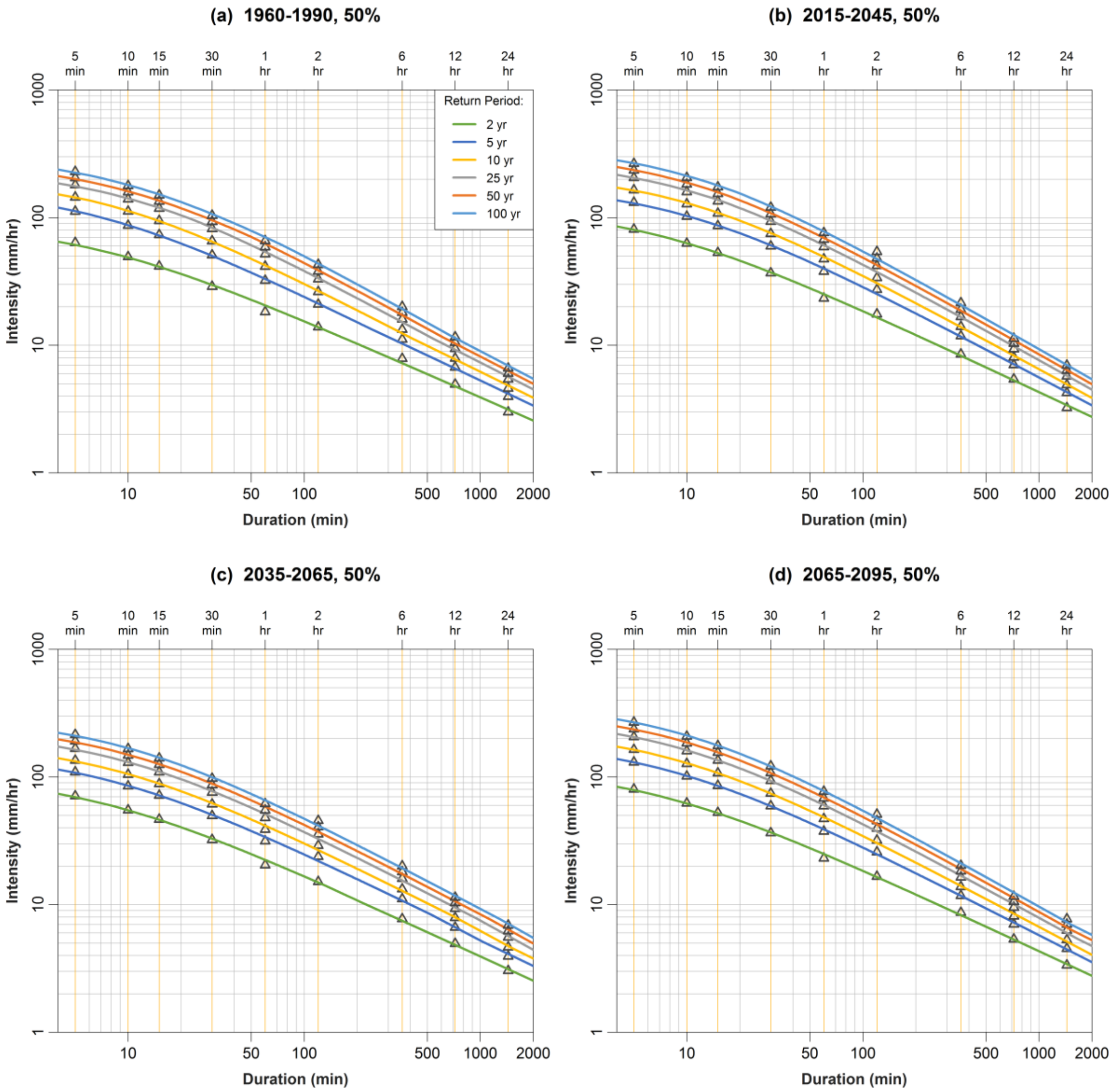

Figure 14. Projected IDF Curves of WIARTON A at 50% percentile.

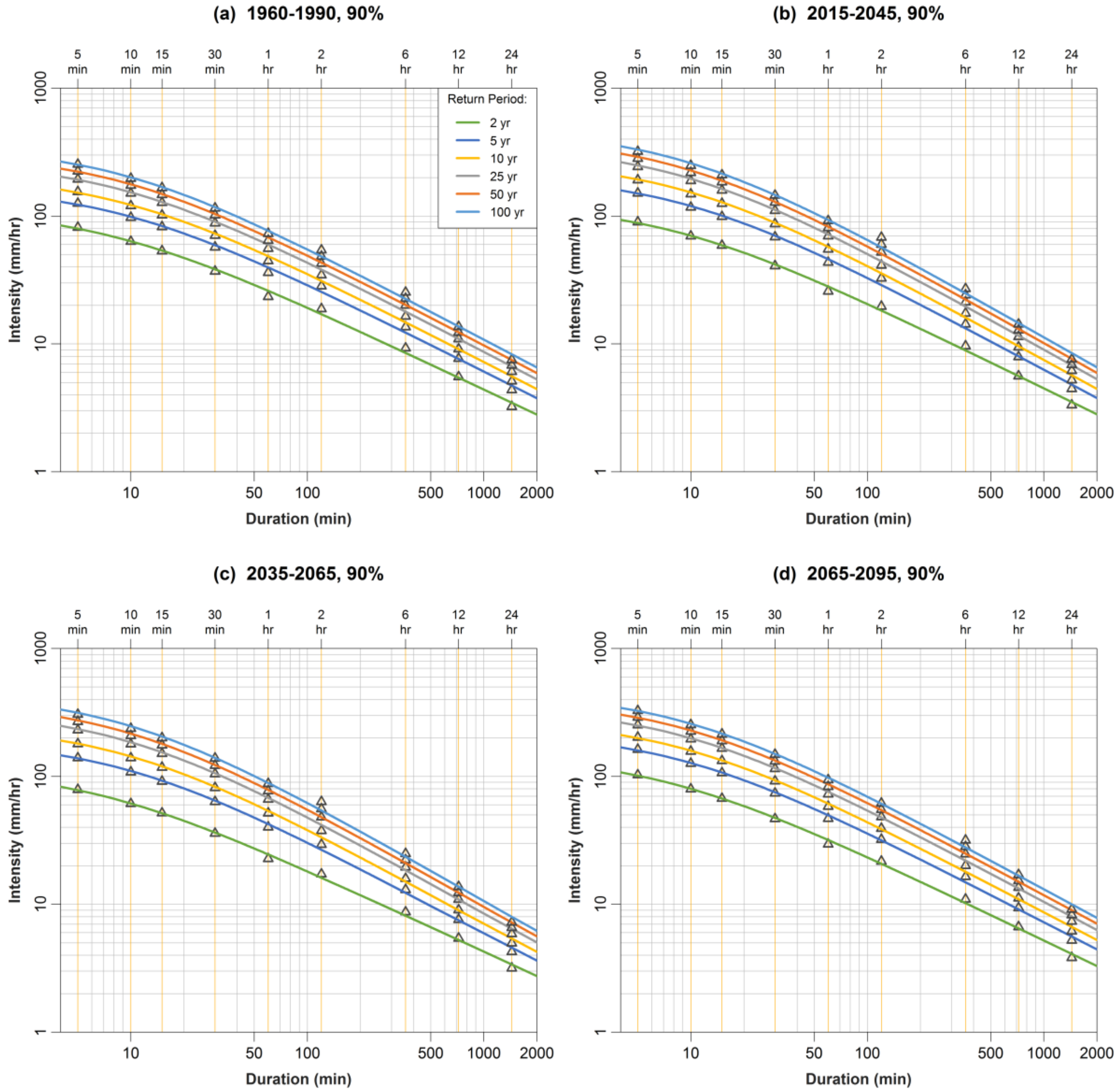

Figure 15. Projected IDF Curves of WIARTON A at 90% percentile.

Figure 16 to Figure 18 show the projected IDF curves at SAULT STE MARIE A station for 10%, 50%, and 90% percentiles respectively, each percentile covers four 31-yr periods: 1960-1990, 2015-2045, 2035-2065, and 2065-2095. There are no apparent increases in the rainfall intensity for the three future periods at 10% percentile relative to the baseline period (i.e. 1960-1990). For the ones at both 10% and 90% percentiles, there are significant increases in the rainfall intensity for the period of 2065-2095 while no apparent changes are reported for the periods of 2015-2045 and 2035-2065.

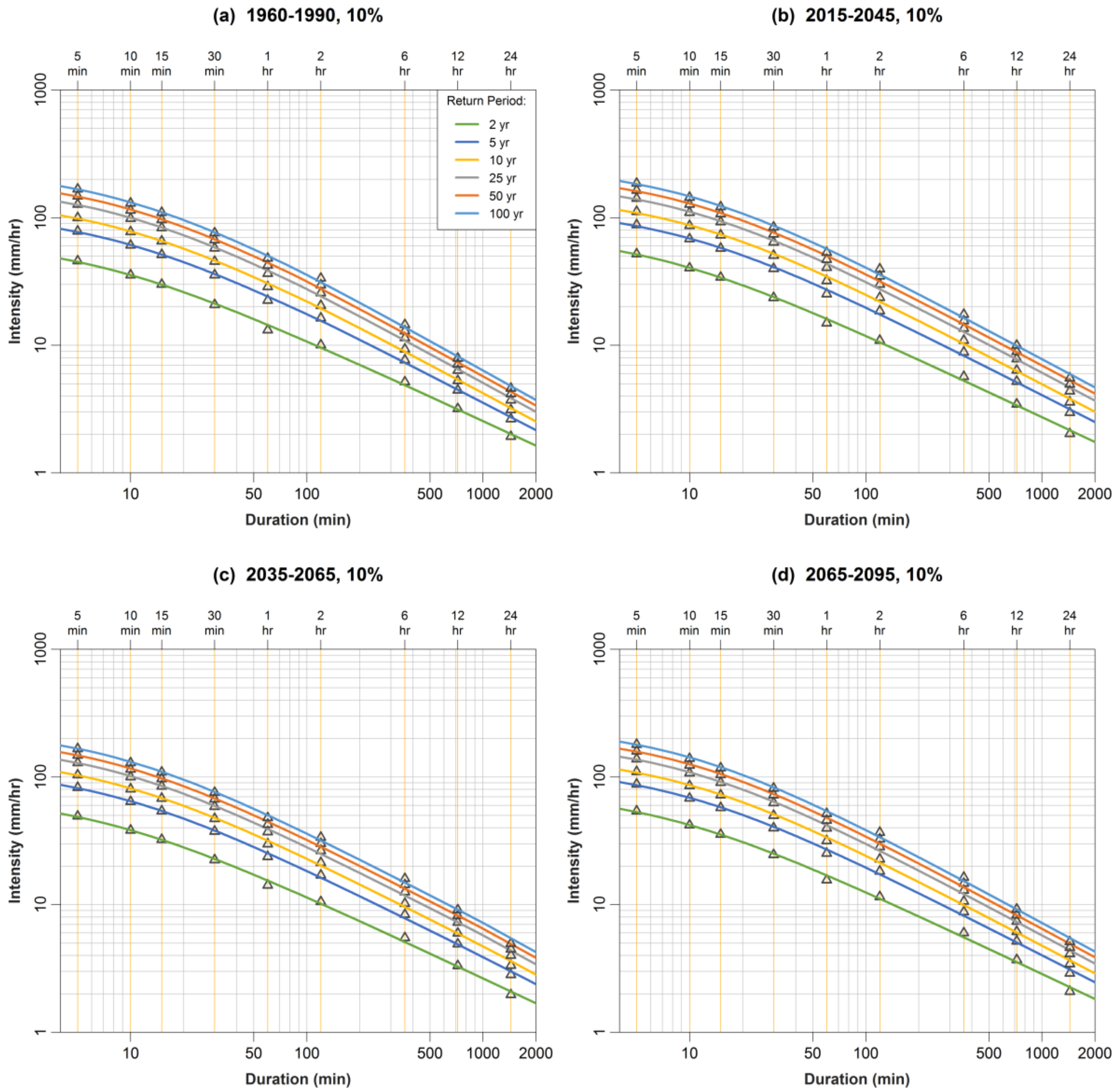

Figure 16. Projected IDF Curves of SAULT STE MARIE A at 10% percentile.

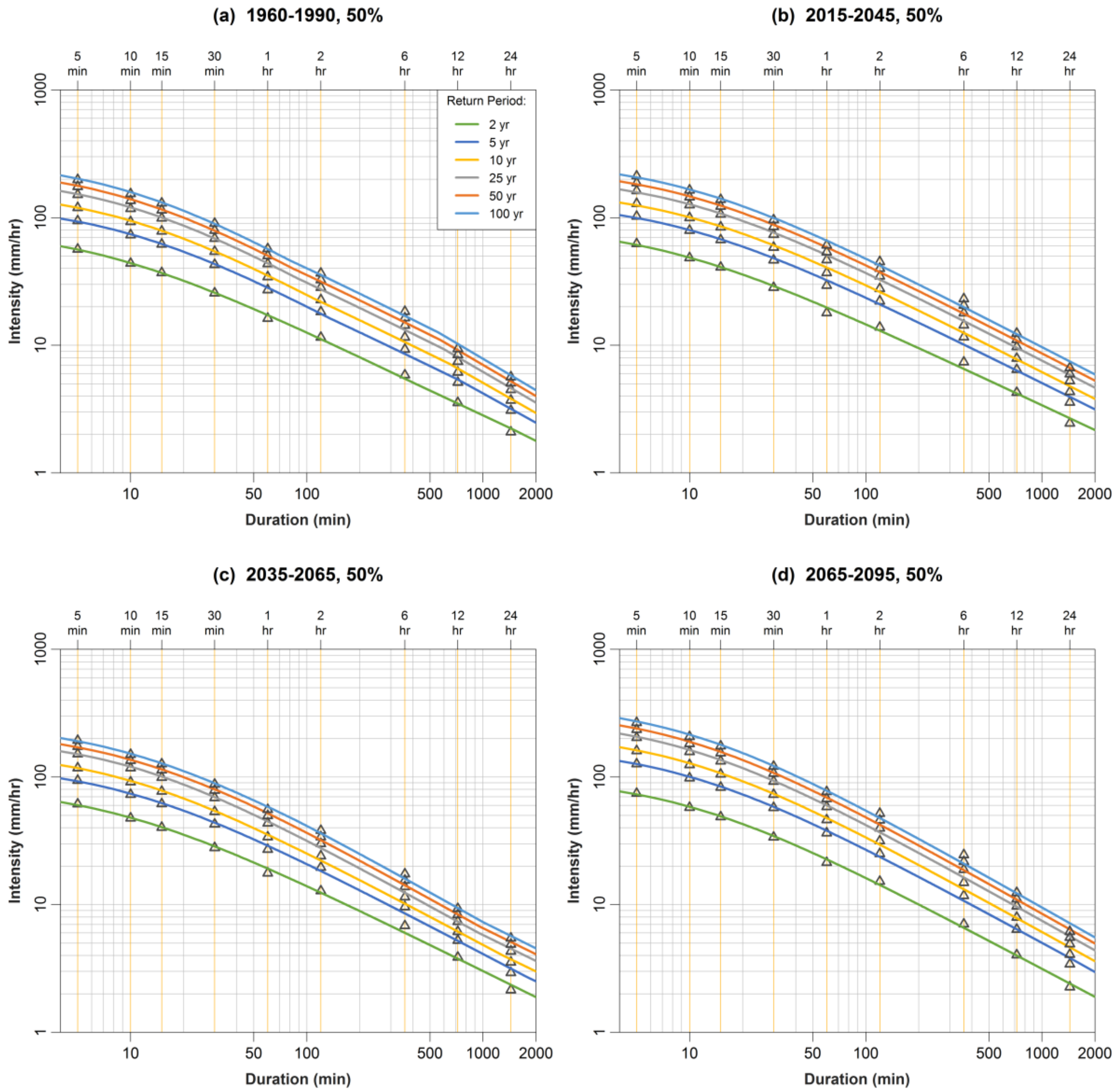

Figure 17. Projected IDF Curves of SAULT STE MARIE A at 50% percentile.

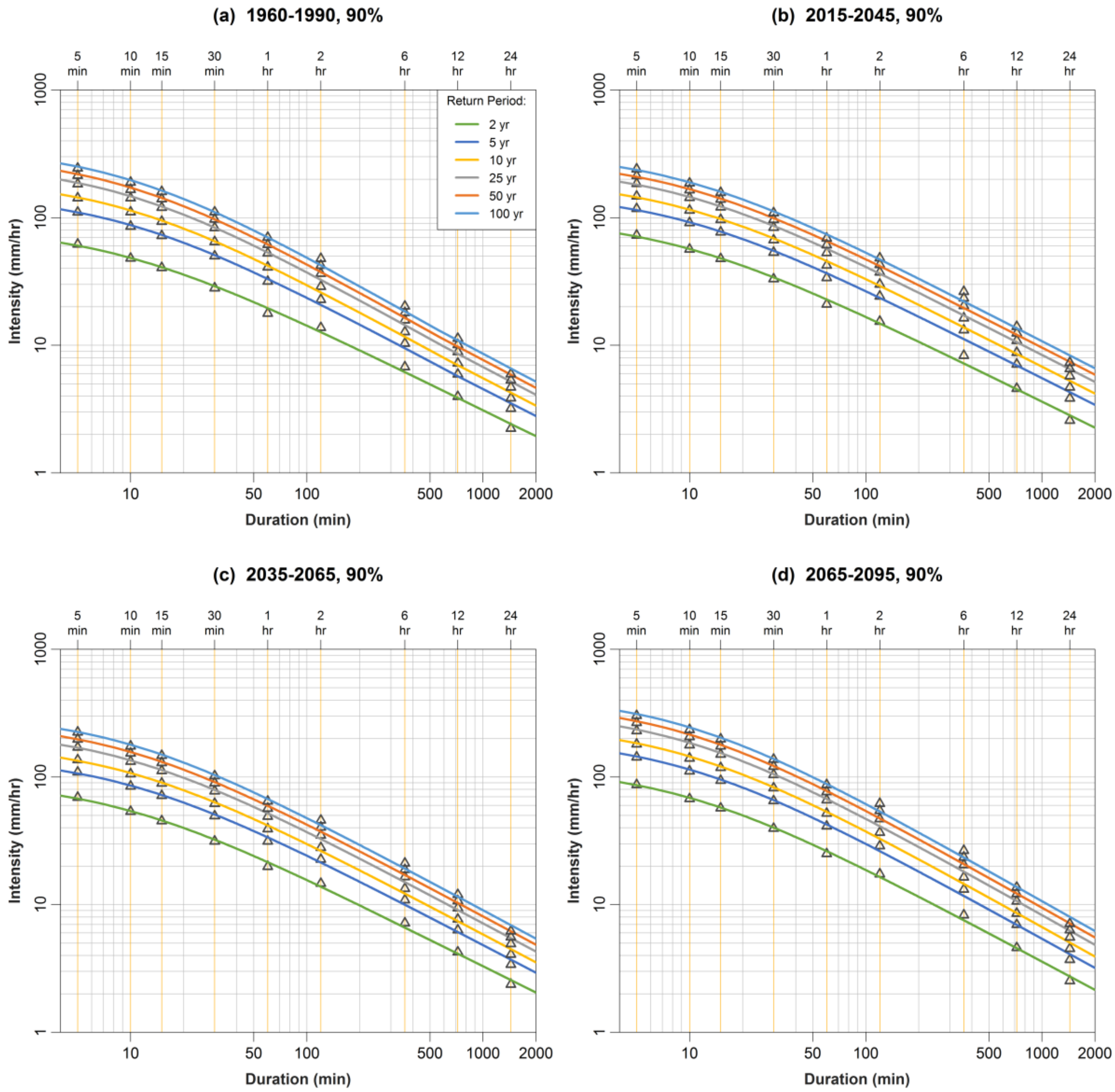

Figure 18. Projected IDF Curves of SAULT STE MARIE A at 90% percentile.

Figure 19 to Figure 21 show the projected IDF curves at NORTH BAY A station for 10%, 50%, and 90% percentiles respectively, each percentile covers four 31-yr periods: 1960-1990, 2015-2045, 2035-2065, and 2065-2095. There are apparent increases in the rainfall intensity for the three future periods at 10% percentile relative to the baseline period (i.e. 1960-1990). Similar patterns but slight increases are reported by the IDF curves at both 50% and 90% percentiles.

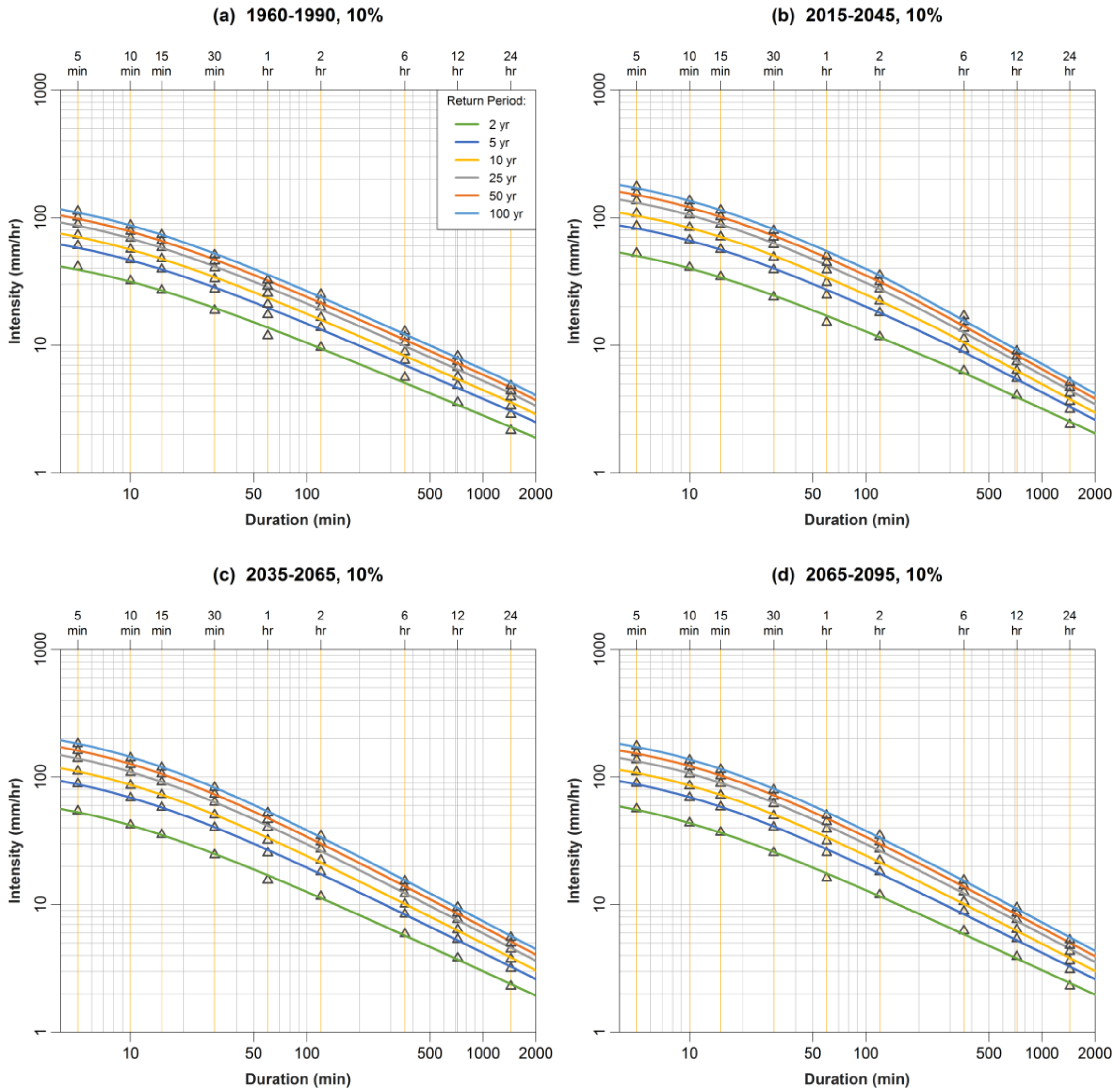

Figure 19. Projected IDF Curves of NORTH BAY A at 10% percentile.

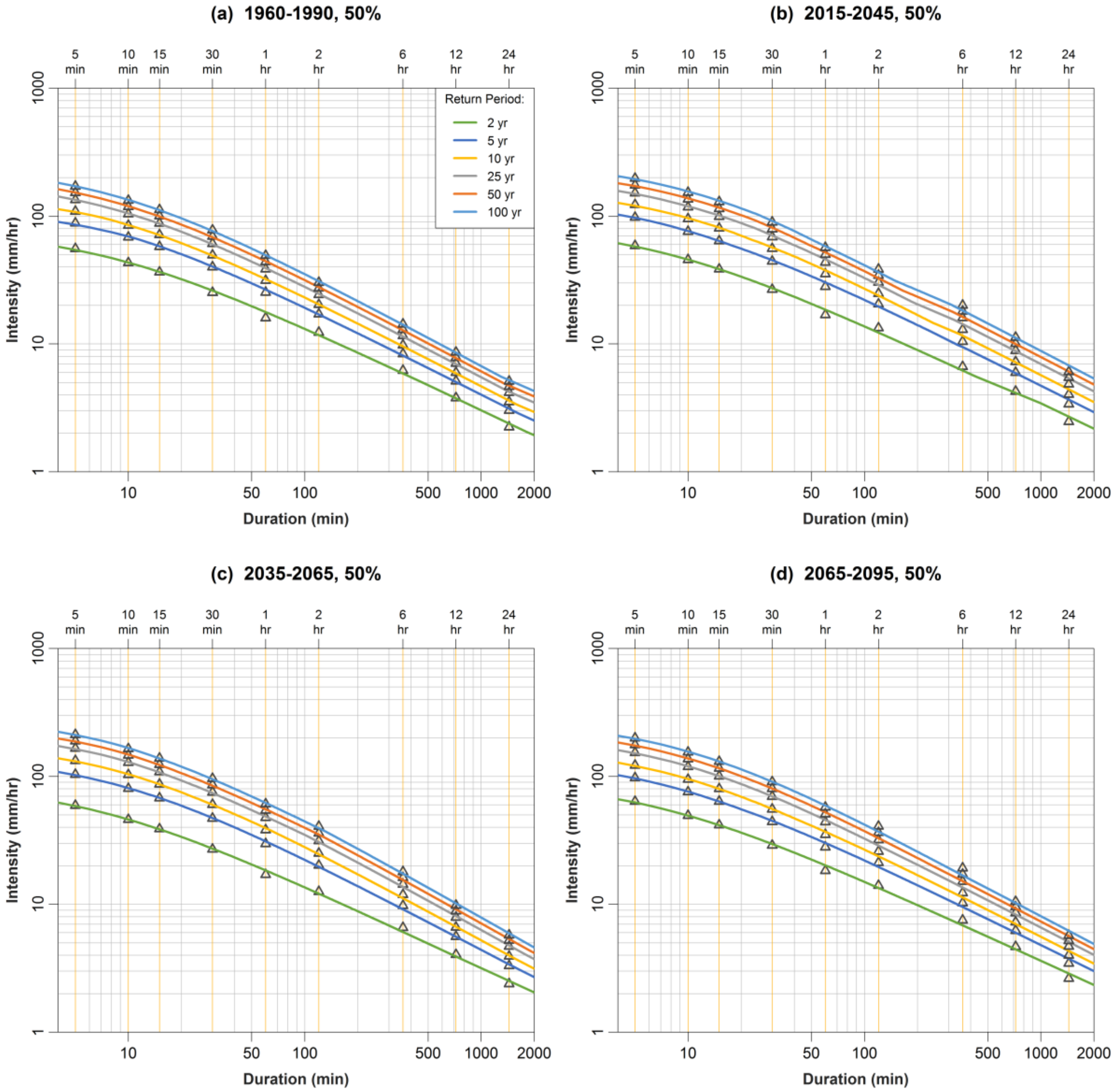

Figure 20. Projected IDF Curves of NORTH BAY A at 50% percentile.

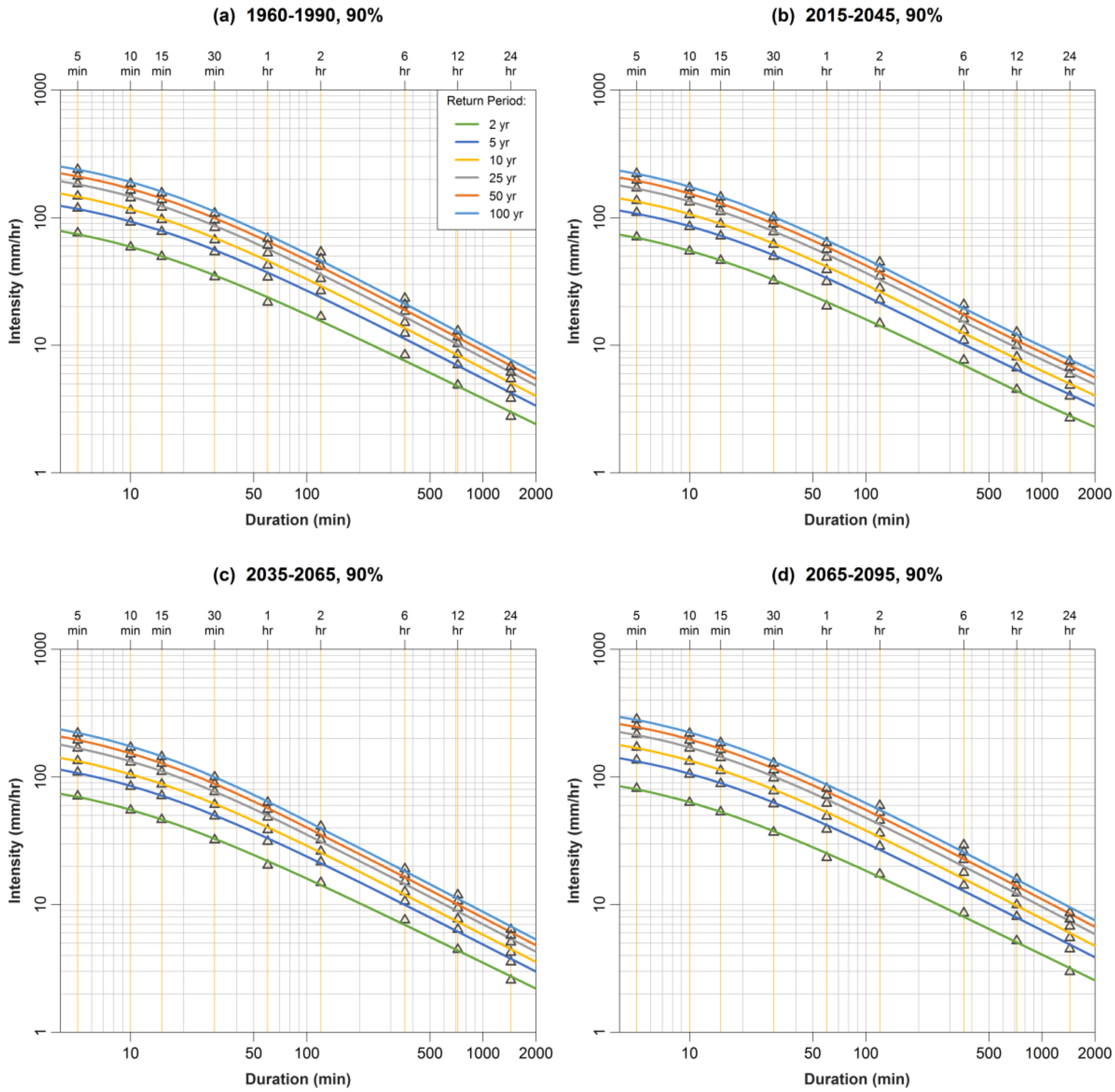

Figure 21. Projected IDF Curves of NORTH BAY A at 90% percentile.

Figure 22 to Figure 24 show the projected IDF curves at OTTAWA MACDONALD-CARTIER INT'L A station for 10%, 50%, and 90% percentiles respectively, each percentile covers four 31-yr periods: 1960-1990, 2015-2045, 2035-2065, and 2065-2095. There are apparent increases in the rainfall intensity for the three future periods at 10% percentile relative to the baseline period (i.e. 1960-1990). Similar patterns are reported by the IDF curves at both 50% and 90% percentiles.

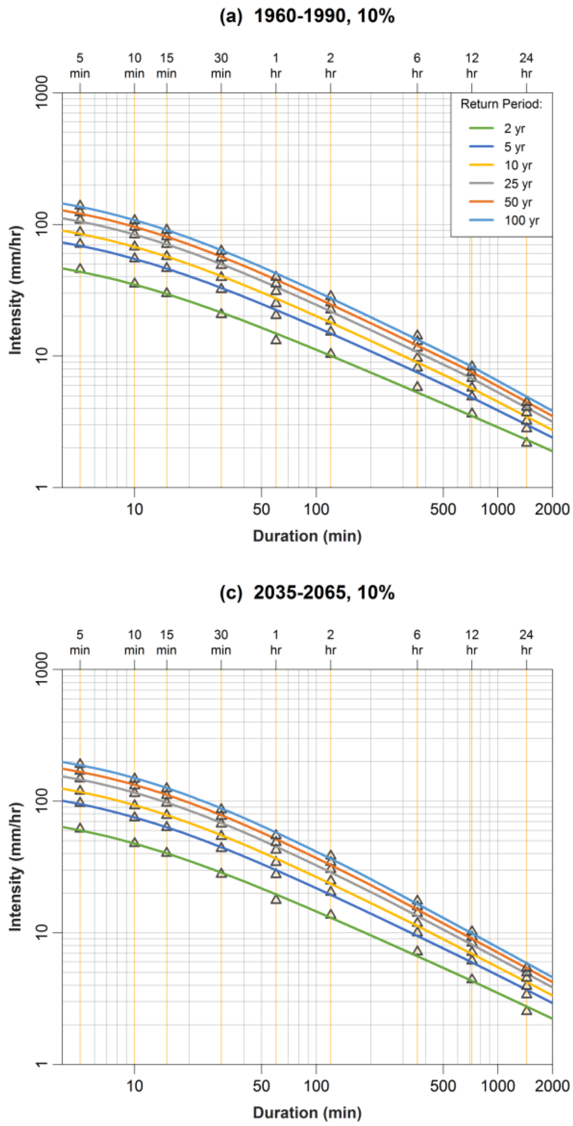

Figure 22. Projected IDF Curves of OTTAWA MACDONALD-CARTIER INT'L A at 10% percentile.

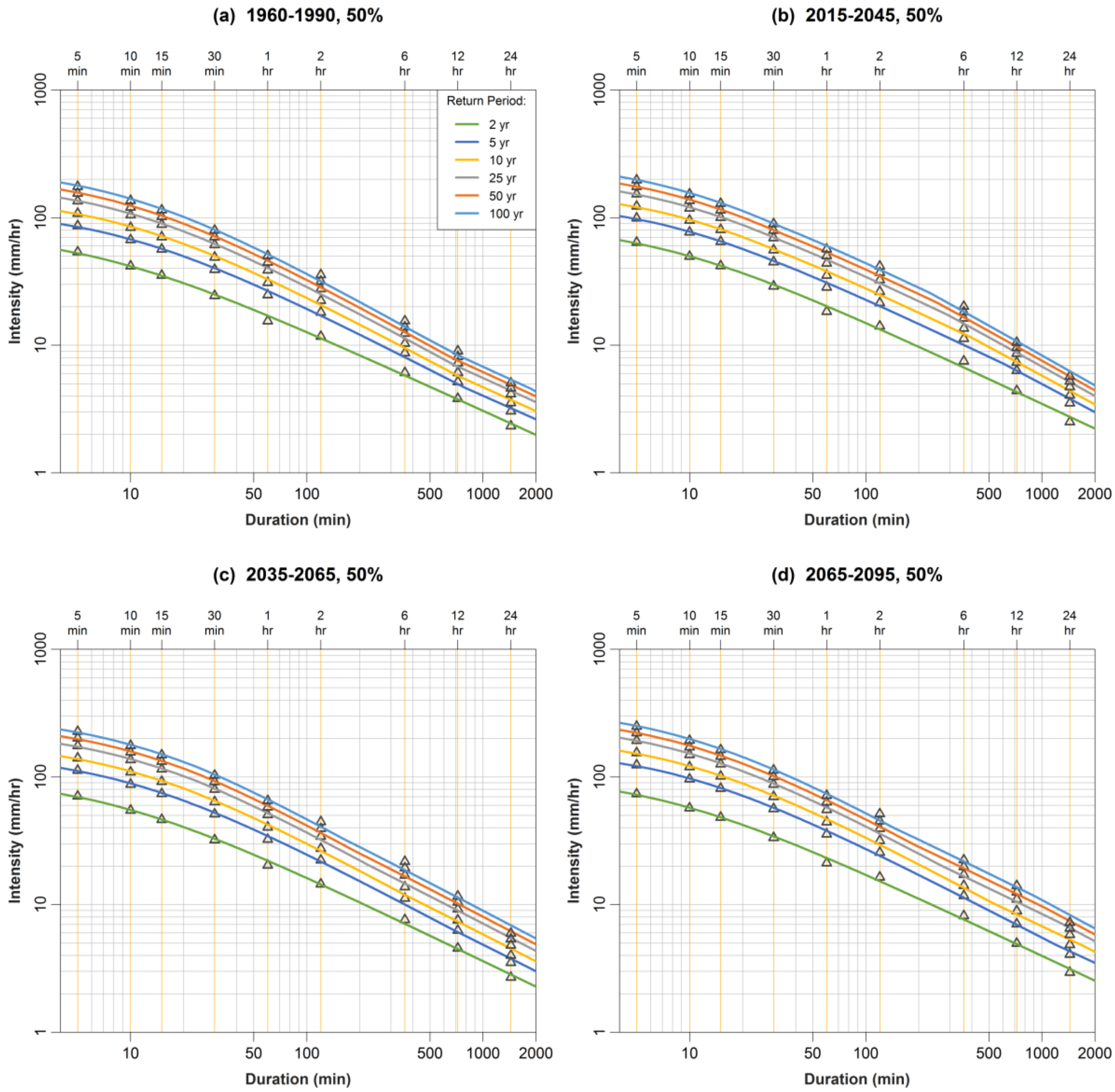

Figure 23. Projected IDF Curves of OTTAWA MACDONALD-CARTIER INT'L A at 50% percentile.

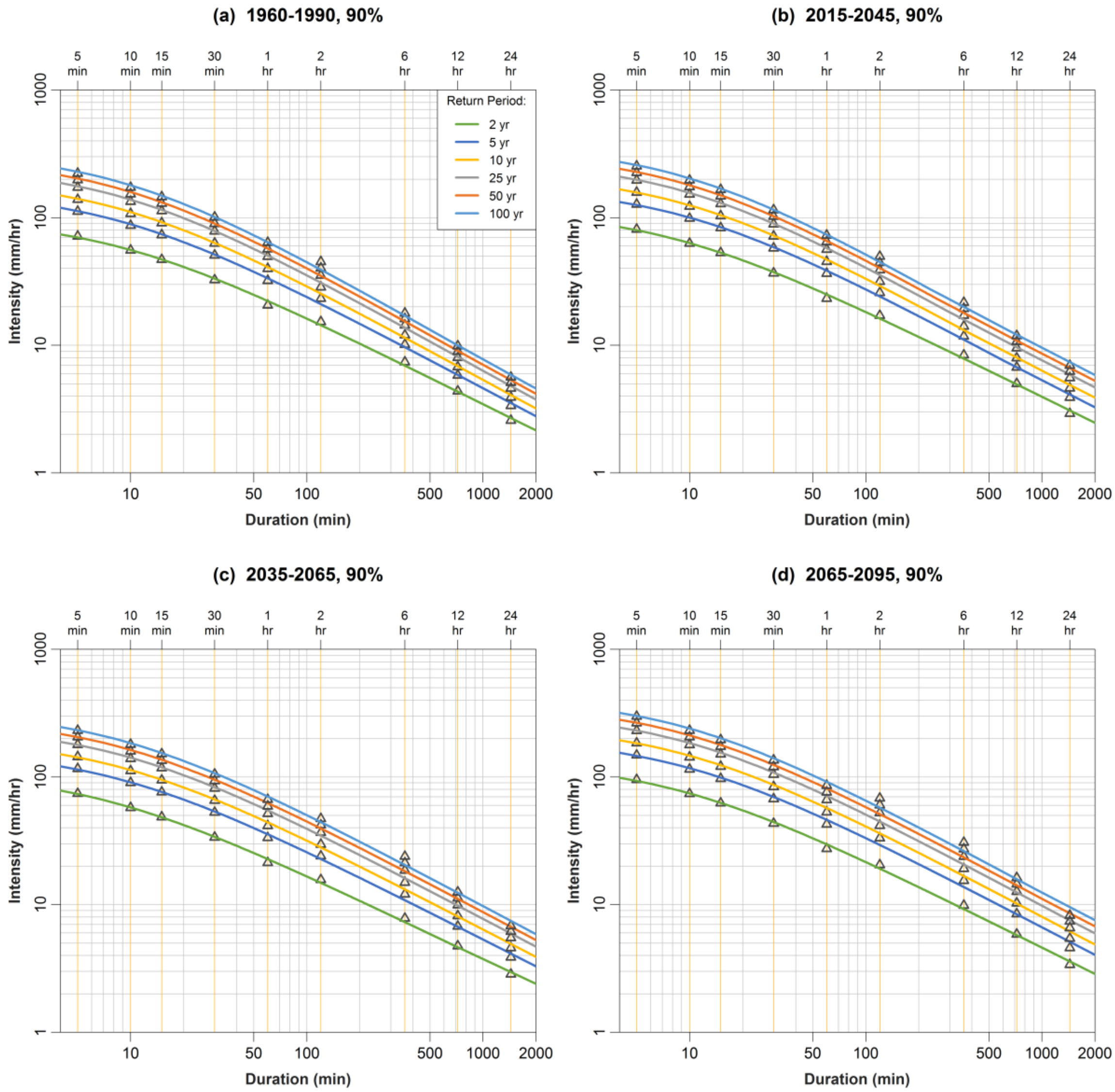

Figure 24. Projected IDF Curves of OTTAWA MACDONALD-CARTIER INT'L A at 90% percentile.

Figure 25 to Figure 27 show the projected IDF curves at SIOUX LOOKOUT A station for 10%, 50%, and 90% percentiles respectively, each percentile covers four 31-yr periods: 1960-1990, 2015-2045, 2035-2065, and 2065-2095. There are apparent increases in the rainfall intensity for the three future periods at 10% percentile relative to the baseline period (i.e. 1960-1990). Similar patterns but slight increases are reported by the IDF curves at both 50% and 90% percentiles.

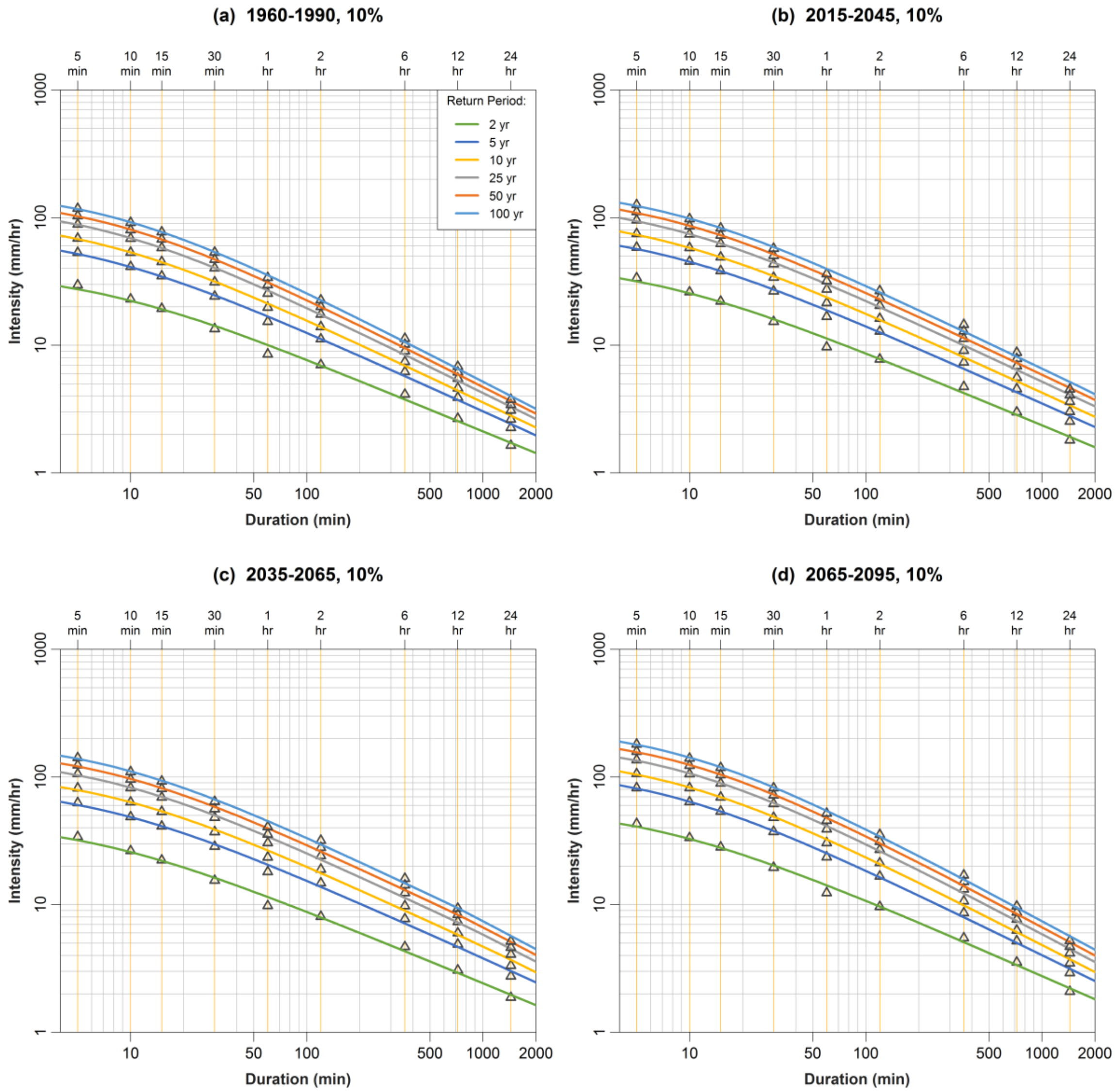

Figure 25. Projected IDF Curves of SIOUX LOOKOUT A at 10% percentile.

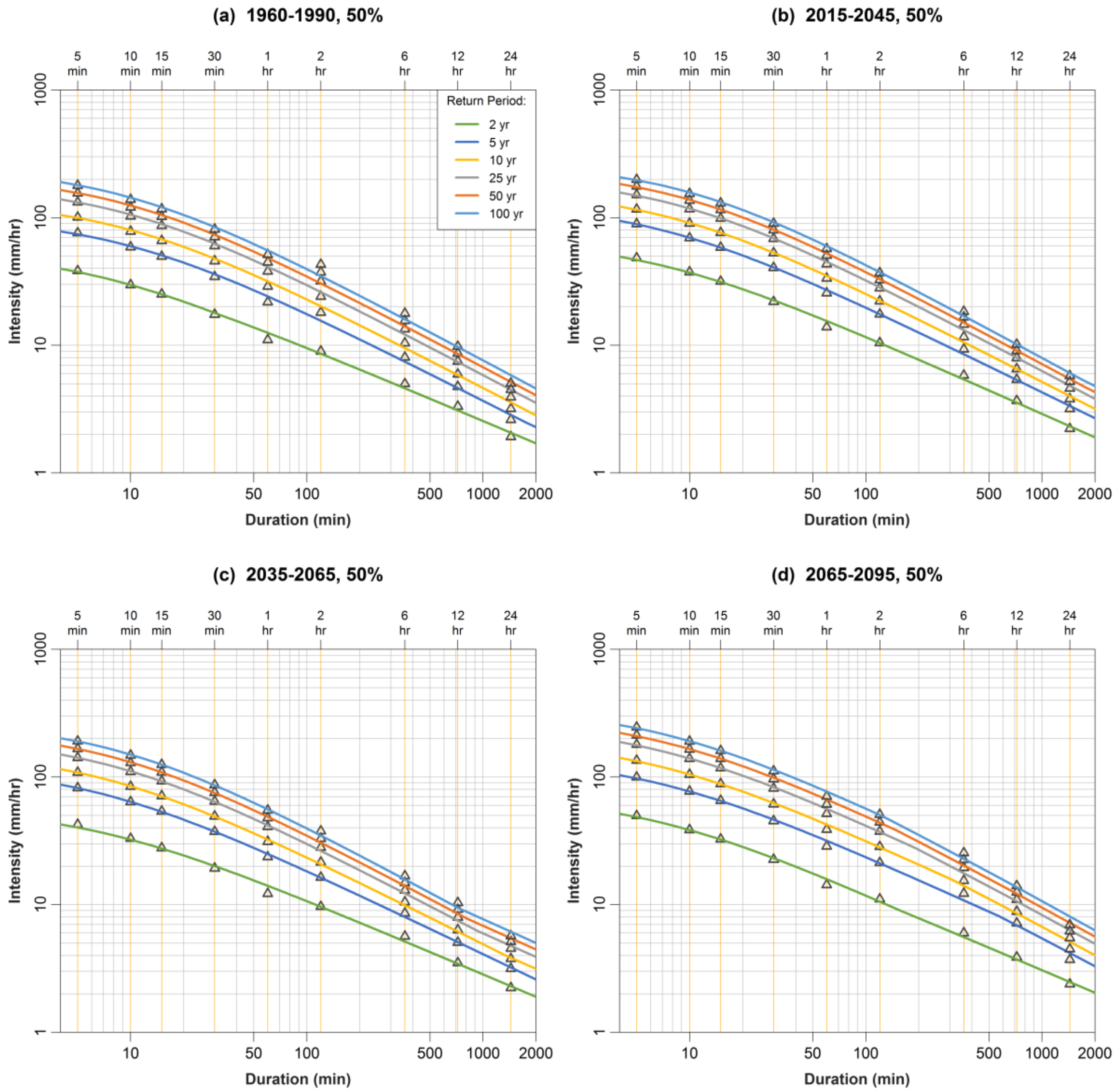

Figure 26. Projected IDF Curves of SIOUX LOOKOUT A at 50% percentile.

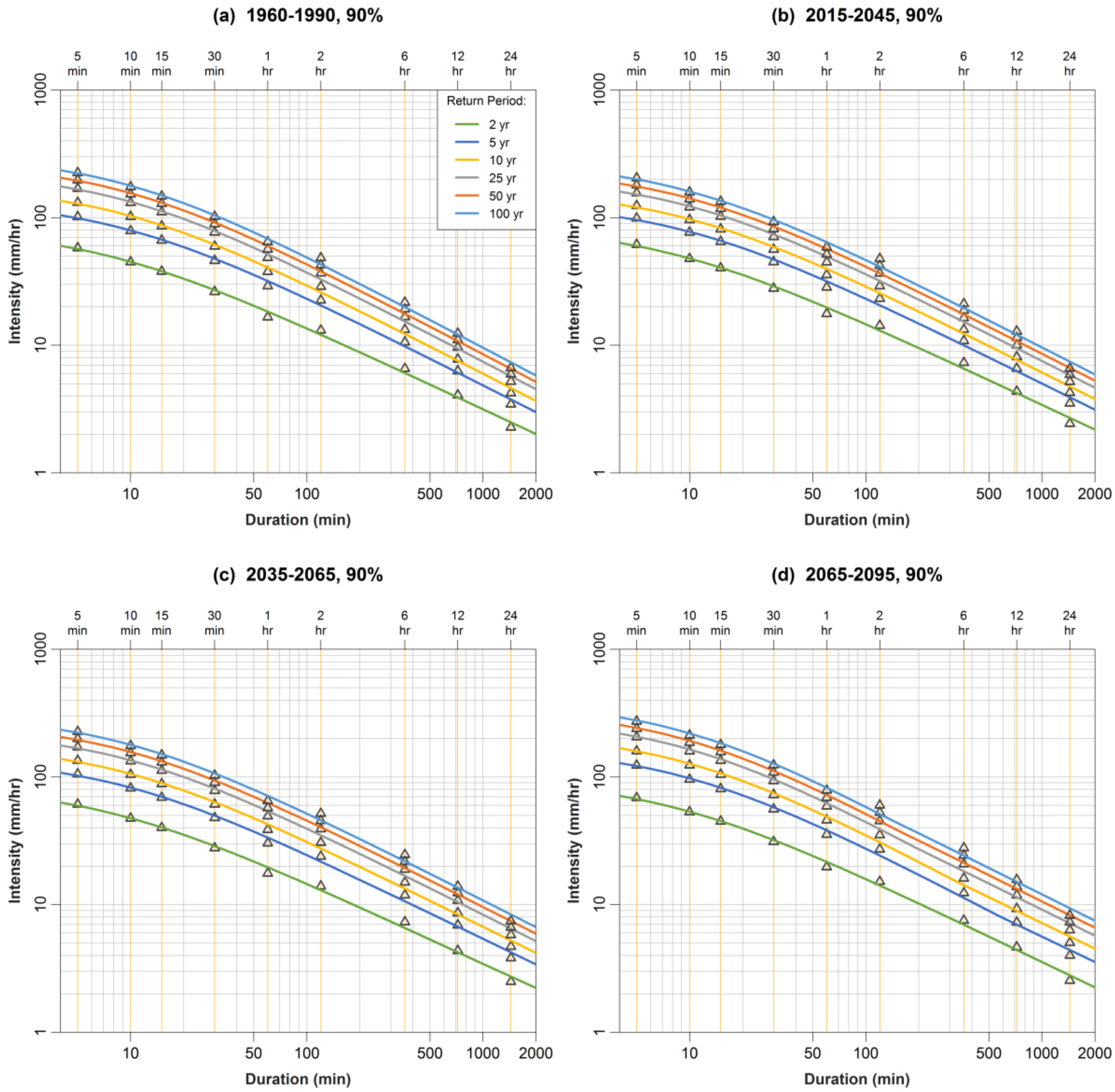

Figure 27. Projected IDF Curves of SIOUX LOOKOUT A at 90% percentile.

Figure 28 to Figure 30 show the projected IDF curves at TIMMINS VICTOR POWER A station for 10%, 50%, and 90% percentiles respectively, each percentile covers four 31-yr periods: 1960-1990, 2015-2045, 2035-2065, and 2065-2095. There are apparent increases in the rainfall intensity for the three future periods at 10% percentile relative to the baseline period (i.e. 1960-1990). Similar patterns but slight increases are reported by the IDF curves at both 50% and 90% percentiles.

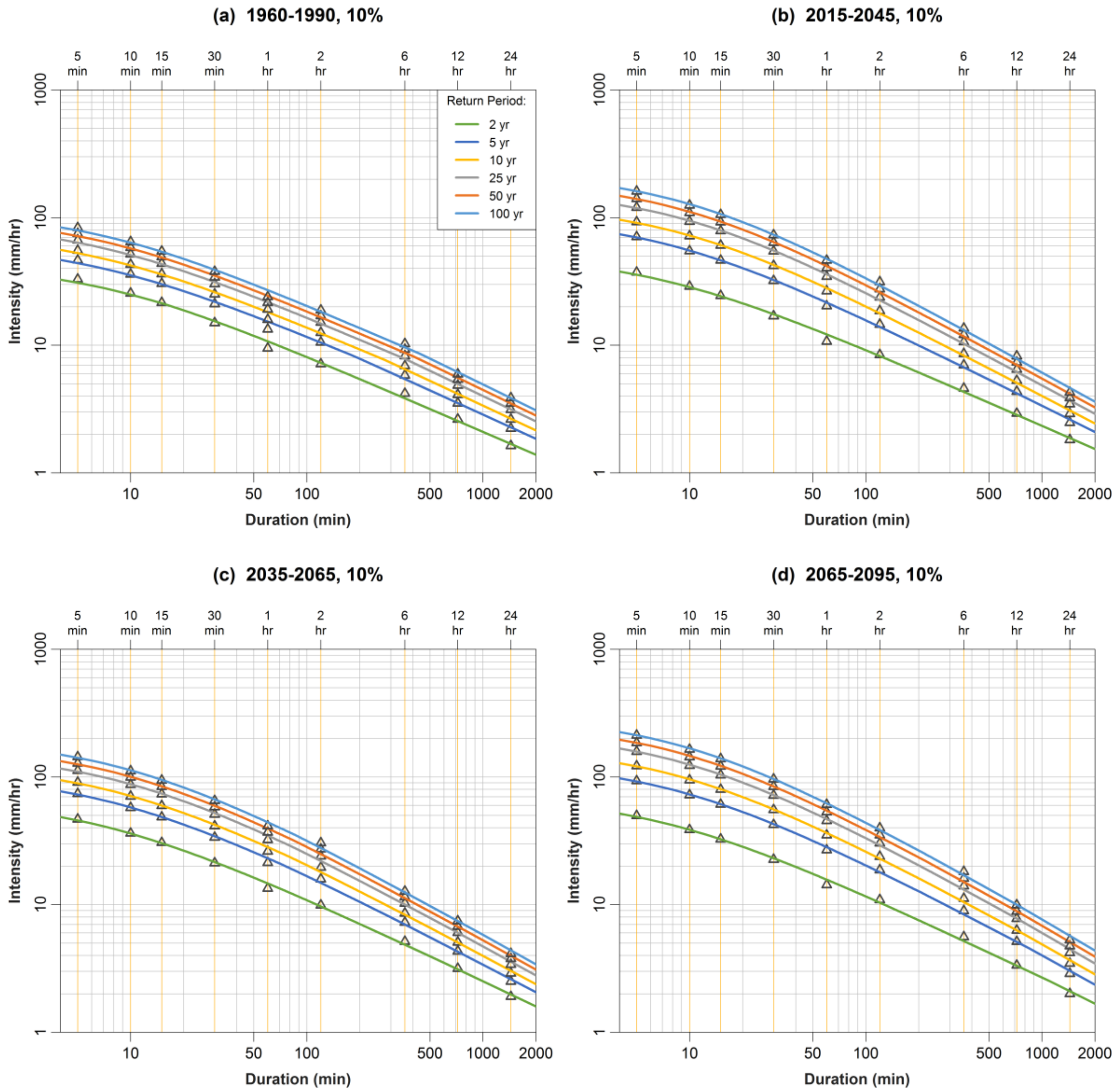

Figure 28. Projected IDF Curves of TIMMINS VICTOR POWER A at 10% percentile.

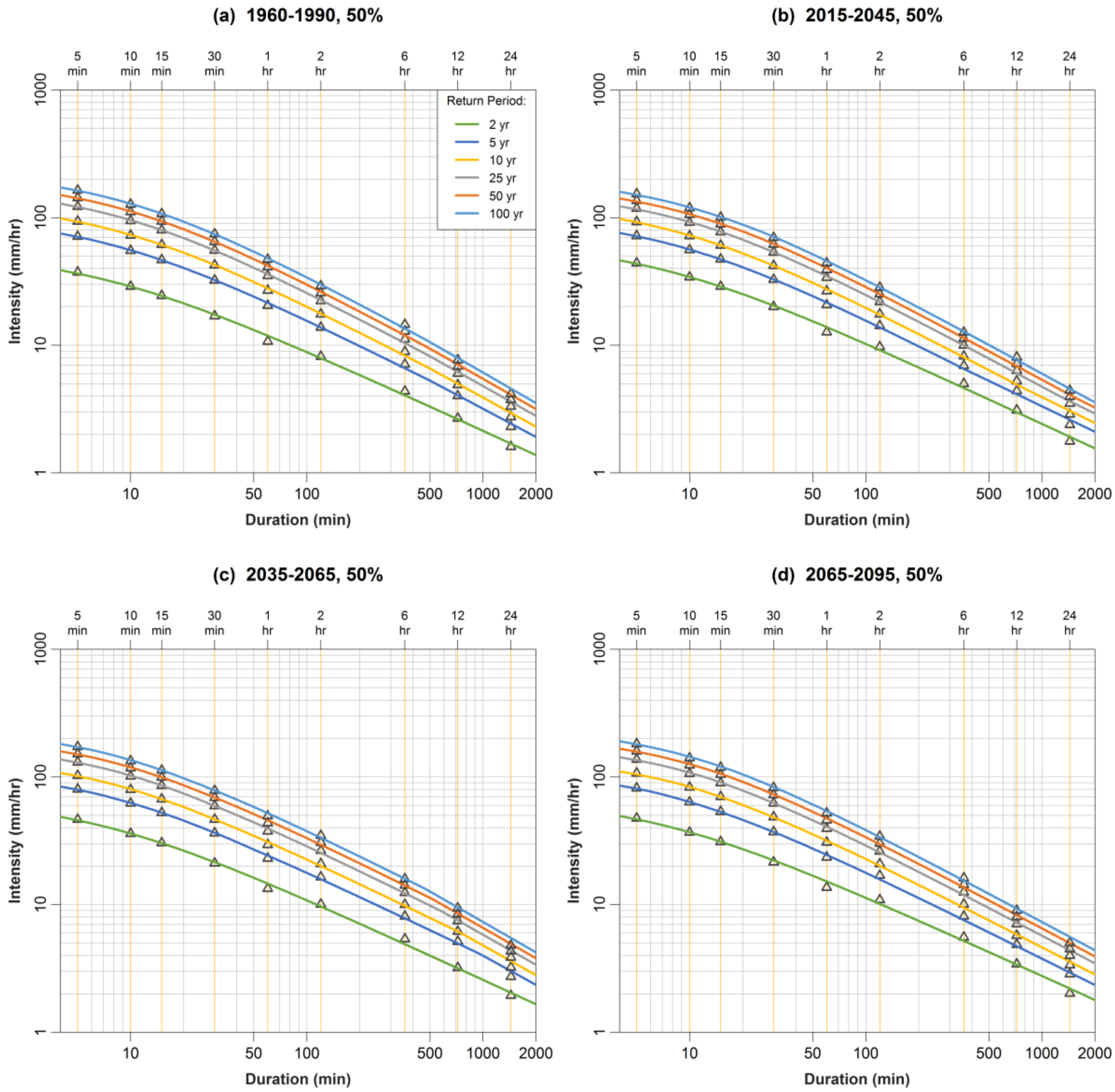

Figure 29. Projected IDF Curves of TIMMINS VICTOR POWER A at 50% percentile.

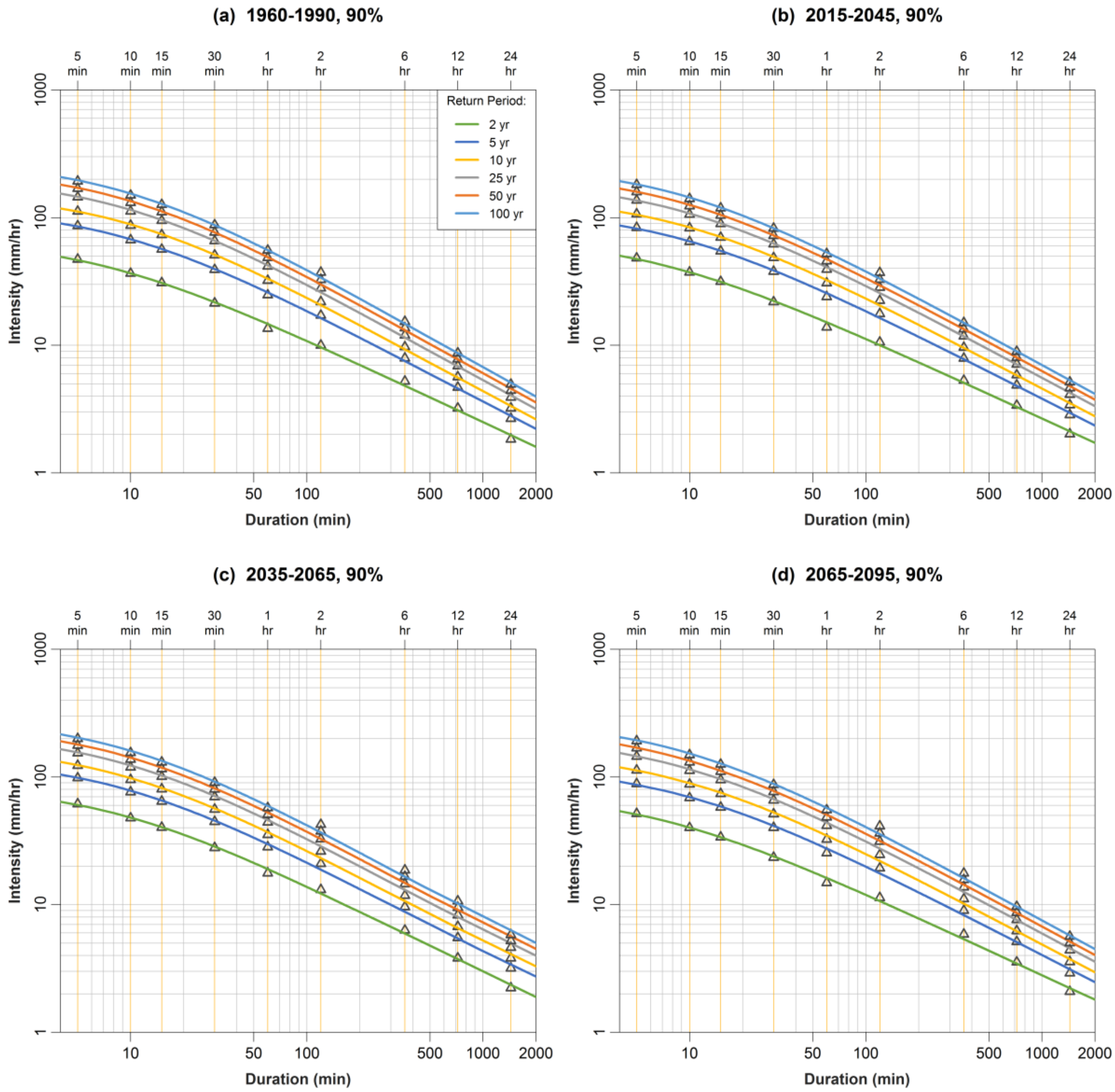

Figure 30. Projected IDF Curves of TIMMINS VICTOR POWER A at 90% percentile.

Figure 31 to Figure 33 show the projected IDF curves at MOOSONEE UA station for 10%, 50%, and 90% percentiles respectively, each percentile covers four 31-yr periods: 1960-1990, 2015-2045, 2035-2065, and 2065-2095. There are apparent increases in the rainfall intensity for the three future periods at 10% percentile relative to the baseline period (i.e. 1960-1990). Similar patterns but slight increases are reported by the IDF curves at both 50% and 90% percentiles.

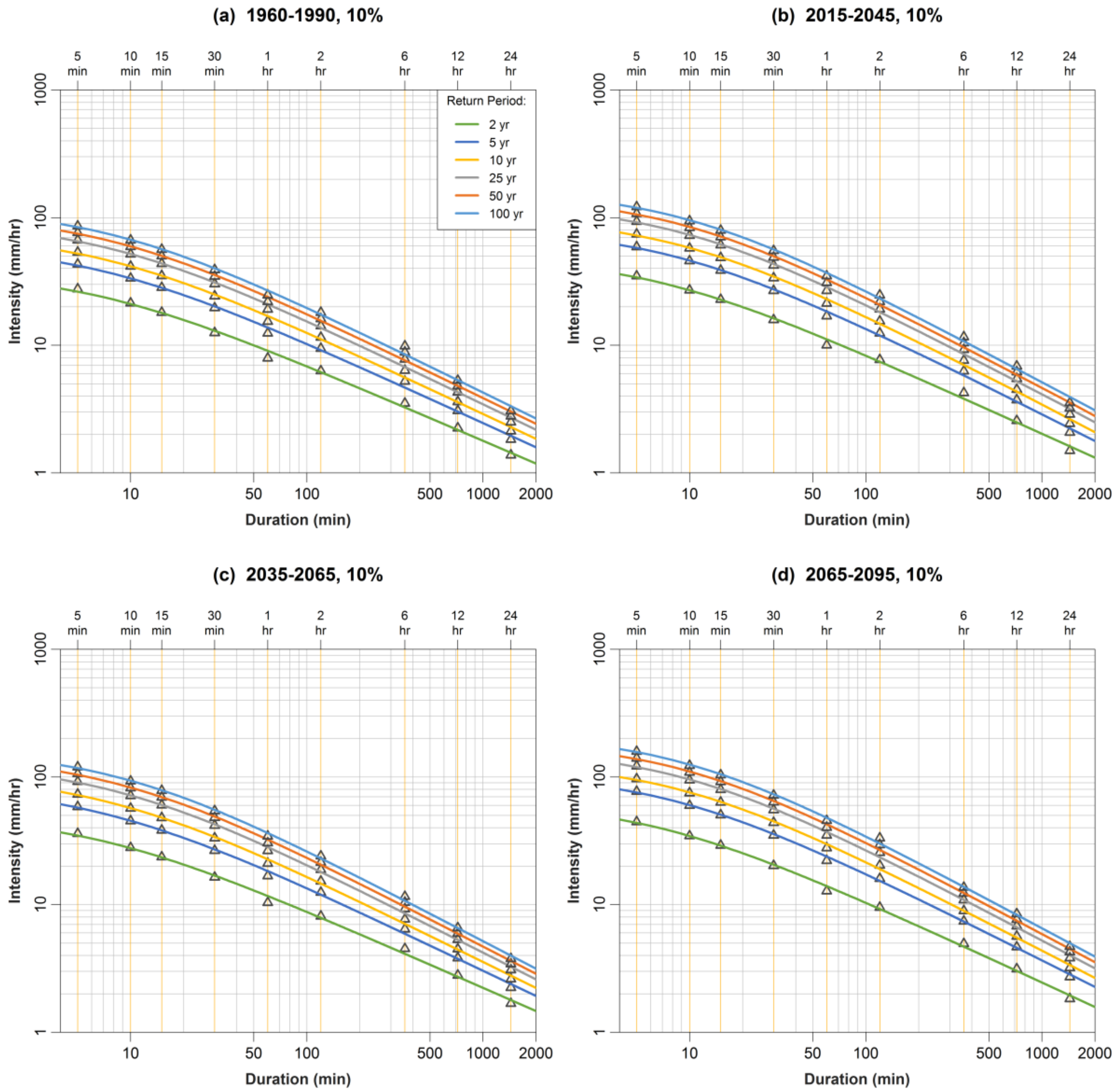

Figure 31. Projected IDF Curves of MOOSONEE UA at 10% percentile.

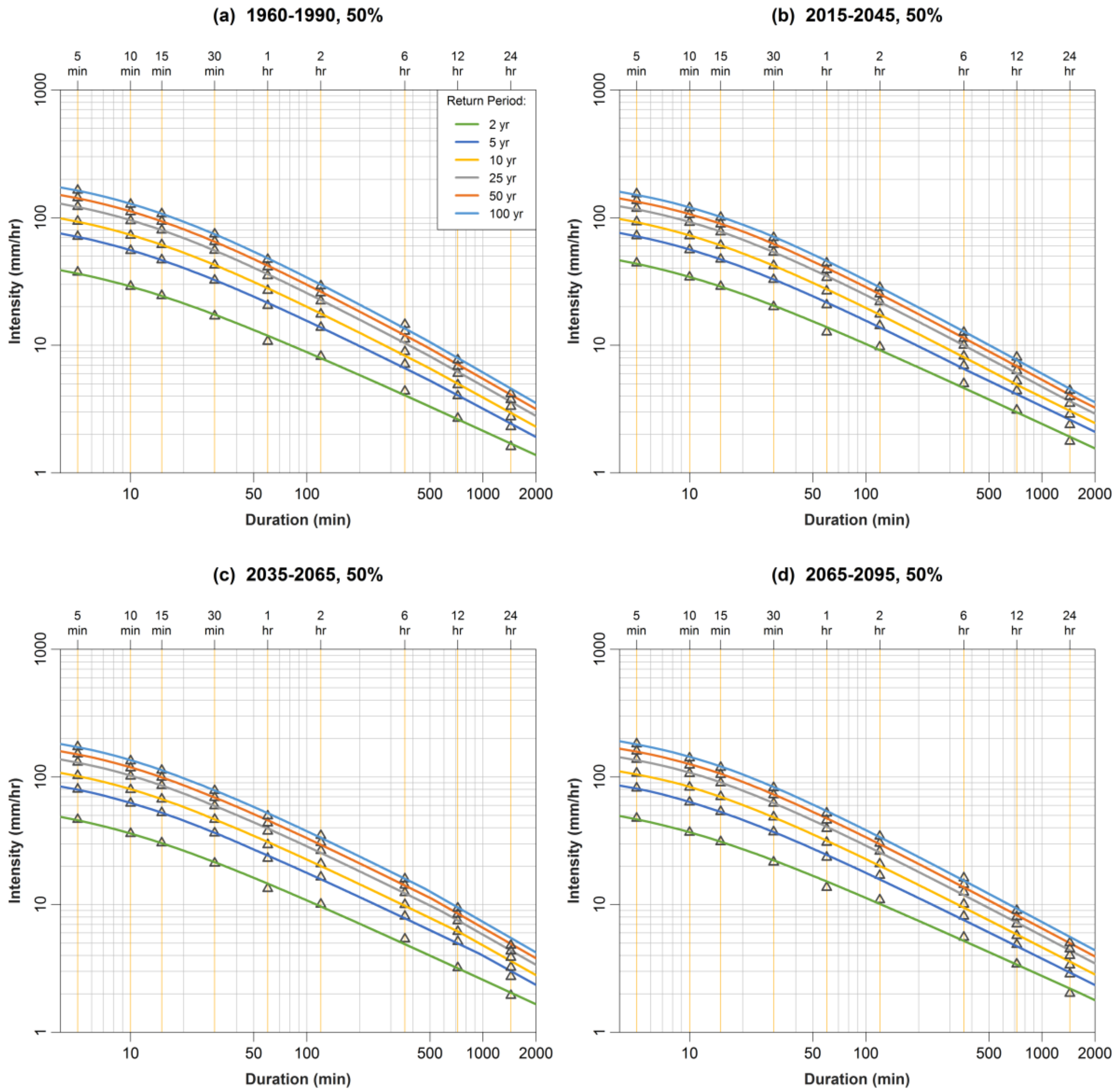

Figure 32. Projected IDF Curves of MOOSONEE UA at 50% percentile.

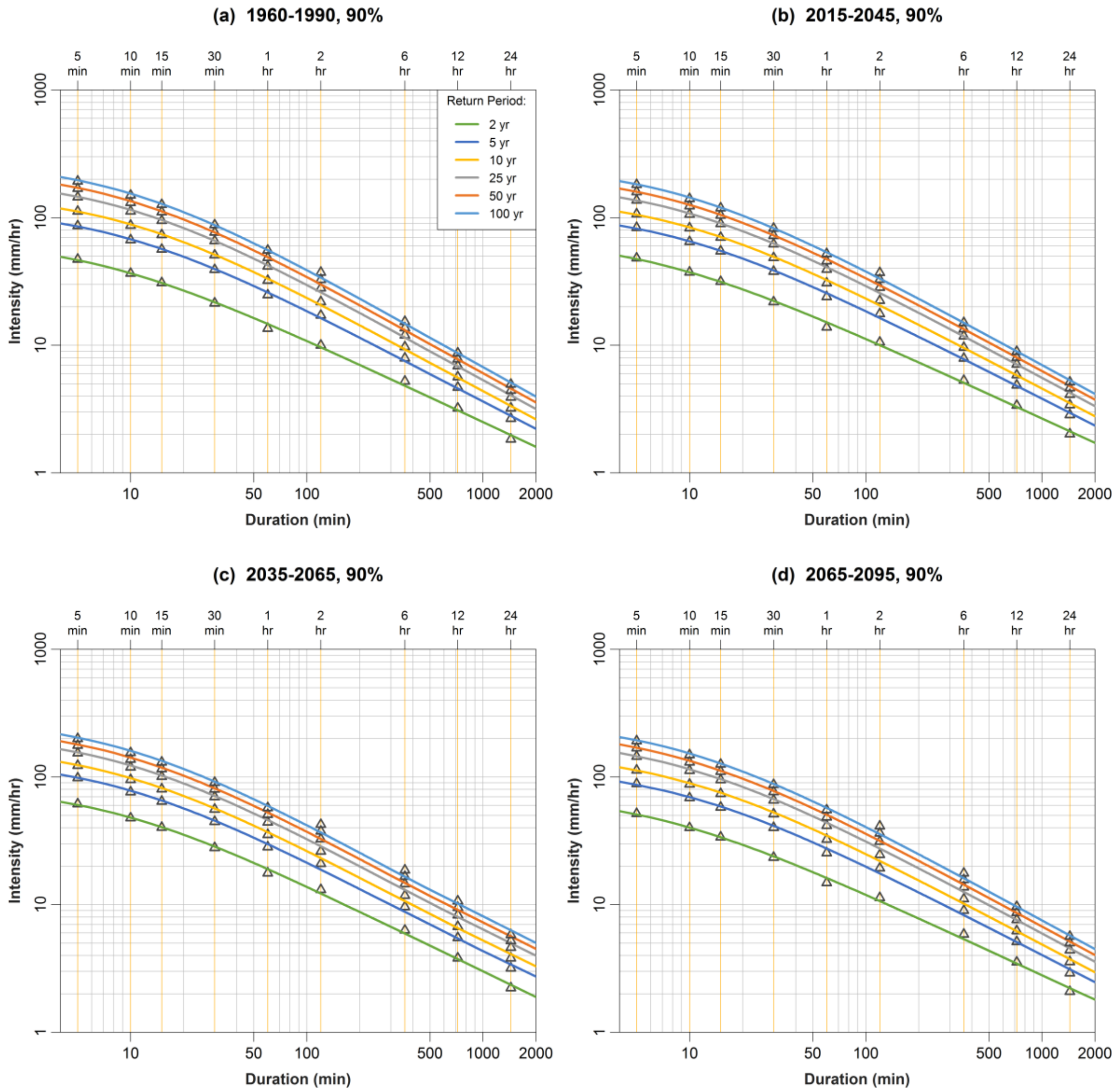

Figure 33. Projected IDF Curves of MOOSONEE UA at 90% percentile.

Figure 34 to Figure 36 show the projected IDF curves at BIG TROUT LAKE station for 10%, 50%, and 90% percentiles respectively, each percentile covers four 31-yr periods: 1960-1990, 2015-2045, 2035-2065, and 2065-2095. There are apparent increases in the rainfall intensity for the three future periods at 10% percentile relative to the baseline period (i.e. 1960-1990). Similar patterns but slight increases are reported by the IDF curves at both 50% percentile while no apparent changes are reported by the ones at 90% percentile.

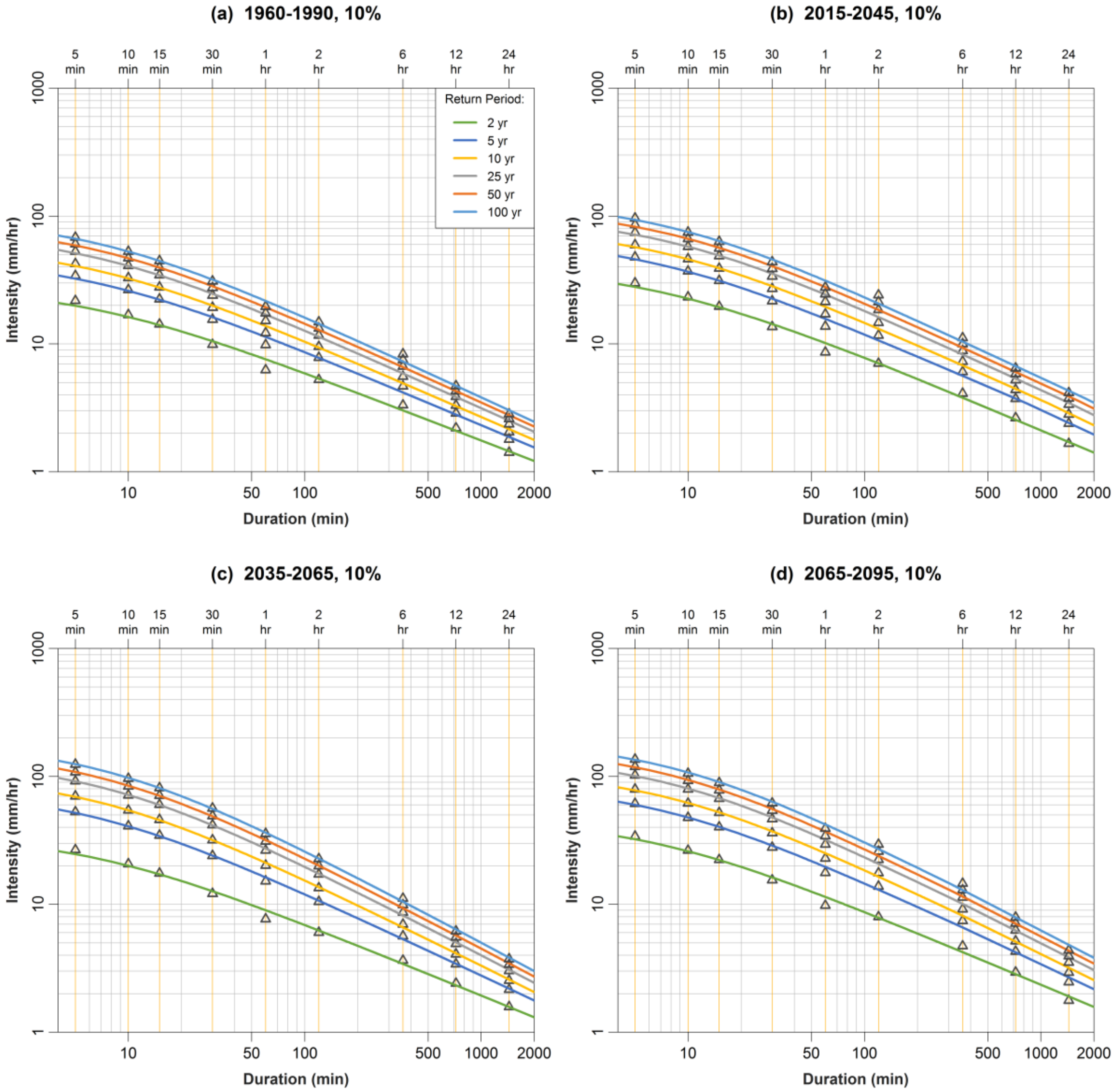

Figure 34. Projected IDF Curves of BIG TROUT LAKE at 10% percentile.

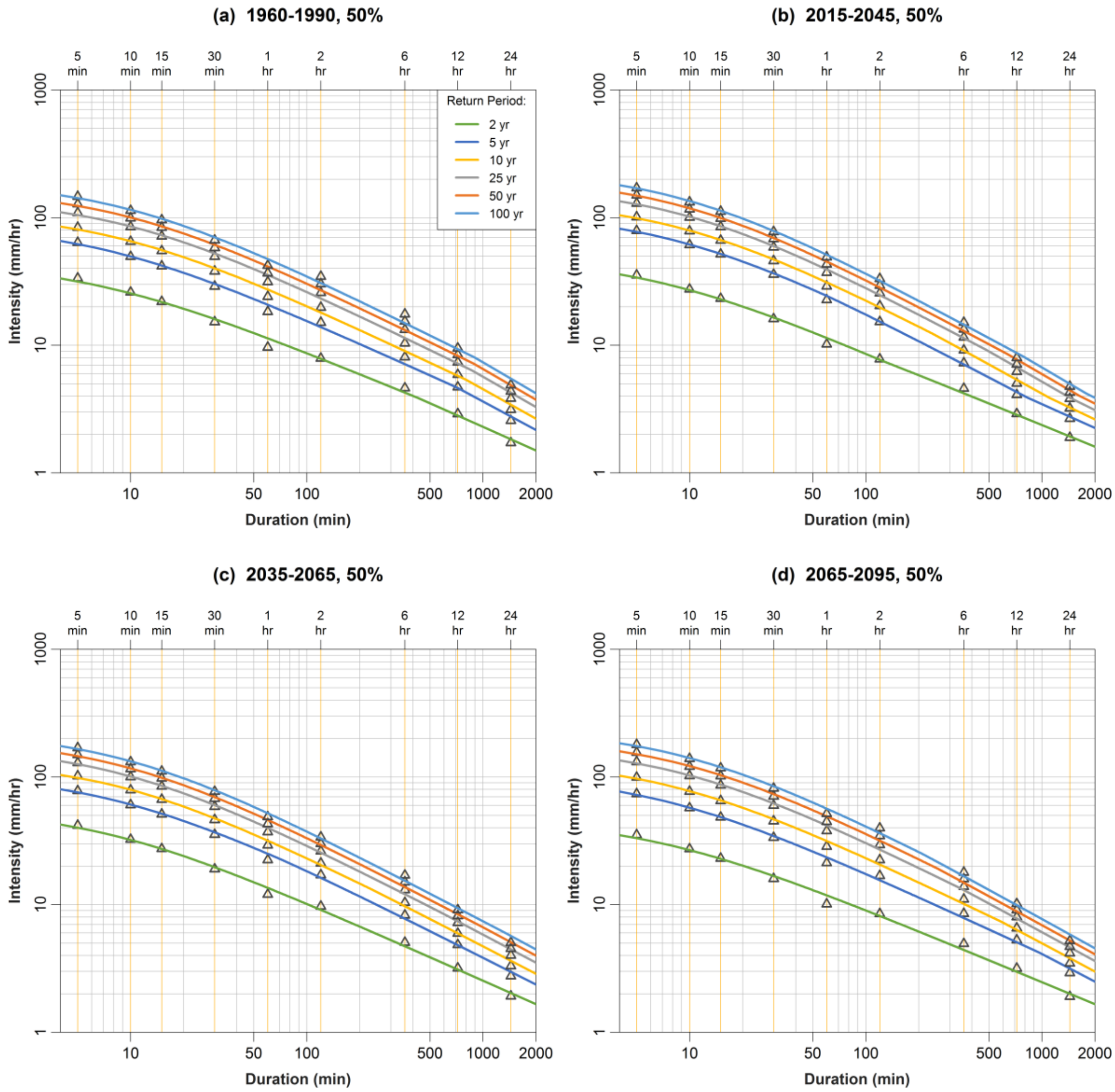

Figure 35. Projected IDF Curves of BIG TROUT LAKE at 50% percentile.

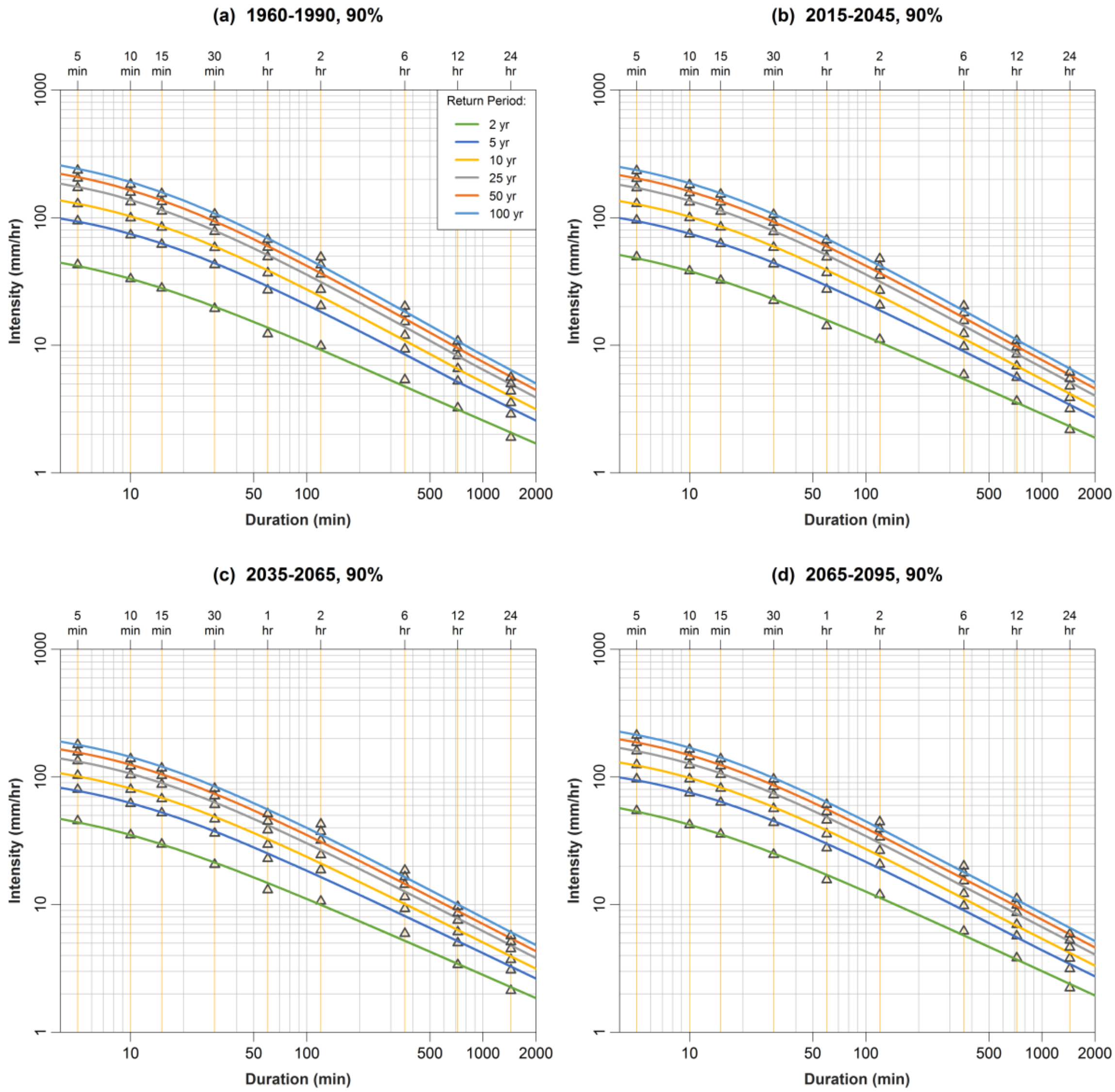

Figure 36. Projected IDF Curves of BIG TROUT LAKE at 90% percentile.

In summary, there would likely be significant changes in the future projected IDF curves at the above selected twelve weather stations relative to the baseline period. All IDF curves presented in this report and posted on the data portal are calculated from the original model outputs of hourly precipitation following the most up-to-date common methodologies. To address uncertainties in projected precipitation and IDF curves, probabilistic projections were developed in this study. Further considerations in future projects include applying bias corrections to precipitation before IDF calculation, advancement in model physics to improve precipitation projections, and calibration in the projected IDF curves.

3. Development of Ontario CCDP

This chapter details the framework of Ontario CCDP and main functionalities such as user access, map overview, IDF curves, and time series downloading, etc, to provide potential users with helpful documentation and guidance regarding the usage of Ontario CCDP.

3.1 Framework of Ontario CCDP

As outlined in Figure 37, Ontario CCDP mainly consists of five modules: user access, map overview, IDF curves, time series downloading, and help center. User access module is designed to facilitate the quick and easy access to the maps of data sets of Ontario CCDP, meanwhile to help us understand who are the major users and what kind of data sets are of most interest through some simple statistics on user access records. The access to Ontario CCDP is free of charge but the user is required to register an account through user registration before downloading data. Map overview is implemented by combining map selector, map layer controller, and panel controller which are developed using web-based technologies and online map visualization tools. It allows user to view projected maps of temperature and precipitation for different periods, averaging options, and percentiles quickly and easily while only is an Internet browser required. Access to IDF curves is also integrated into Ontario CCDP by combining IDF curves selector and viewer, which allows user to preview IDF curves for each grid point at different periods and percentiles and to download the corresponding data file for further analysis. Time series downloading module is the most challenging but meanwhile the most interesting functionality of Ontario CCDP, with daily and hourly time series spanning from 1960 to 2095 for up to seven climate variables. This module is supported by huge data volume in the order of 5 TB. By integrating variable selector and grid data downloader, it allows user to easily locate and download the time series at specific points of interest. The time series data file can be used directly for driving impact models (e.g. hydrological model, crop model) to facilitate assess the impacts of changing climate at regional or local scales. Ontario CCDP also includes a useful tool – help center, which consist of about us, FAQs, and contact us, to provide necessary documentation and guidance regarding the usage of the data portal.

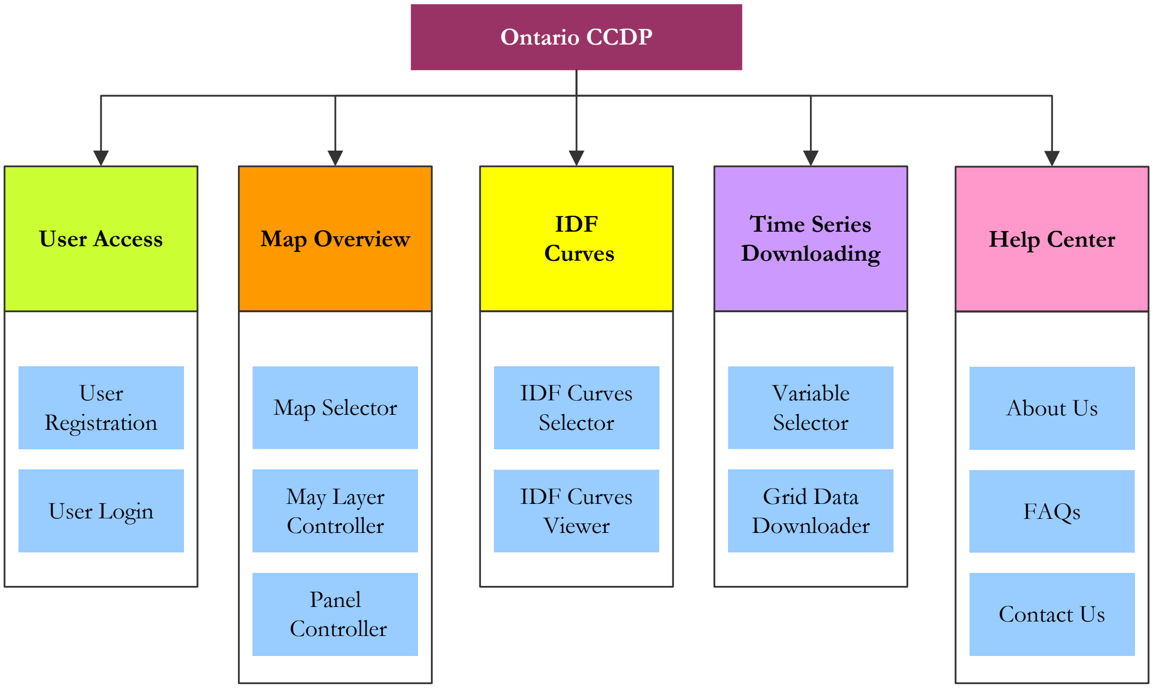

Figure 37. Framework of Ontario CCDP.

The official website of Ontario CCDP is hosted by the IEESC at the University of Regina, and can be accessed through Internet at: http://ontarioccdp.ca. Figure 38 shows the homepage of Ontario CCDP.

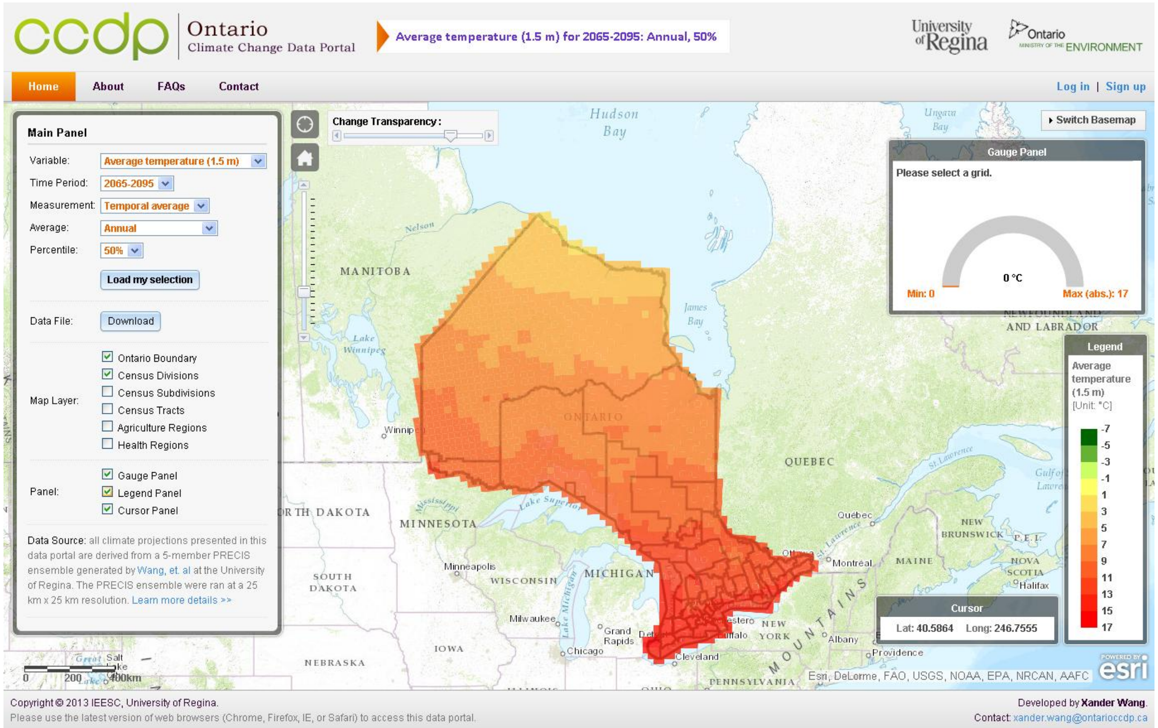

Figure 38. Homepage of Ontario CCDP.

3.2 Functionalities of Ontario CCDP

Overview of Ontario CCDP

As shown in Figure 39, the homepage of Ontario CCDP is designed with neat and friendly layout so that users can easily find what they are looking for. In detail, it consists of: main menu, user links, current selection, main panel, projected map, map viewer controller, basemap switcher, gauge panel, legend panel, cursor panel, info panel, and map scale. The usage of each component in the homepage will be introduced in the following content.

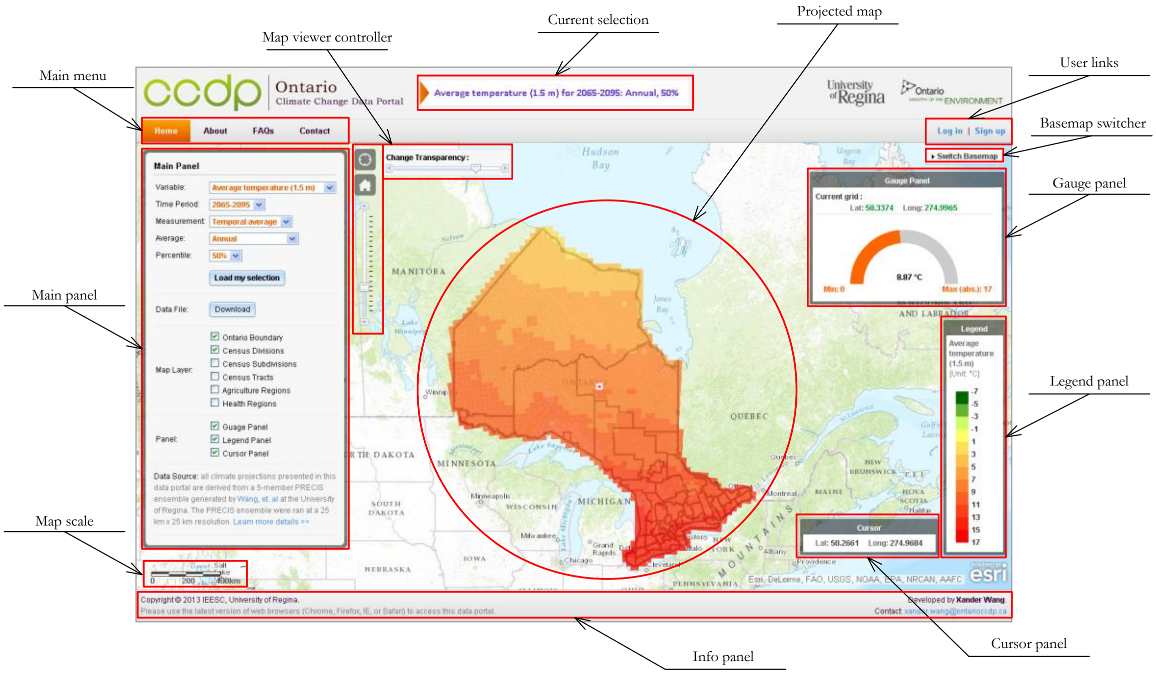

Figure 39. Overview of Ontario CCDP.

User Registration

It is free to view the projected maps and IDF curves and download the corresponding data files and time series. However, users are required to create an account through user registration before downloading any data from Ontario CCDP. Users' information required for registration (as shown in Figure 40) are collected purely for usage statistics for future improvement of this data portal to better meet users' needs, the IEESC will keep these information confidential and will not share them with any other third parties.

User Login

After registration, users can log into the Ontario CCDP using the registered email address and password. Users can also request sending the login password to the email address used for their registration in case of forgetting it, as shown in Figure 41.

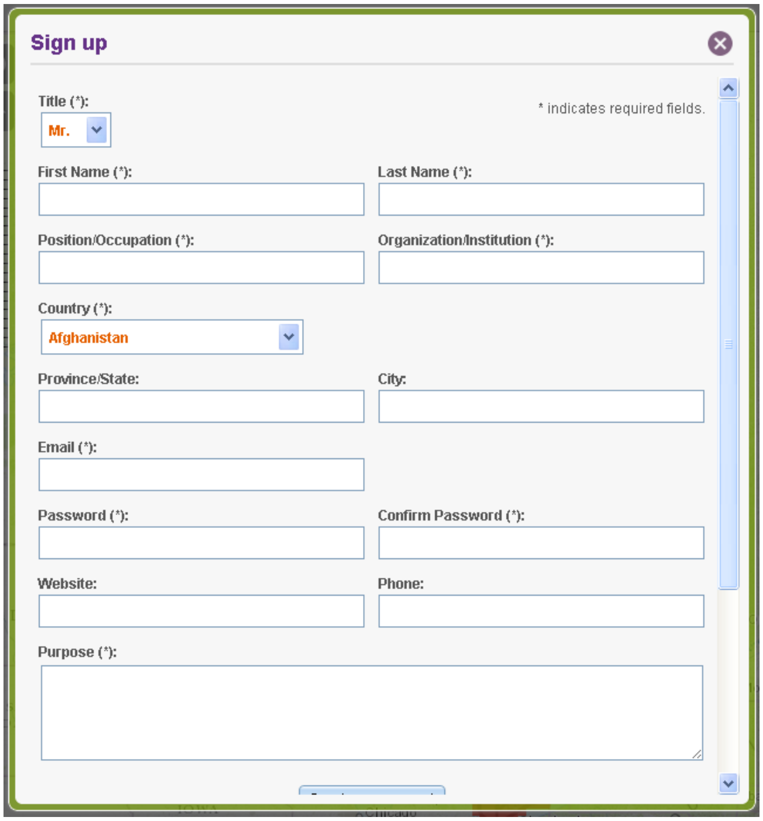

Figure 40. User registration.

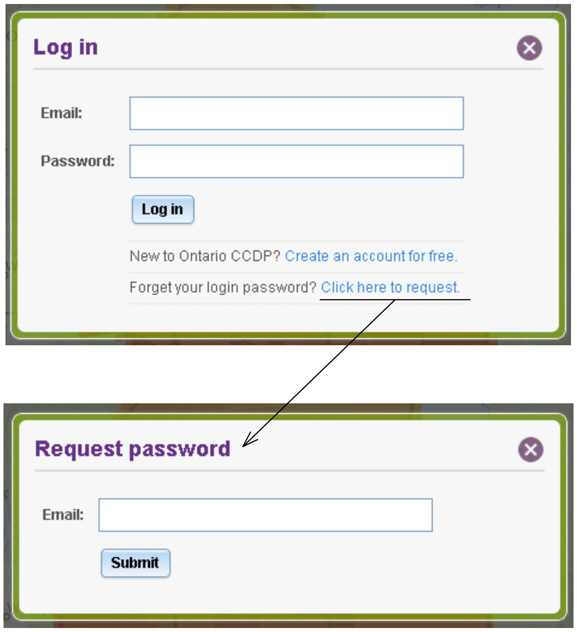

Figure 41. User login.

Main Panel

The main panel of Ontario CCDP serves as a main controller which allows users to select variable, time period, measurement, averaging options, and percentile (as shown in Figure 42). Users can also switch on map layers, including Ontario boundary, census divisions, census subdivisions, census tracts, agriculture regions, and health regions, and other info panels such as gauge panel, legend panel, and cursor panel. The download button will be available only when the measurement is set as temporal average, and users can click on this button to download the corresponding data file.

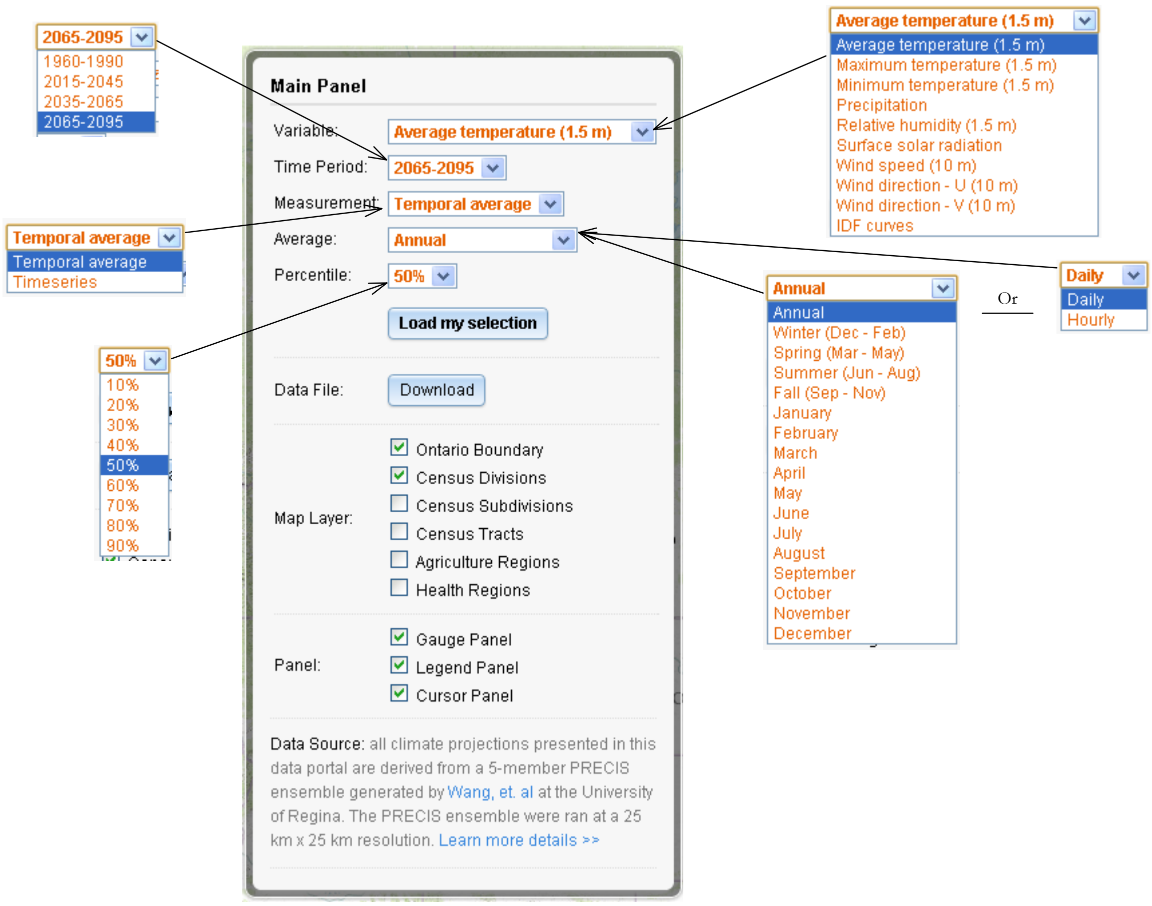

Figure 42. Main panel of Ontario CCDP.

Gauge Panel

The gauge panel is available only for temporal averaging variables. It can help measure how the quantity of the selected variable, in the form of absolute value, on a given grid is distributed in the interval bounded by zero and the maximum of all grids (as shown in Figure 43).

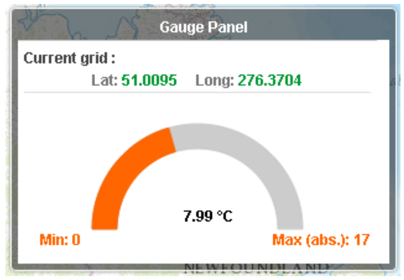

Figure 43. Gauge panel.

Legend Panel

The legend panel is available only for temporal averaging variables. It is to help understand the patterns of projected maps with different colors (as shown in Figure 44).

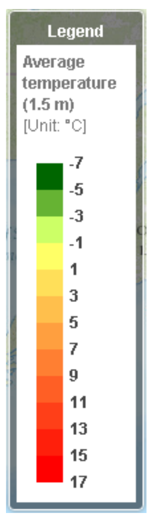

Figure 44. Legend panel.

Cursor Panel

The cursor panel is to display the current position of your cursor on the map, in the form of latitude and longitude, as shown in Figure 45.

Figure 45. Cursor panel.

Basemap Switcher

The basemap switcher allows users to choose different base map for various analyzing purposes, which is shown in Figure 46.

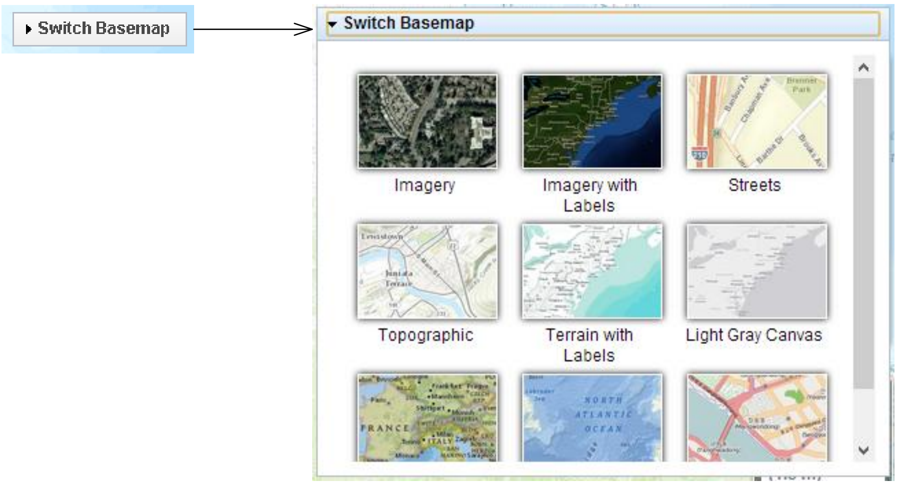

Figure 46. Basemap switcher.

Map Viewer Controller

As shown in Figure 47, the map viewer controller allows users to change transparency of projected maps, find users' current location, reset the map to default extent, and zoom in/out the map.

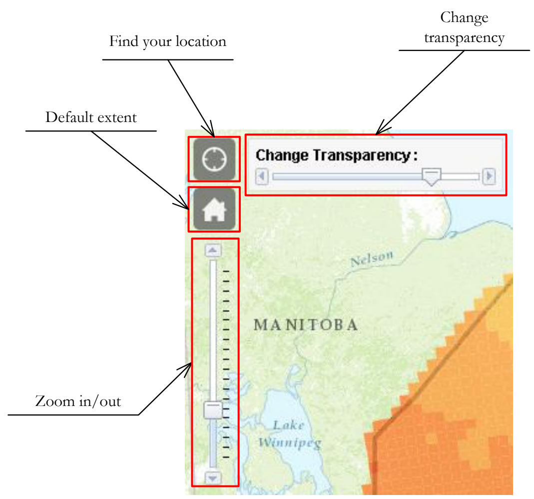

Figure 47. Map viewer controller.

Projected Map

As shown in Figure 48, the projected map is to display the current map selected by users. This is a gridded map with the spatial resolution of 25 km x 25 km. A pop-up window, including the latitude and longitude of current grid as well as the corresponding data value for the selected variable, will be displayed when clicking on each grid cell.

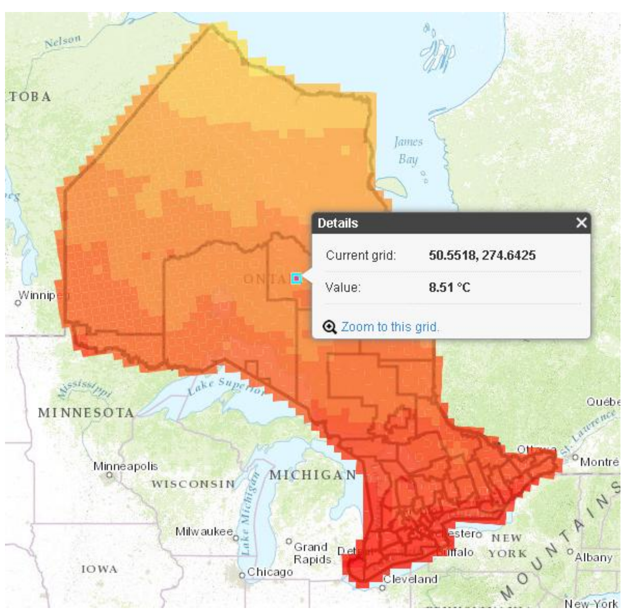

Figure 48. Projected map.

IDF Curves

To access IDF curves, users need to set the variable as IDF curves and choose the correct time period (say 2965-2095) and percentile (say 50%) in the main panel, then click on 'Load my selection' (as shown in Figure 49). After the loading is ready, the current selection will be updated to IDF curves for 2065-2095: 50% in this example, and the projected map will be changed into a gridded map in green color. By clicking on a given grid point, a pop-up window will be displayed including the central position of current grid, IDF curves, as well as a downloading link to its data file. Users can view the full-size IDF curves by clicking on the graph and download the data file corresponding to this graph by clicking on the downloading link.

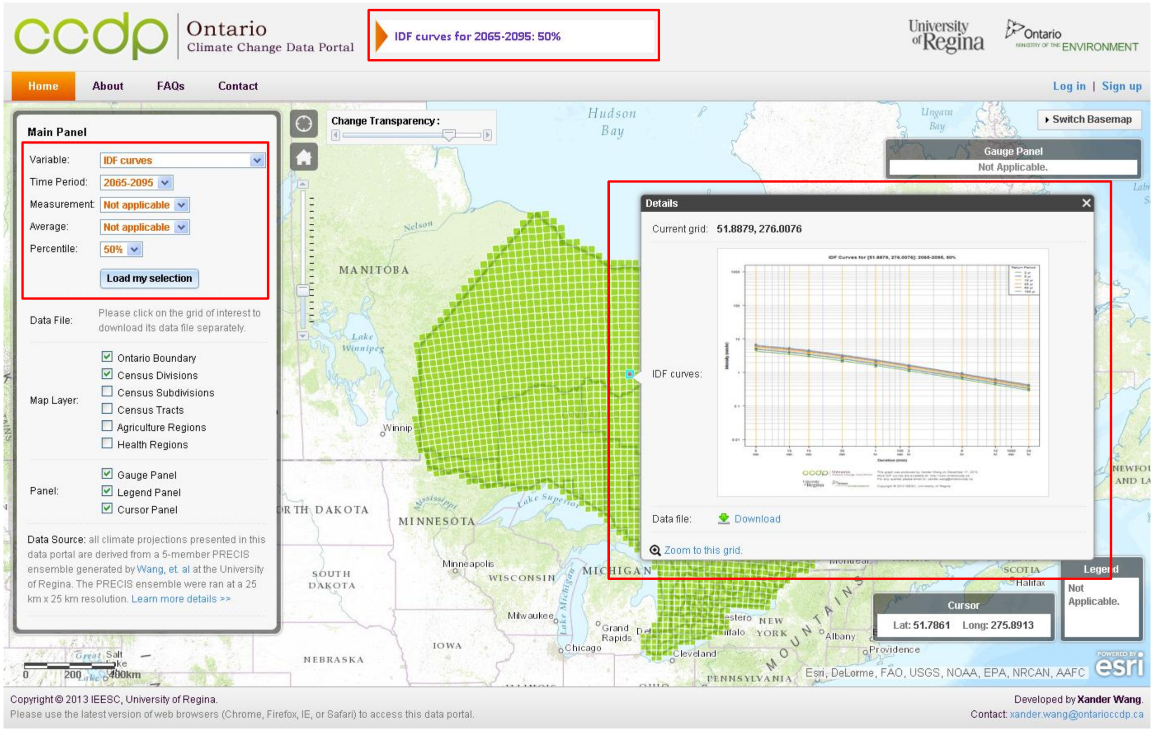

Figure 49. IDF curves.

Time Series Downloading

The process of downloading time series from Ontario CCDP is illustrated in Figure 50. First, users select the variable of interest in the main panel and click 'Load my selection' to update your selection. Once this is ready, users can click on a specific grid point and a pop-up window, including the latitude and longitude of current grid as well as a downloading link to its time series data file. By clicking on the downloading link, a save as window will be displayed to ask users to specify the location to store a zipped file which contains the corresponding time series.

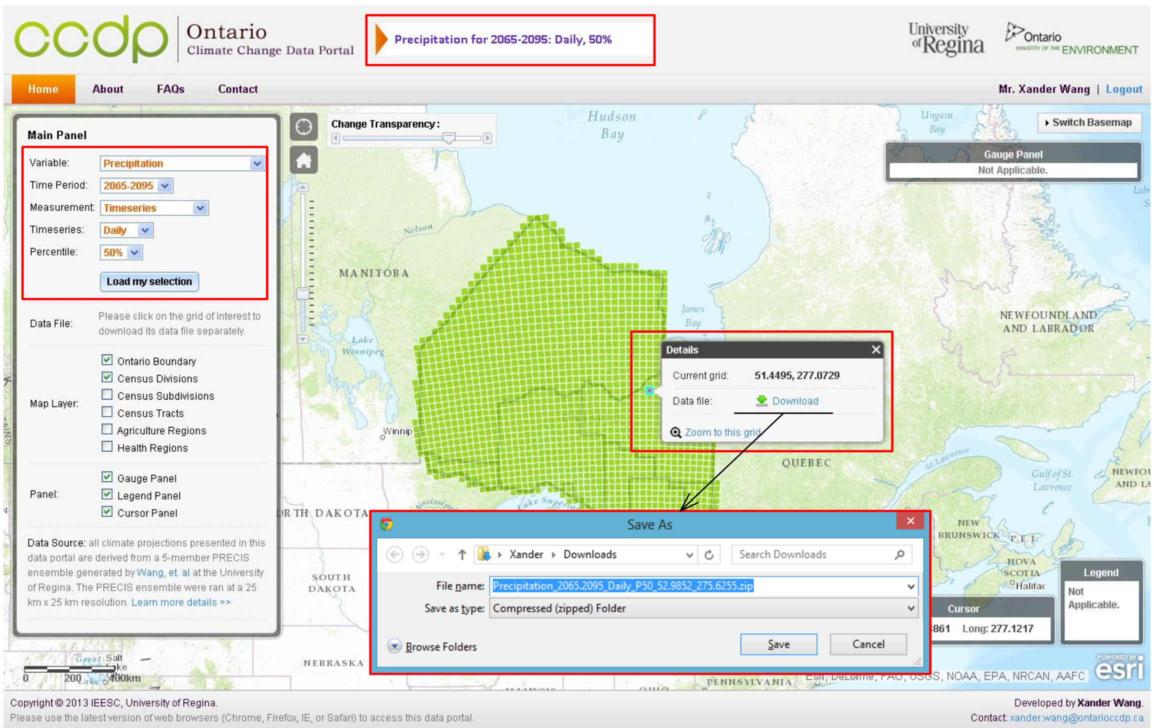

Figure 50. Time series downloading.

About Panel

As shown in Figure 51, the about panel includes a brief introduction about Ontario CCDP. Users are suggested to read this carefully before using Ontario CCDP.

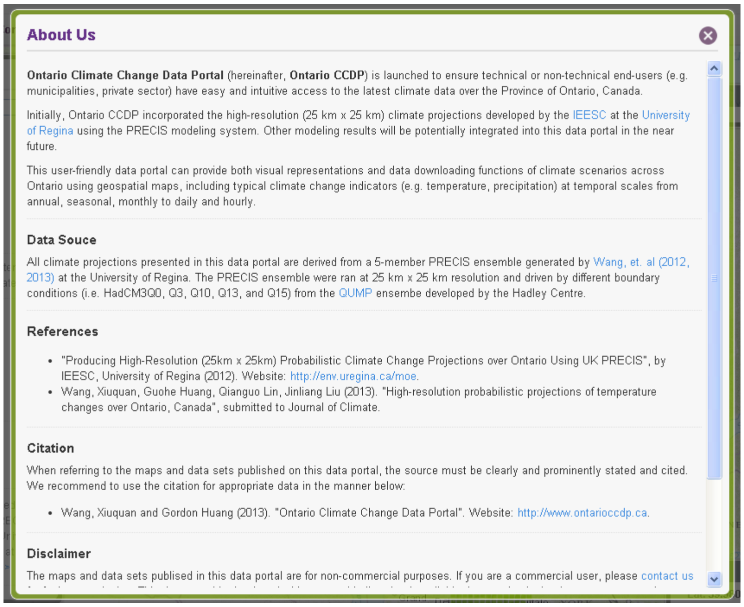

Figure 51. About panel.

FAQs Panel

As shown in Figure 52, the FAQs panel contains a list of frequently asked questions and the corresponding answers made by developer of Ontario CCDP. Users are recommended to look through all questions before accessing the data and info provided by Ontario CCDP.

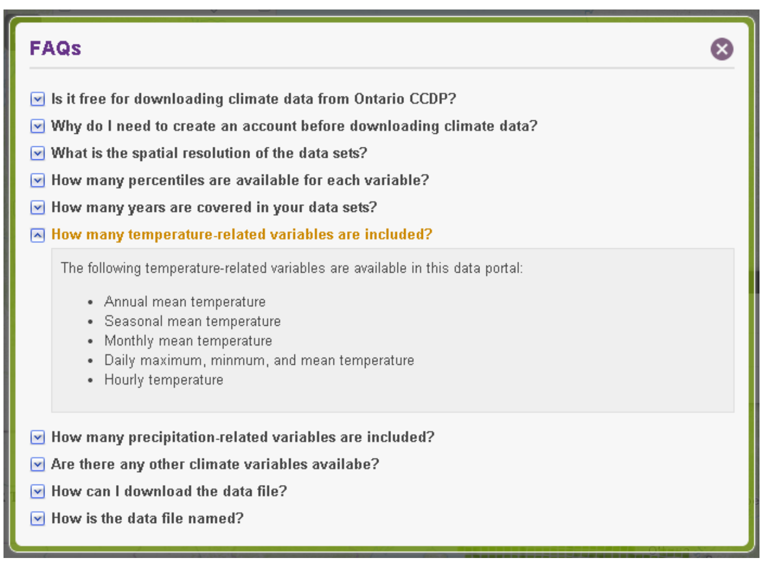

Figure 52. FAQs panel.

Contact Panel

As shown in Figure 53, the contact panel shows the detailed contact information so that users can direct their questions, comments or suggestions to the correct person.

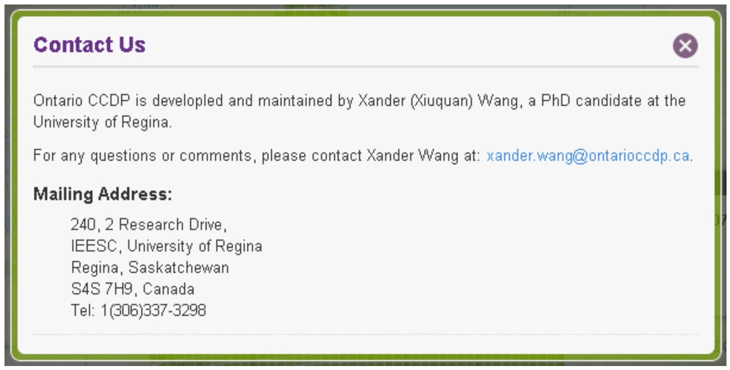

Figure 53. Contact panel.

4. Projected Maps of Temperature and Precipitation

This chapter summarizes the main findings from the projected maps of temperature and precipitation at 50% percentile, for the periods of 1960-1990, 2015-2045, 2035-2065, and 2065-2095, with annual and seasonal averaging. More projected maps covering monthly averaging at different percentiles are available on the Ontario CCDP.

4.1 Projected Maps of Temperature

Figure 54 to Figure 58 show the projected maps of annual and seasonal mean temperature at 50% percentile for the periods of 1960-1990, 2015-2045, 2035-2065, and 2065-2095. There is a consistent warming trend reported by all maps from the baseline period to future periods. The annual mean temperature of north Ontario projected for the baseline period is below zero, but it will go beyond 1 ℃ to the end of this century. The annual mean temperature in south Ontario will jump from [5, 9] ℃ in 1960-1990 to [11, 15] ℃ in 2065-2095. The winter mean temperature in south Ontario will increase from [-6, 3] ℃ in the baseline period to as high as [0, 6] ℃, while the spring one increases from [3, 9] ℃ to [9, 13] ℃, the summer one from [16, 22] ℃ to [22, 28] ℃ and the fall one from [10, 14] ℃ to [16, 18] ℃.

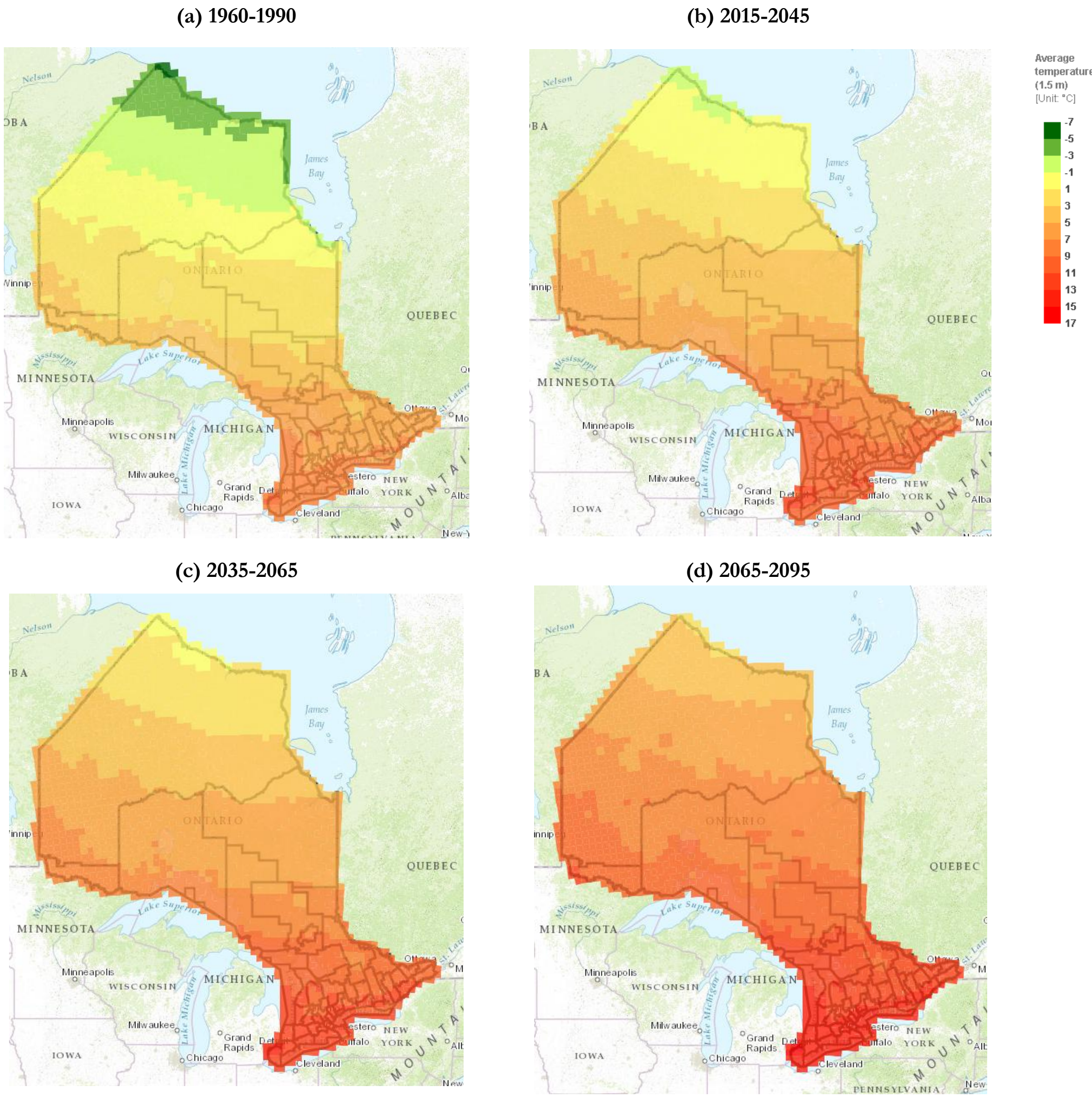

Figure 54. Projected maps of annual mean temperature.

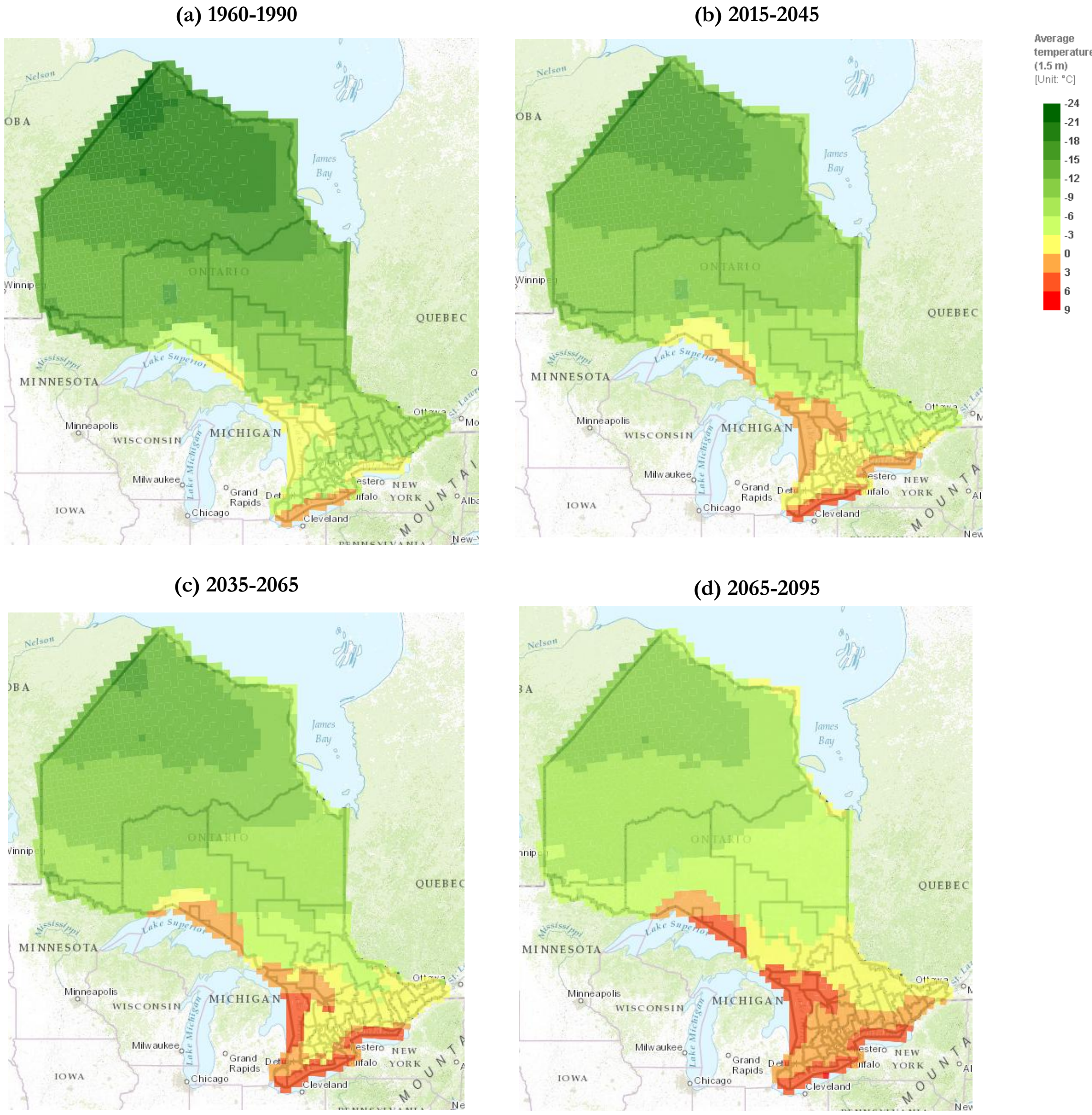

Figure 55. Projected maps of winter mean temperature.

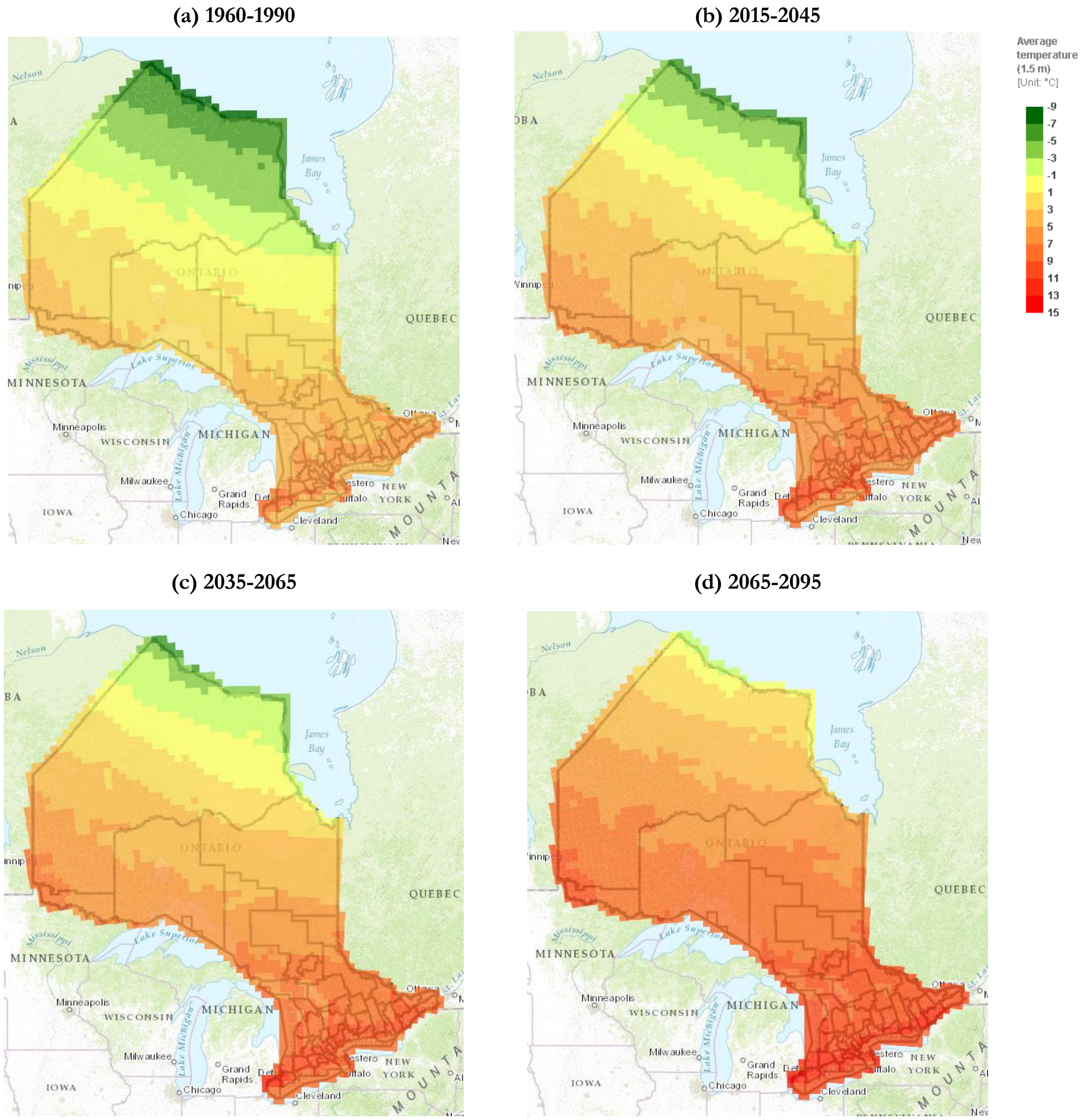

Figure 56. Projected maps of spring mean temperature.

(a) 1960-1990 (b) 2015-2045 (c) 2035-2065 (d) 2065-2095

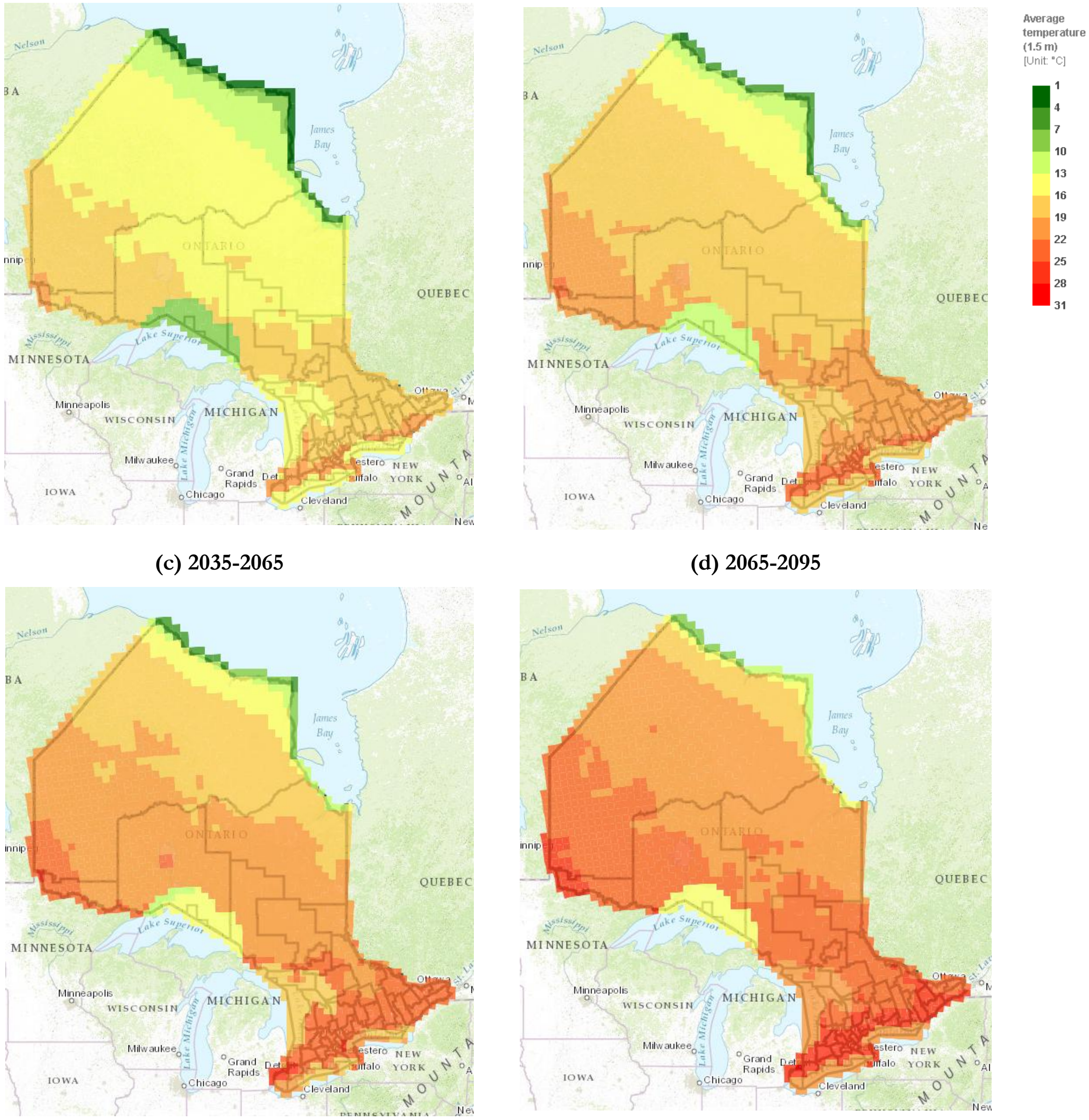

Figure 57. Projected maps of summer mean temperature.

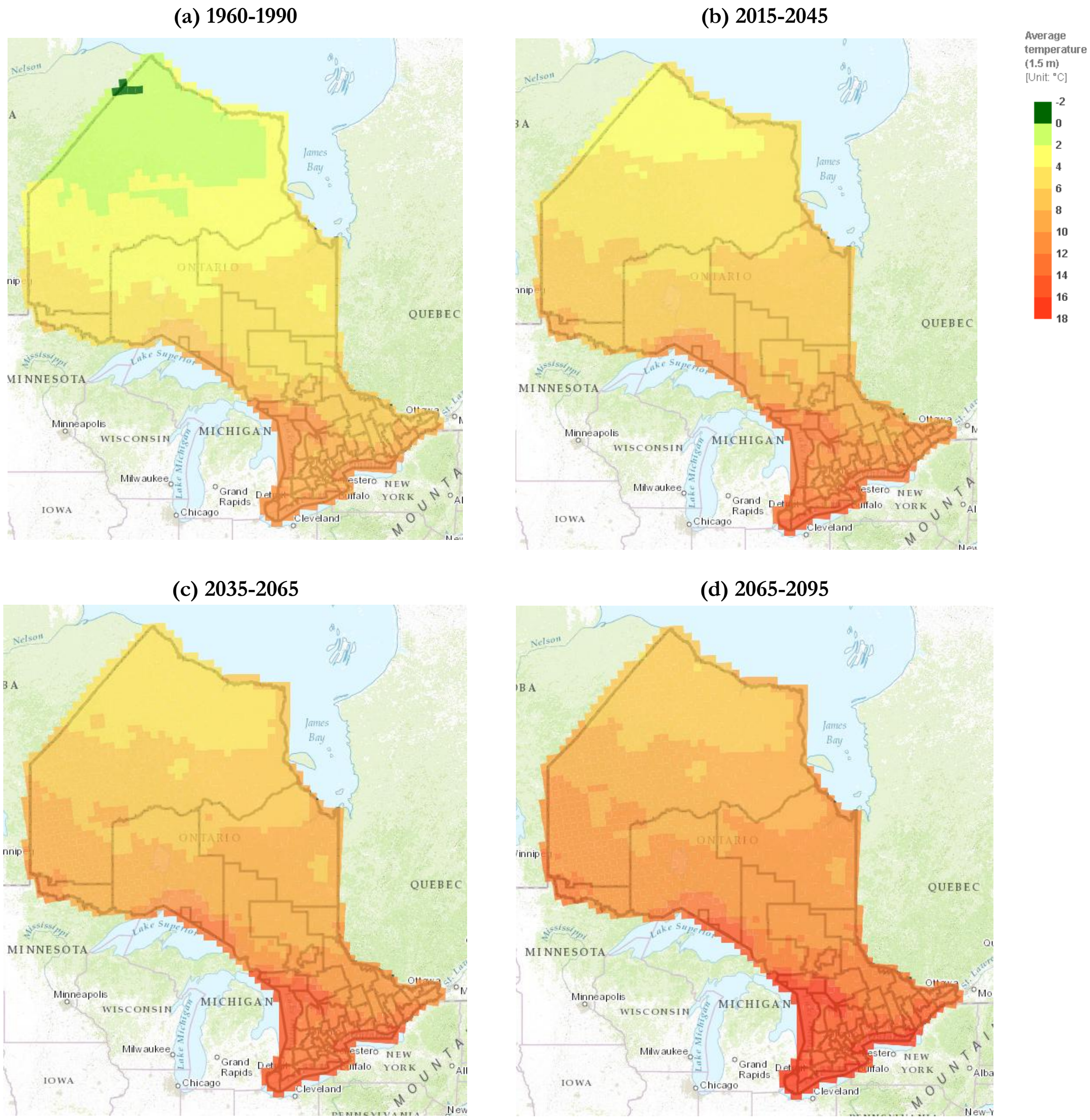

Figure 58. Projected maps of fall mean temperature.

4.2 Projected Maps of Precipitation

Figure 59 to Figure 63 show the projected maps of annual and seasonal total precipitation at 50% percentile for the periods of 1960-1990, 2015-2045, 2035-2065, and 2065-2095. There are no apparent changes projected from the baseline period to the future periods. However, there is a common decreasing pattern in precipitation from south to north for all maps. The projected annual precipitation in south Ontario will be as high as 1400 mm, while it might be as low as 400 mm in the north. Precipitation in summer will be ranging from 220 to 370 mm in the northern and middle regions, which is apparently higher than other seasons. However, south Ontario seems to be projected with the highest precipitation in spring, where the seasonal total precipitation will be as high as 370 to 420 mm.

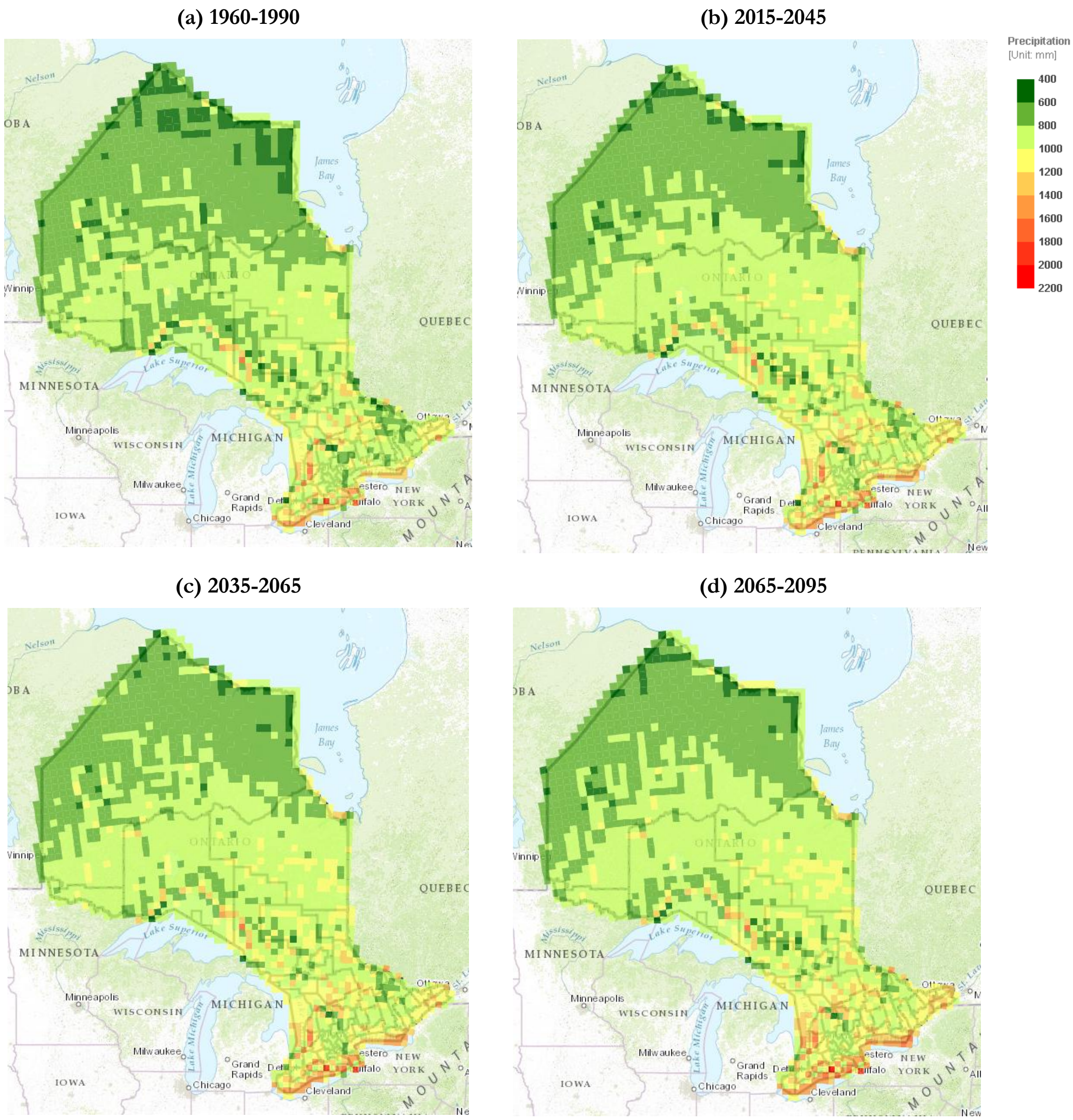

Figure 59. Projected maps of annual precipitation.

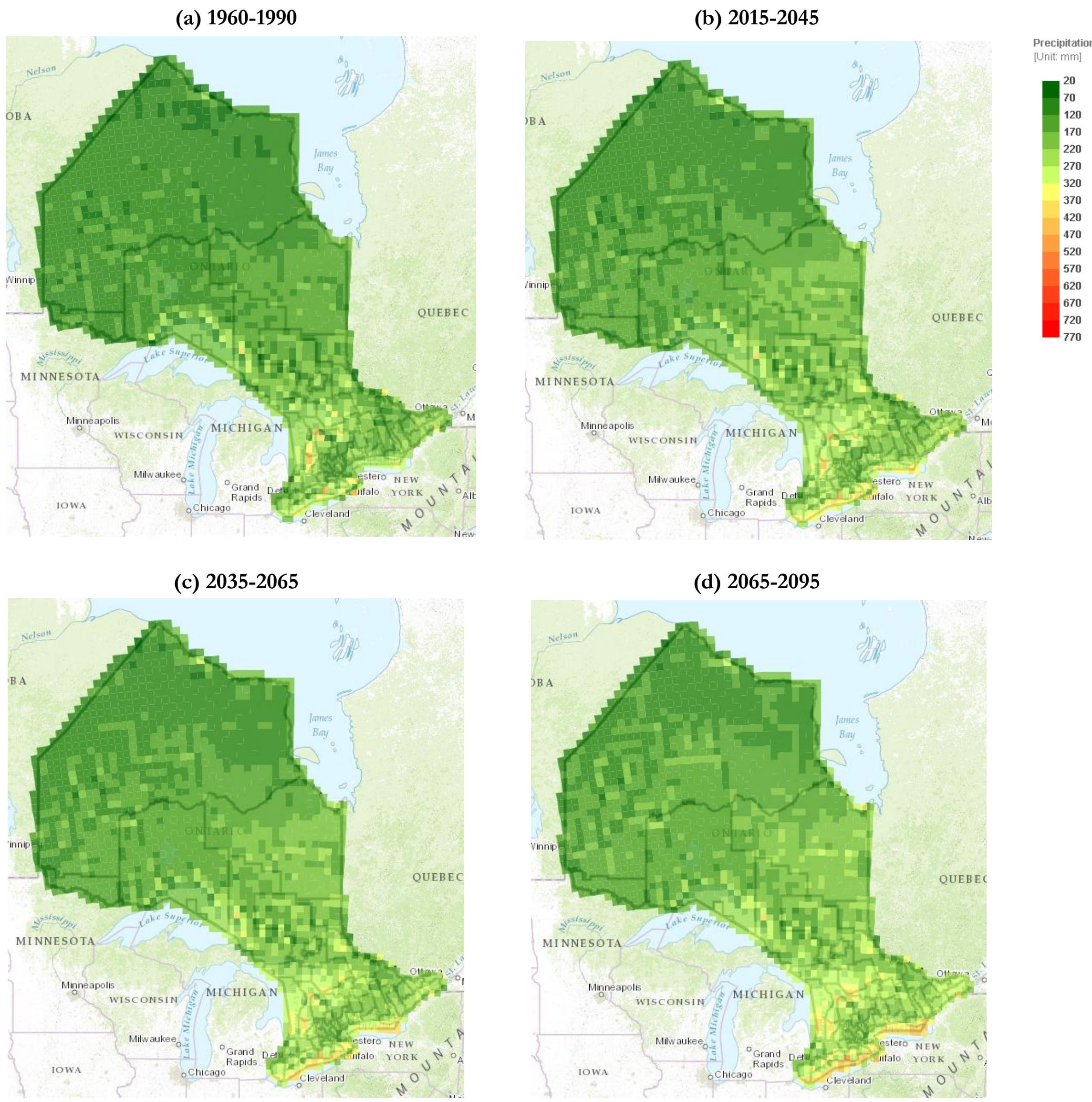

Figure 60. Projected maps of winter precipitation.

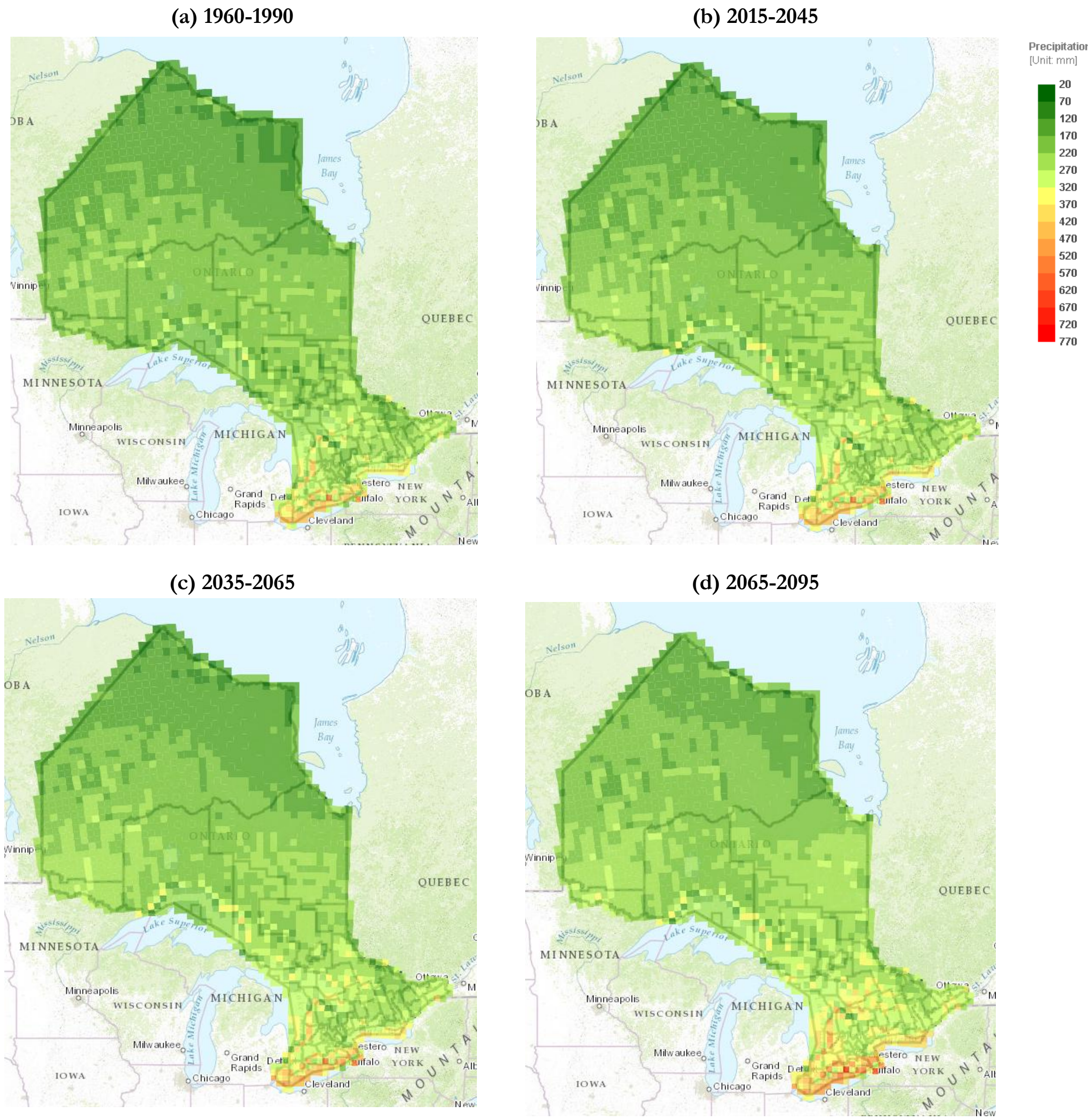

Figure 61. Projected maps of spring precipitation.

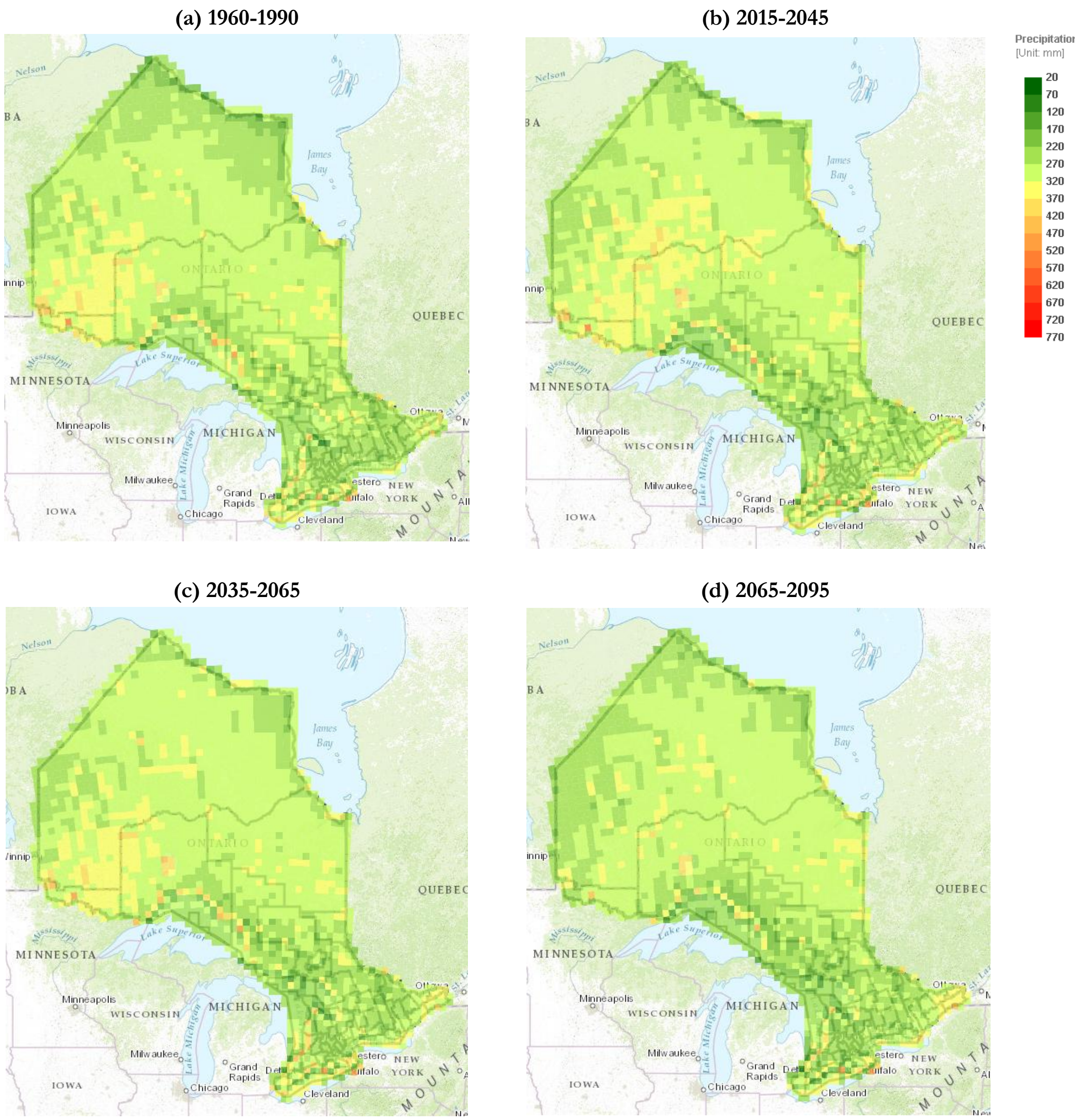

Figure 62. Projected maps of summer precipitation.

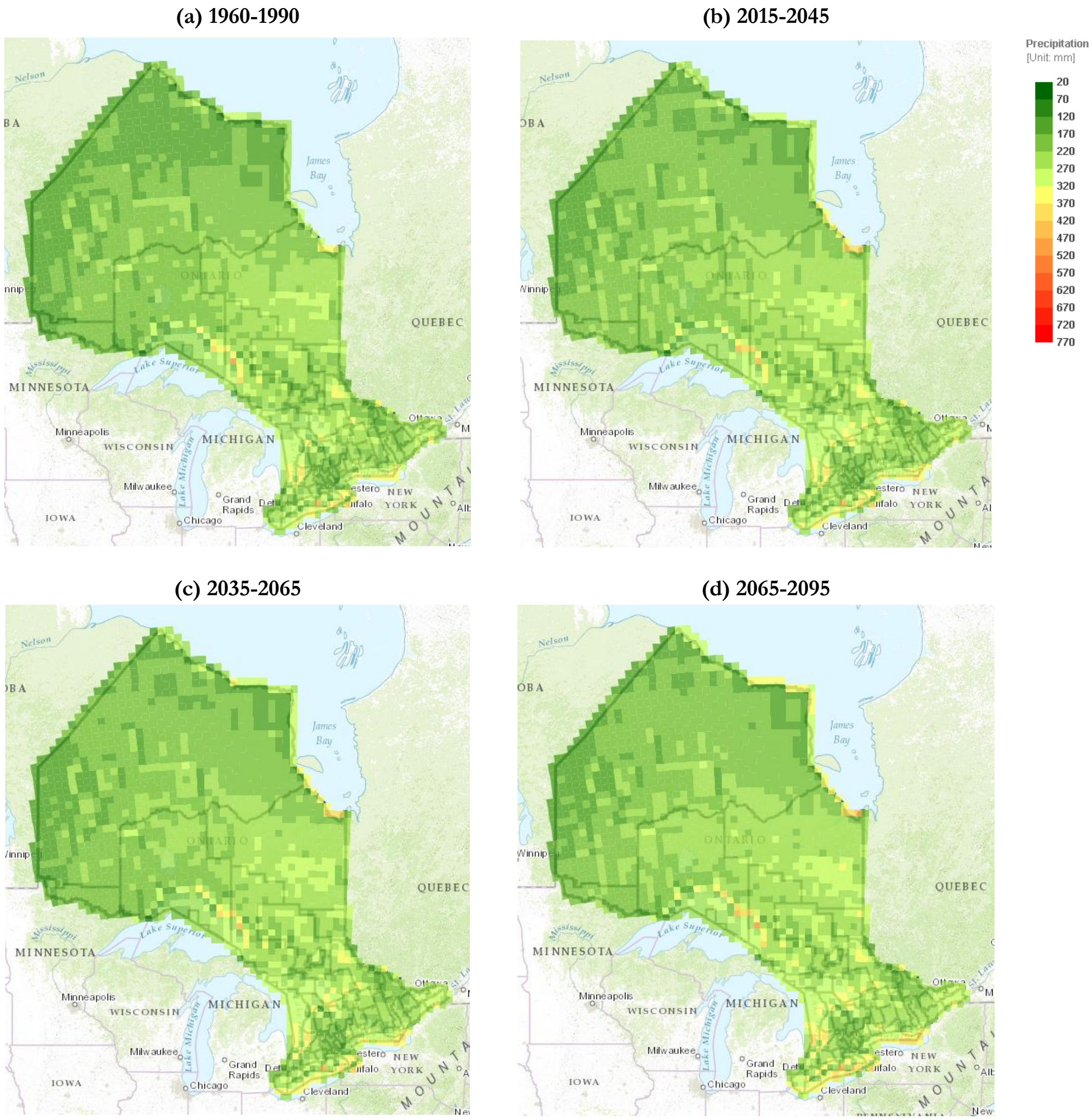

Figure 63. Projected maps of fall precipitation.

Appendix I: PRECIS Grids over Ontario

The PRECIS system uses Arakawa B grid layout in its modeling framework, which leads to the differences in the latitude and longitude of wind grids (i.e. wind speed, wind direction components: U and V) from that of mass grids which are used for the alignment of non-wind diagnostics (e.g. temperature, precipitation). The mass grids and wind grids over Ontario used by the PRECIS model are shown as follows:

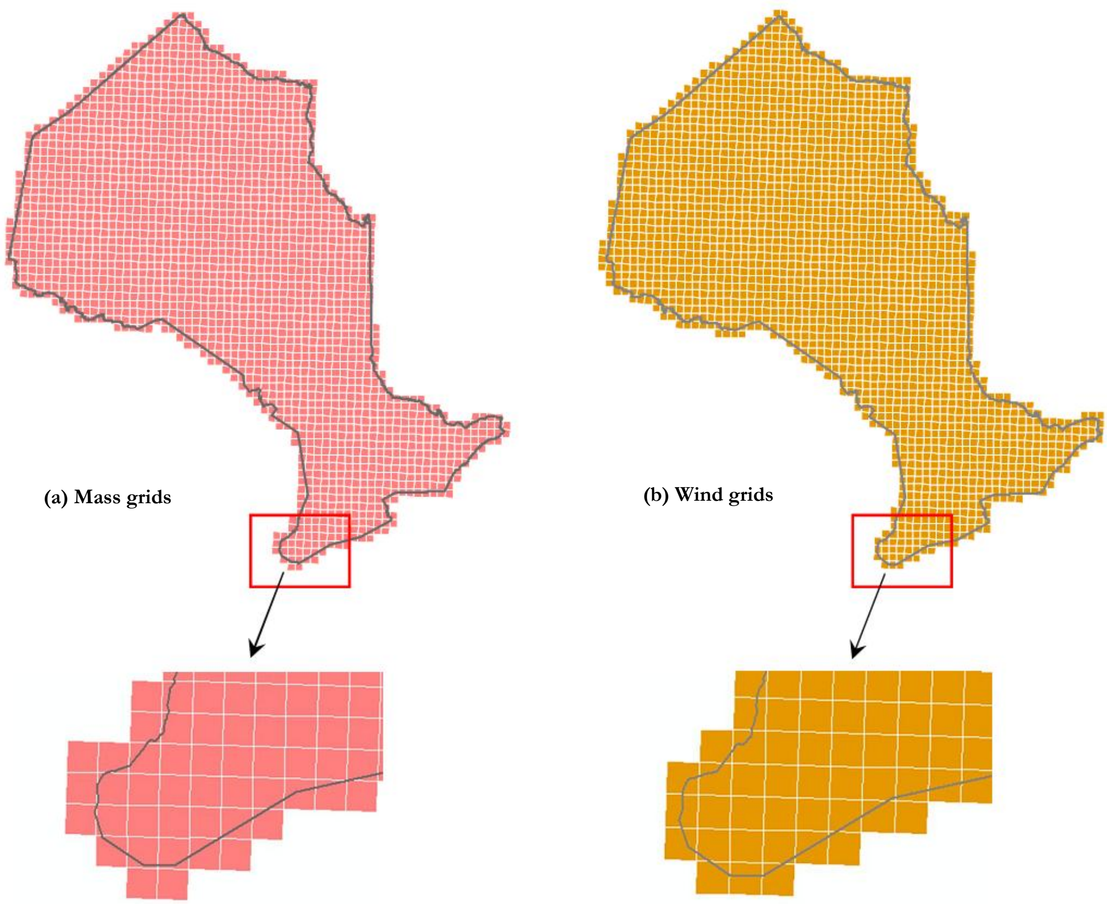

Figure 64. PRECIS mass and wind grids over Ontario

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