SWAT Conference 2025

Climate Change Impacts on Soil Water Availability and Farm Sustainability in a Boreal Watershed.

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Introduction

(https://parks.canada.ca)

(Power, 2019)

- The **Upper Humber River Watershed** (UHRW) in Western Newfoundland is an ecologically, economically, and culturally important region. It supports diverse land uses, including agriculture, forestry, and recreation

- Understanding the impacts of climate change on the UHRW is important for developing planning strategies and ensuring **sustainability**

- **For the adaptation** due to climate change as a fixed fact in the future, watershed decision makers require quantitative results for the establishment of strategy

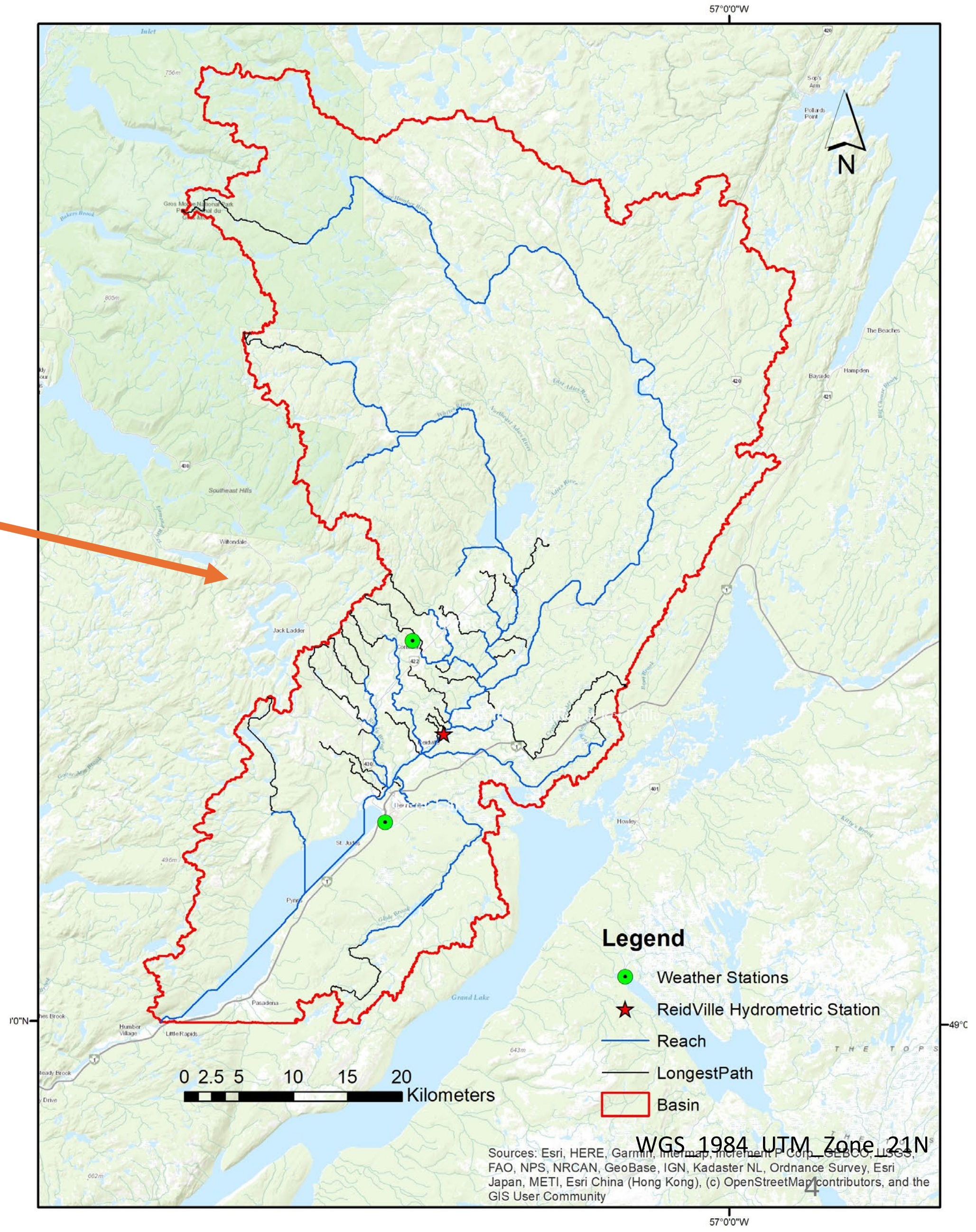
Objectives

1. Calibrate and evaluate a **soil and water assessment tool (SWAT) hydrological model** for the Upper Humber River Watershed (UHRW)

2. Assess the impacts of **climate change** on **soil water availability** using the SWAT model

3. Evaluate farm sustainability through **efficiency analysis** using the **Data Envelopment Analysis (DEA)** method

Study Area



- **Location**: Boreal zone, western Newfoundland
- **Area**: 2,890 km² (62% forested)
- **Climate-sensitive** boreal watershed
- **Increasing vulnerability**: Temp. rise, variable precipitation, farm viability

SWAT Hydrological Model

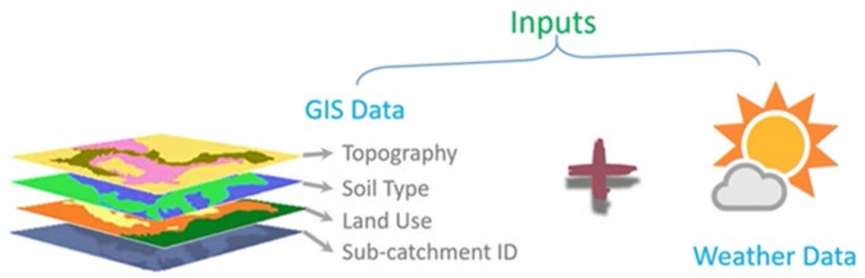
The model's hydrologic component is governed by the water balance equation:

$$SW_t = SW_o + \sum_{i=0}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$$

SW_t = Final soil water content (mm)
SW_o = Initial soil water content on day i (mm)
R_{day} = Amount of precipitation on day i (mm)
Q_{surf} = Amount of surface runoff on a day i (mm)
E_a = Amount of evapotranspiration on day i (mm)
W_{seep} = Amount of water entering the vadose zones on day i (mm)
Q_{gw} = Amount of return flow on day i (mm)

(Arnold et al., 2012)

SWAT Input



Data	Type	Source
Canadian Digital Elevation Model	Raster, (resolution -20 m)	http://geogratis.gc.ca
Land use	Raster, (resolution - 10 m)	https://www.esri.com/
Soil type	Vector	http://www.agr.gc.ca
Streamflow	Daily	https://wateroffice.ec.gc.ca
Climate	Daily	https://climate-scenarios.canada.ca

Climate Change data - CMIP5

(Coupled Model Intercomparison Project Phase 5**)**

Scenarios –

Representative Concentration Pathways (RCPs)

- **RCP 2.6**
- **RCP 4.5**
- **RCP 8.5**

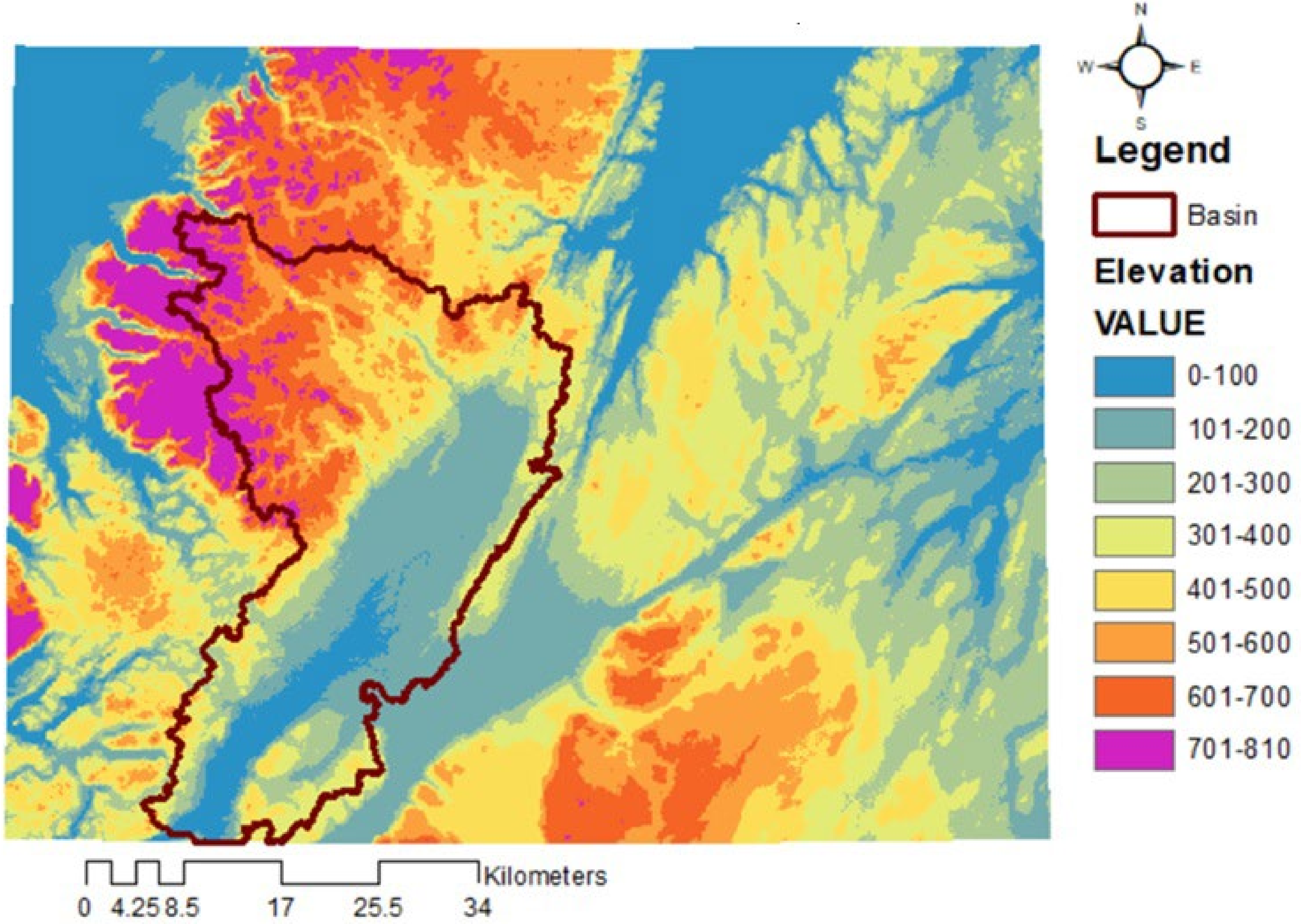
Global Circulation Model **- 12**

CMIP5 Multi-model Ensembles **-** RCPs

- Precipitation
- Maximum Temperature
- Minimum Temperature

Digital Elevation Model (DEM)

- DEM - resolution is **20 m × 20 m**.
- Projected to the WGS1984 UTM Zone 21 N coordinate system in desktop **ArcMap 10.7**.



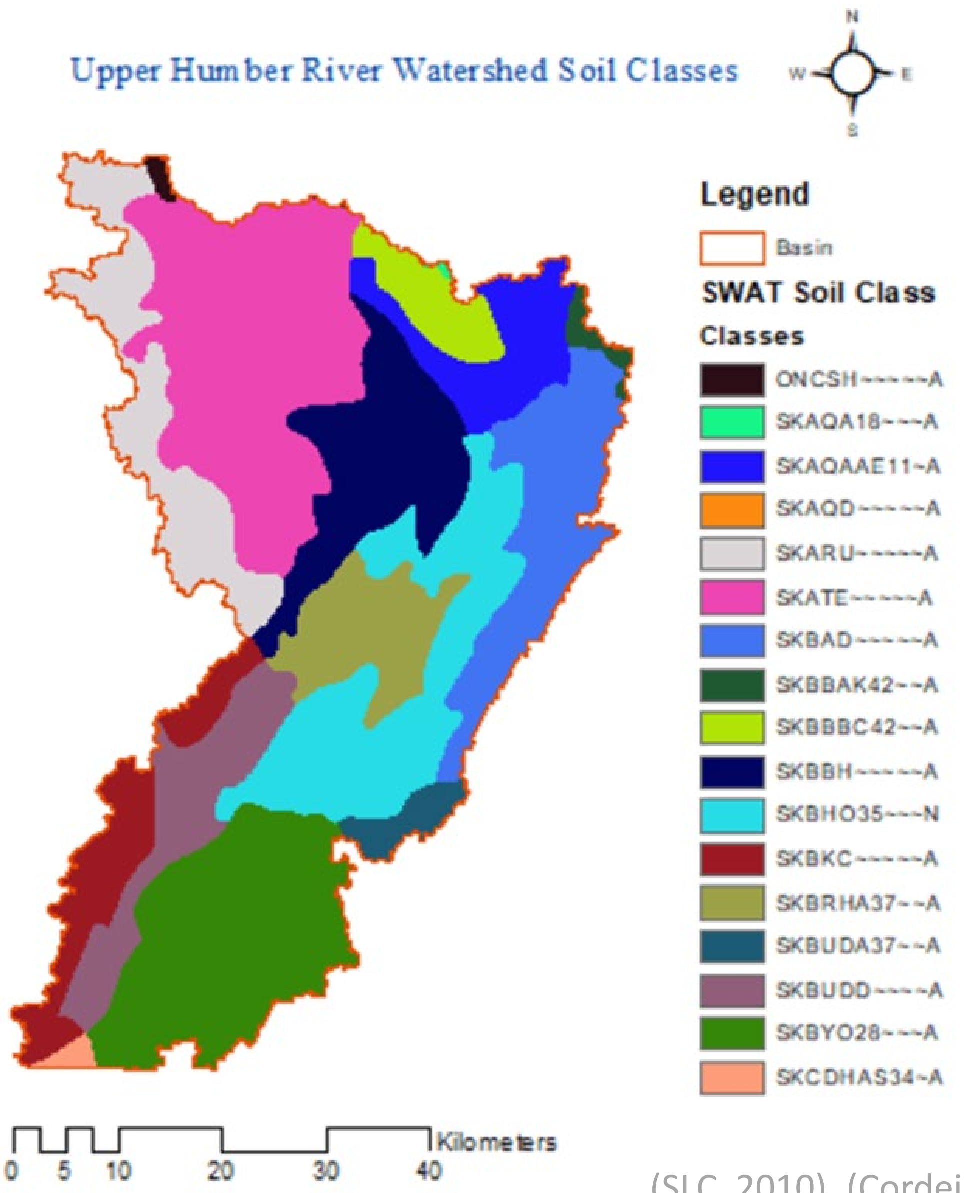
Soil data

Soil and Landscapes of Canada (SLC) –
SLC version 3.2 contains soil data for the main agricultural regions of Canada.

Database created - Agriculture and Agri-Food Canada

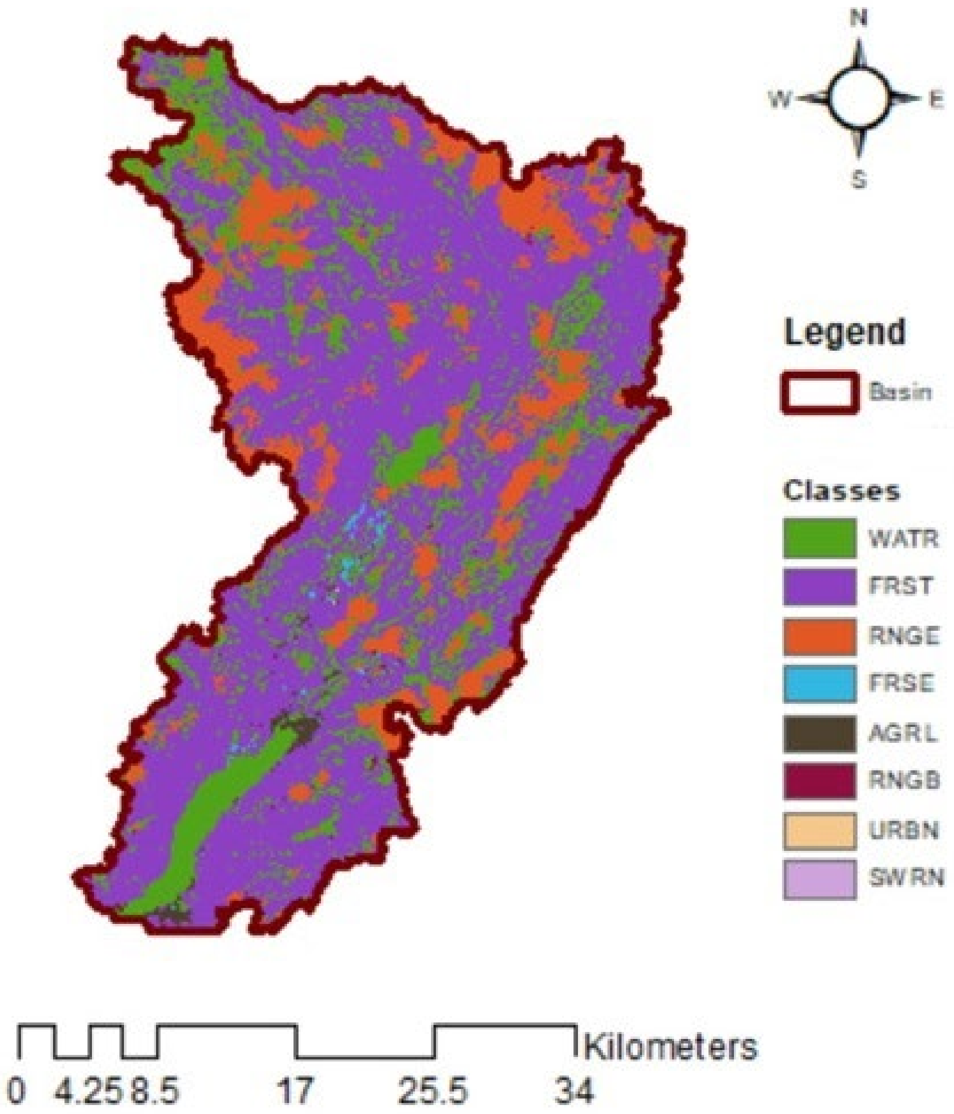
Soil Database -11 838 different soil records (Canada)

692 different soil records (NL)
Loam soil covers 27% of the watershed.



(SLC, 2010), (Cordeiro et al., 2018)

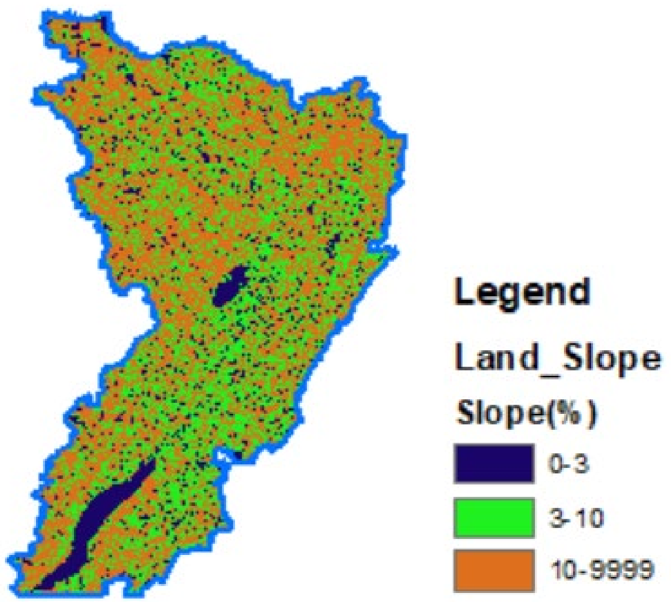
Land use land cover (LULC)

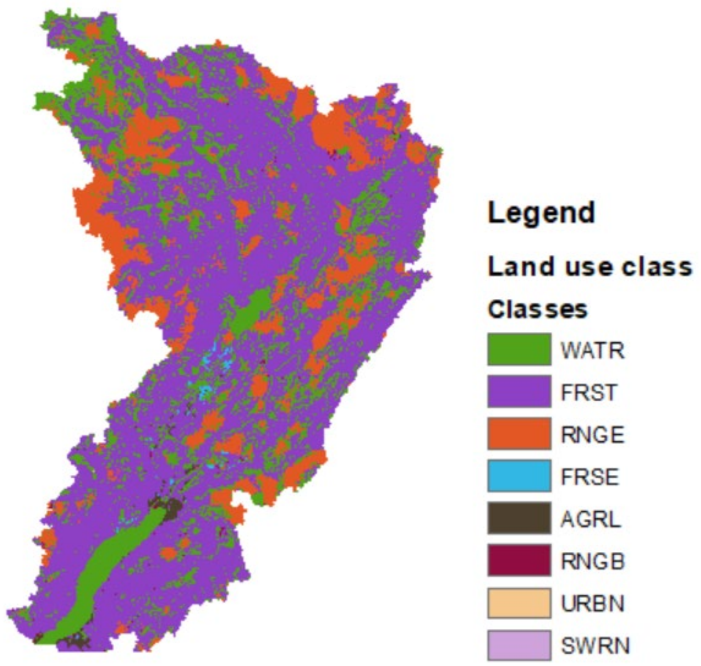


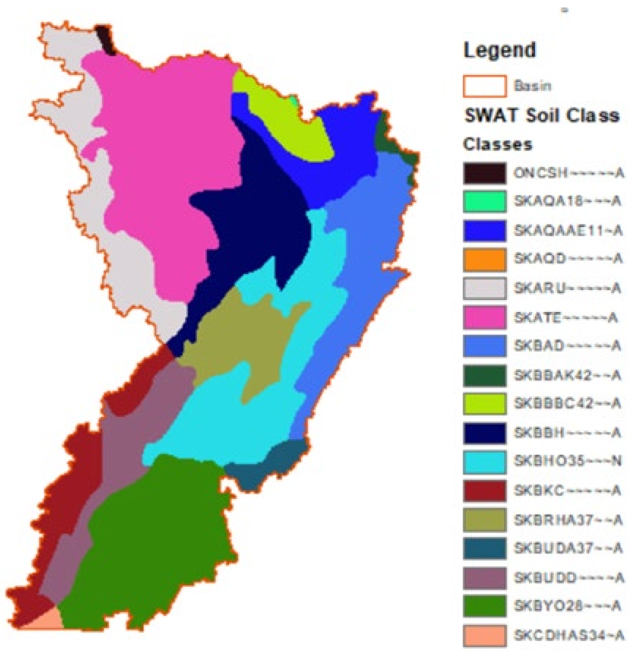
Land Use class	Class definitions	Area (Km^2)
WATR	Water	636.02
FRST	**Forest-Mixed**	**1792.42**
RNGE	Range land	433.65
FRSE	Forest-Evergreen	8.67
AGRL	Agricultural Land	17.92
RNGB	Range-Brush	5.49
URBN	Urban	0.30
SWRN	Southwestern Range	0.01

- Variable mapped: Land use/land cover in 2022
- Source imagery: Sentinel-2
- Cell Size: 10m
- Source: Esri Inc.

Hydrological Response Unit(HRU)

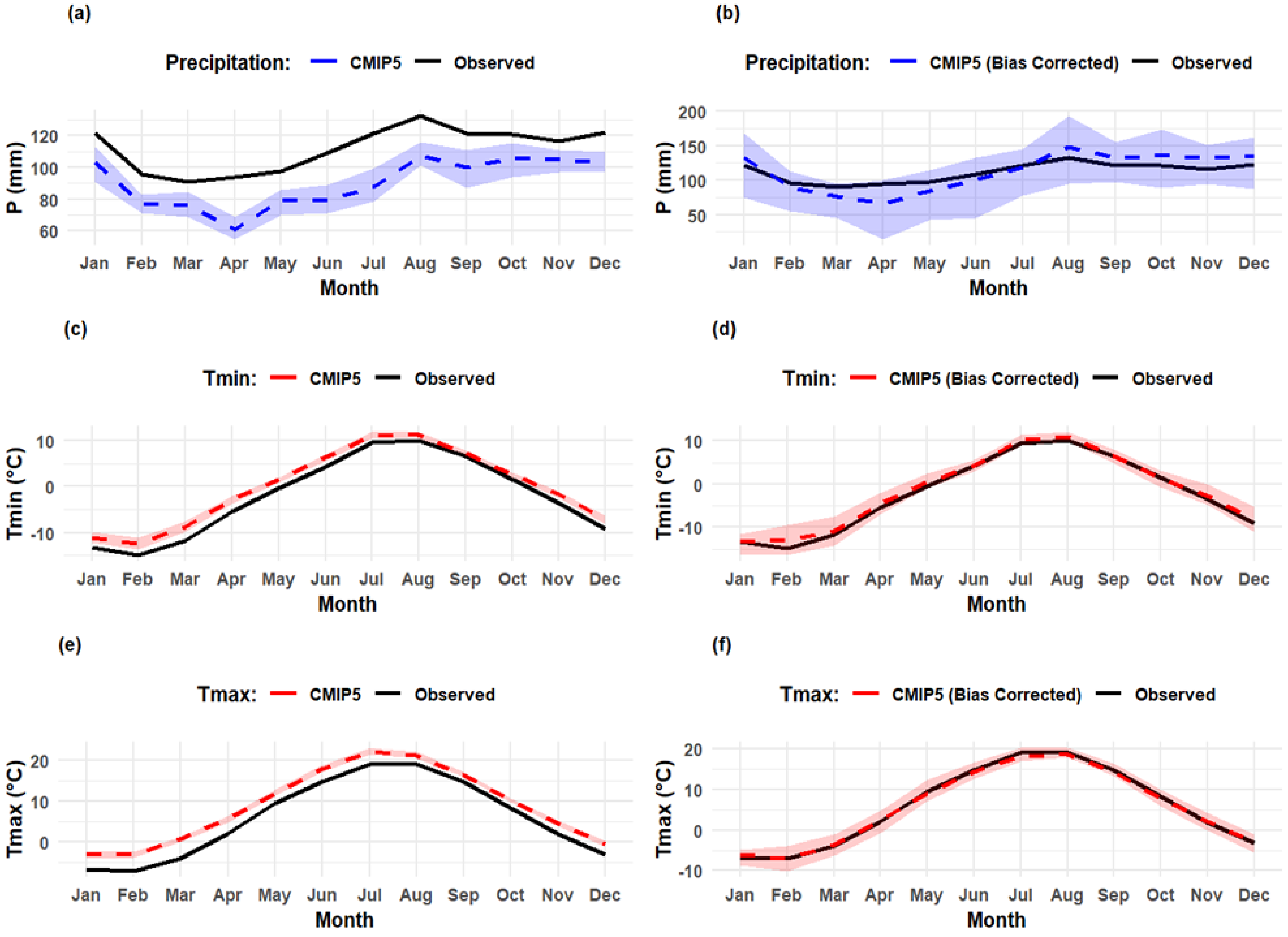






- **HRU - smallest spatial unit** of the model that represent areas of common physical characteristics.
- Approach all similar land uses, soils, and slopes within a subbasin.

CMIP5 Climate Data - Bias Correction

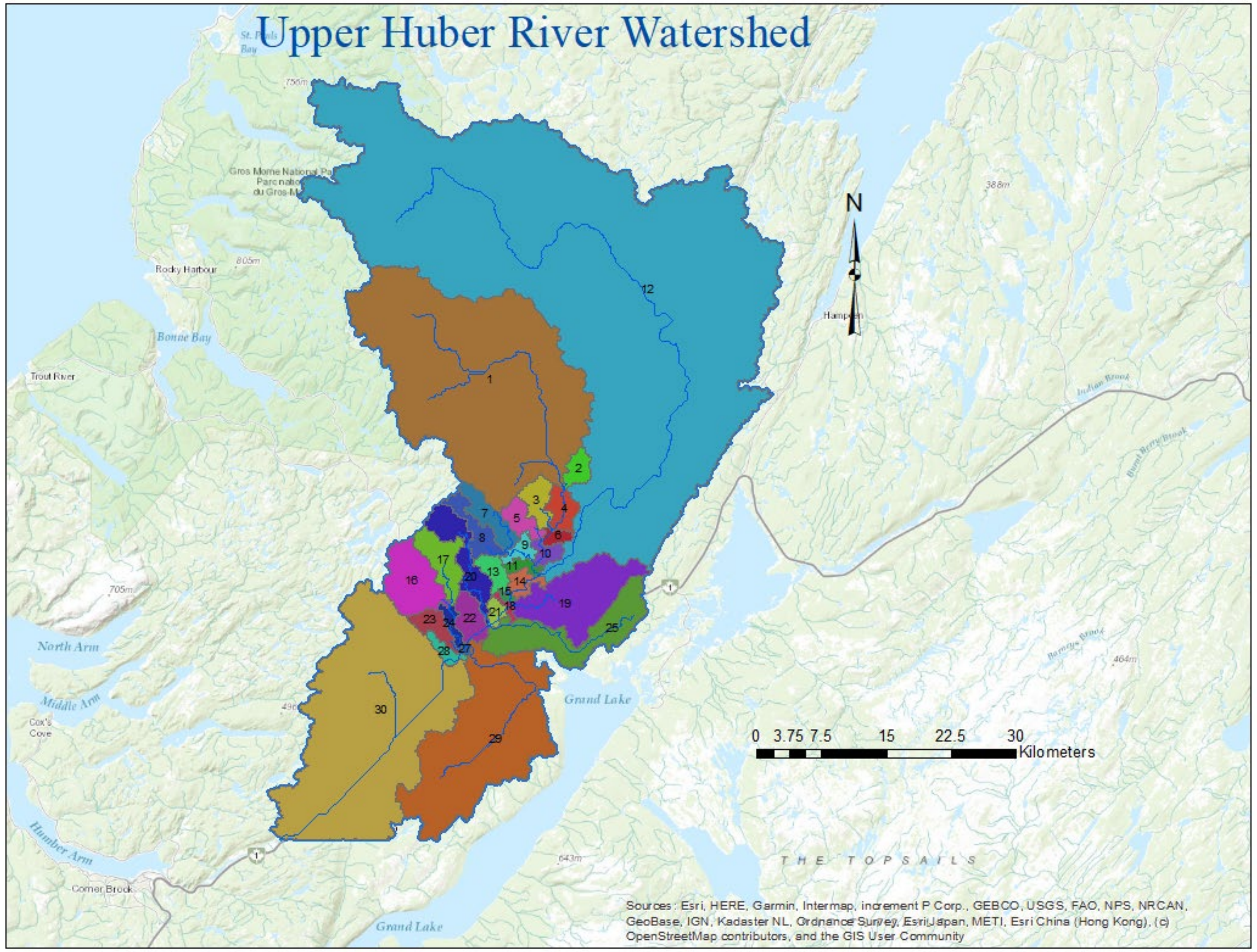


Reduced Uncertainty Range: 10th–90th percentile shaded area

Initial Bias in GCM Projections (Plots a, c, e)

Effectiveness of Bias Correction (Plots b, d, f)

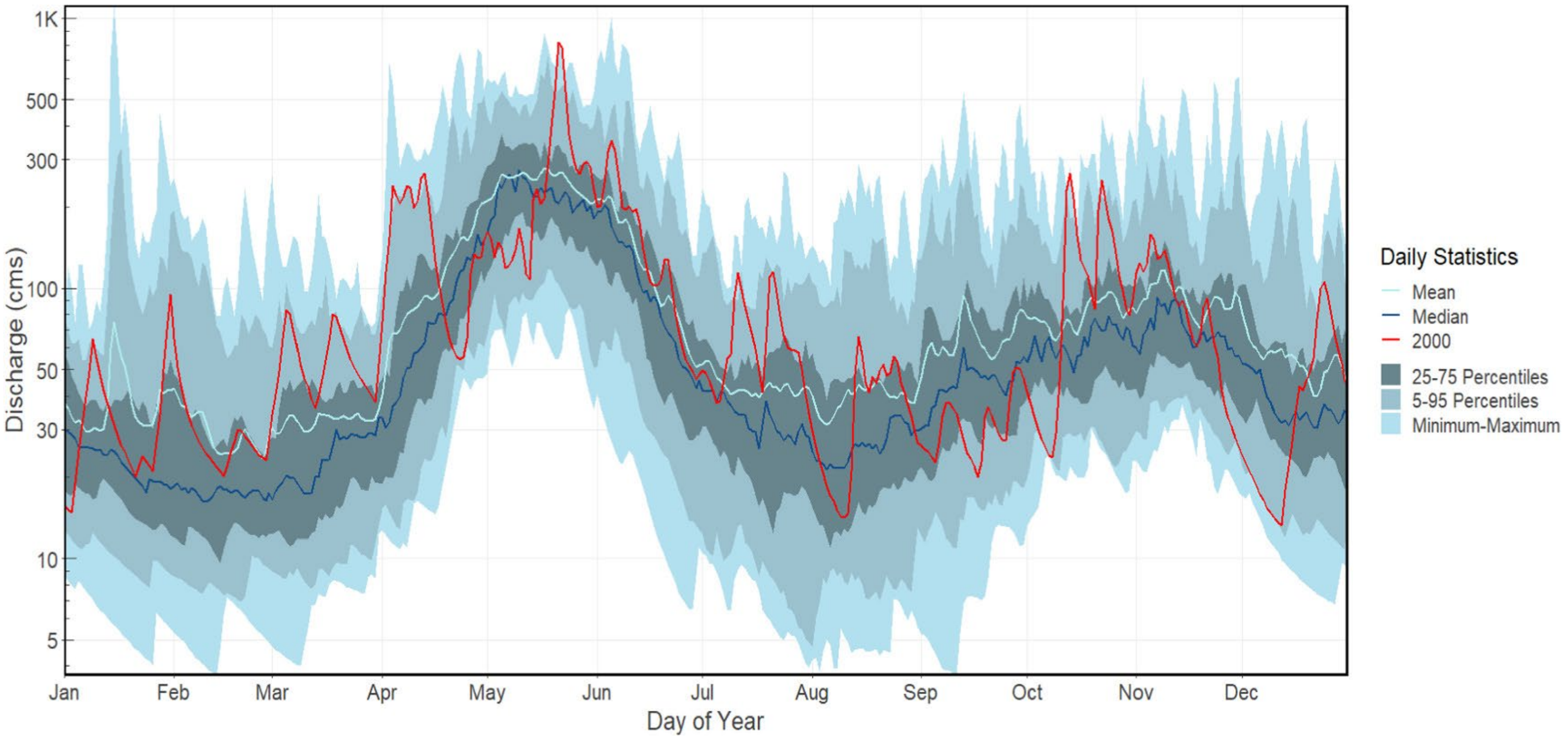
SWAT Model setup



Set up	SWAT
Sub Basin	30
HRU	251
Watershed area	2,890 Km^2
Simulation length	(2025-2100)
Warm up period	5 Year
Output timesteps	Monthly

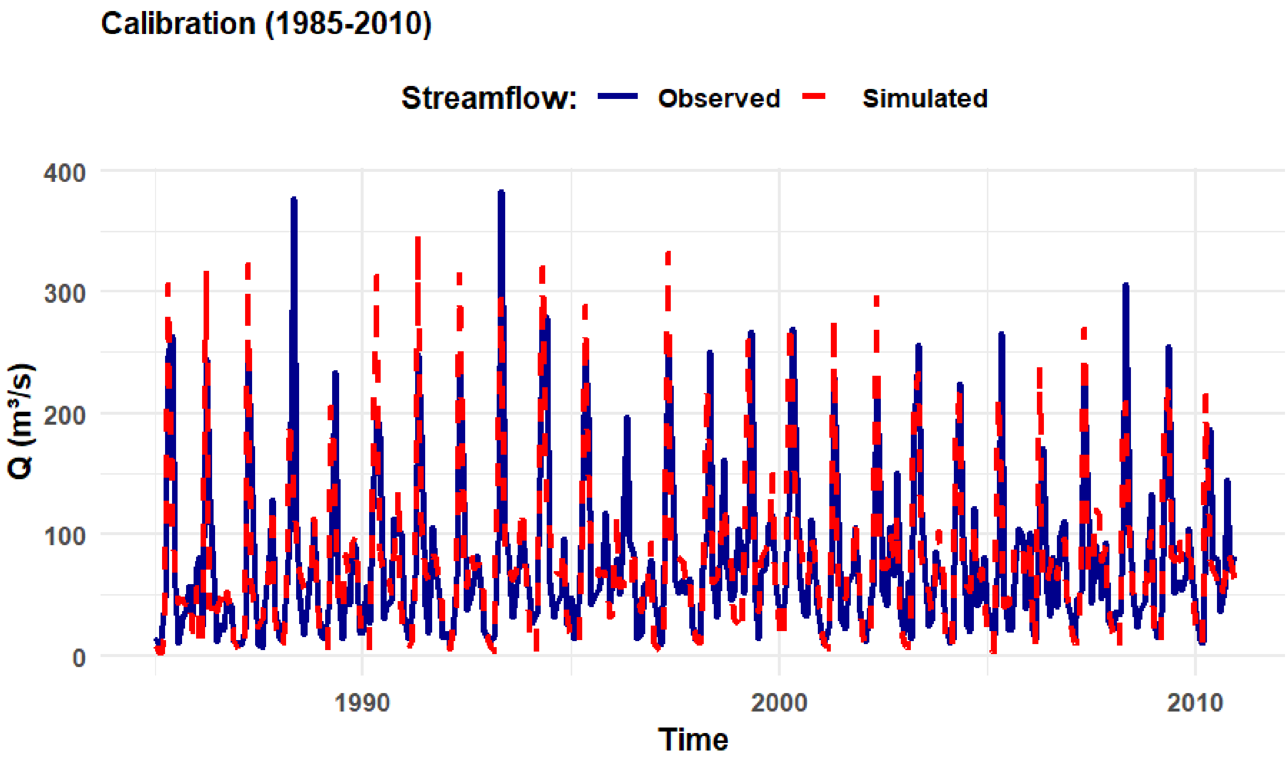
Upper Humber River Flow

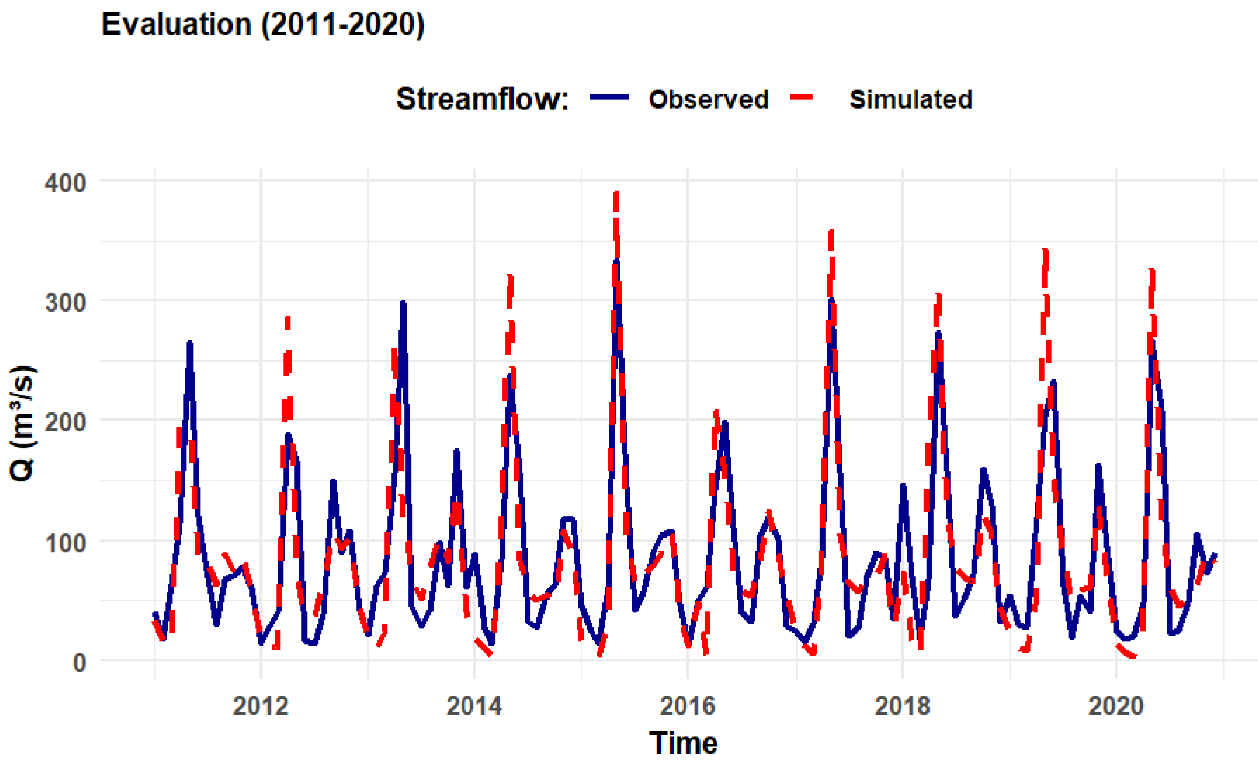
Daily streamflow analysis for the Upper Humber River Watershed (water years 1985–2022)



Specific focus on the year 2000 (red line). Maximum, minimum, mean, and median streamflow or discharge Q (cms = cubic meters per second, $m^3\ s^{-1}$), and 5 and 95% exceedance levels for each day of the year.

Model calibration and performance





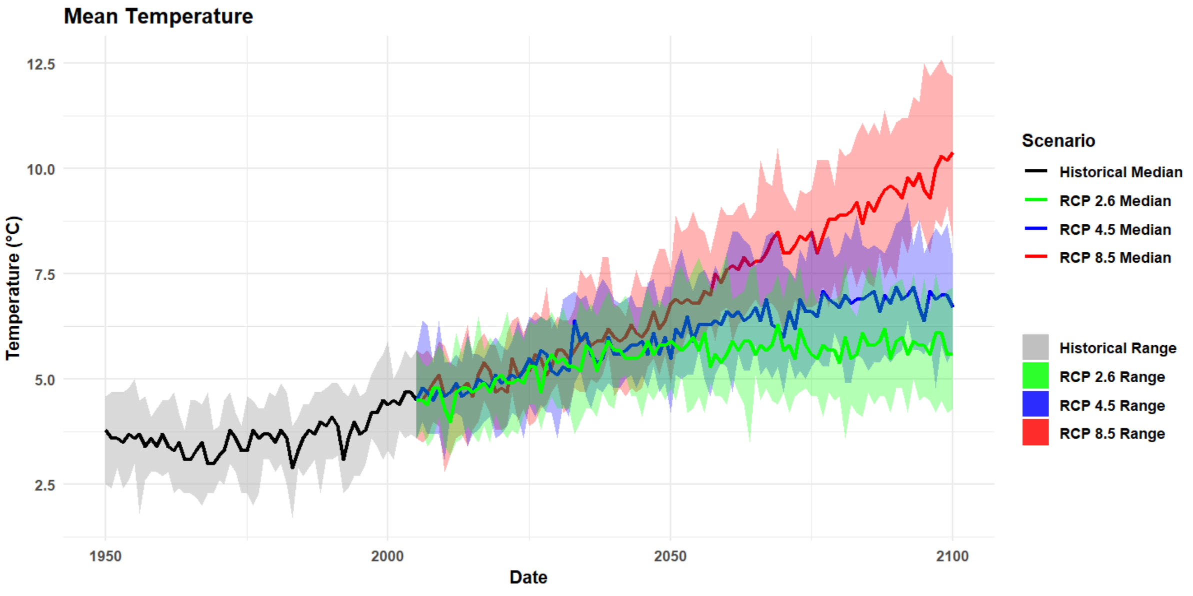
Period	Year	Statistical analysis of model performance		
		R^2	PBIAS	NSE
Calibration	1984-2010	0.79	6.9	0.79
Validation	2011- 2021	0.83	- 8.1	0.82

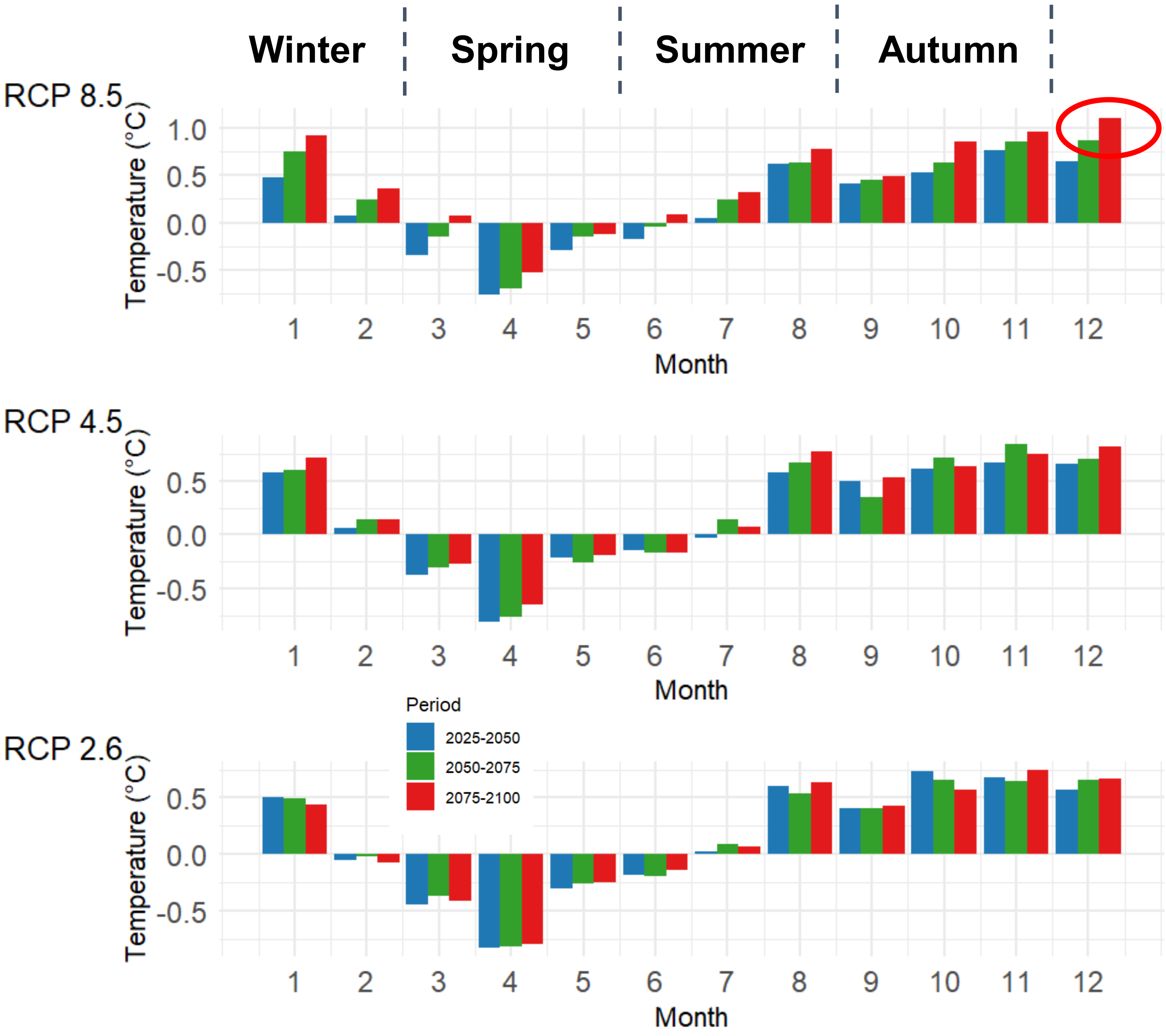
Coefficient of determination (R^2), Percent bias (PBIAS), Nash–Sutcliffe Efficiency (NSE)

(Islam *et al* 2024)

Climate Change

Temperature Change (ºC)



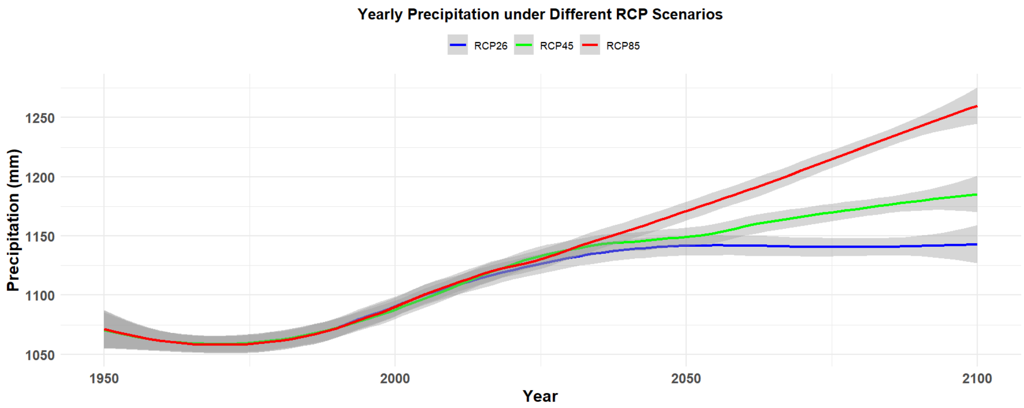


For the 1981-2010 period, the annual average temperature was **3.6 ºC**.

RCP 8.5, annual average temperatures are projected to be **5.8 ºC** for the 2025-2050 period,
7.9 ºC for the 2051-2075 period and
9.0 ºC for the last 25 years of this century.

Precipitation

Precipitation Change

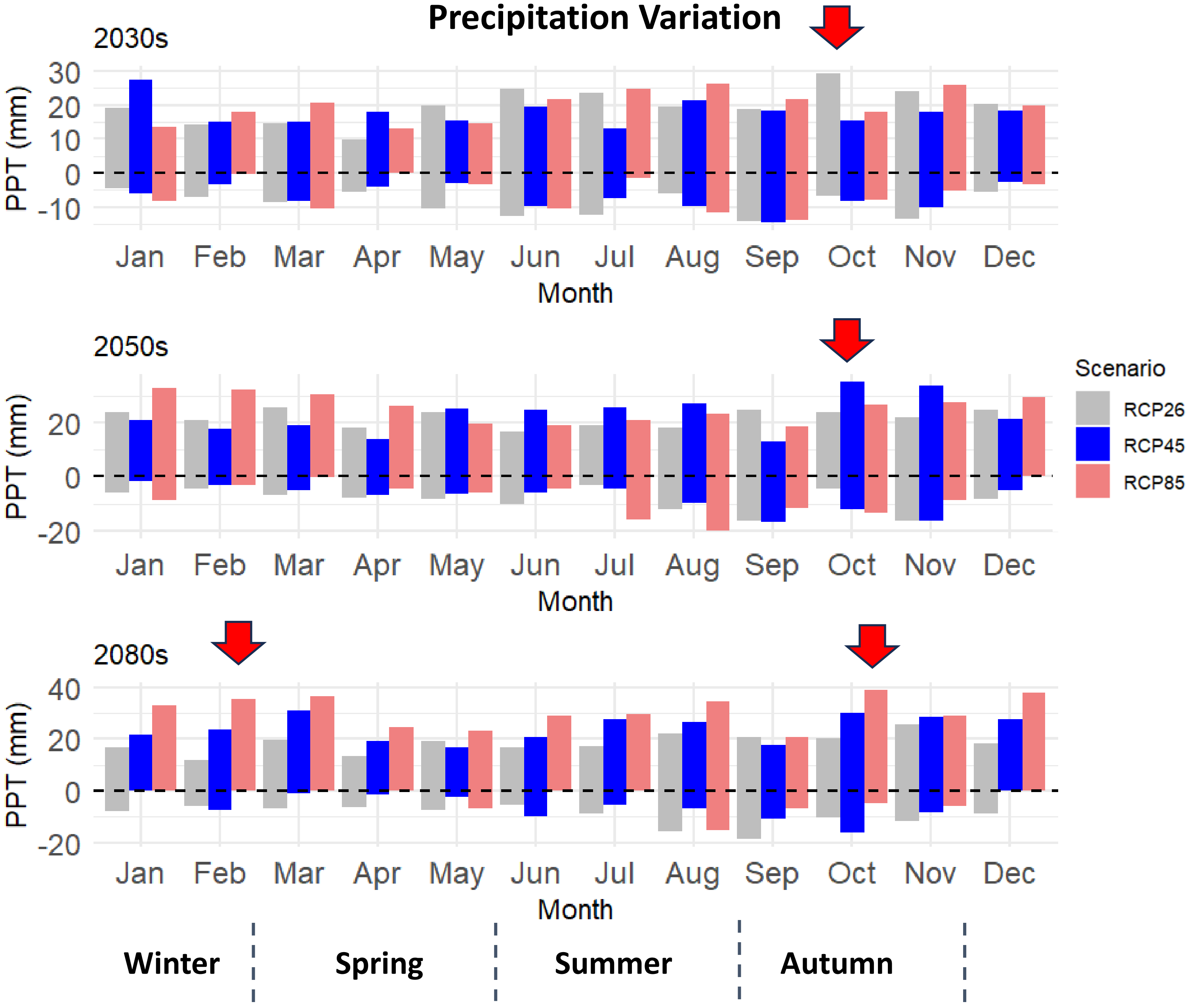


Shaded region represents the 90% confidence interval around the smooth line

Average annual precipitation for the 1981-2010 period was **1135** mm.

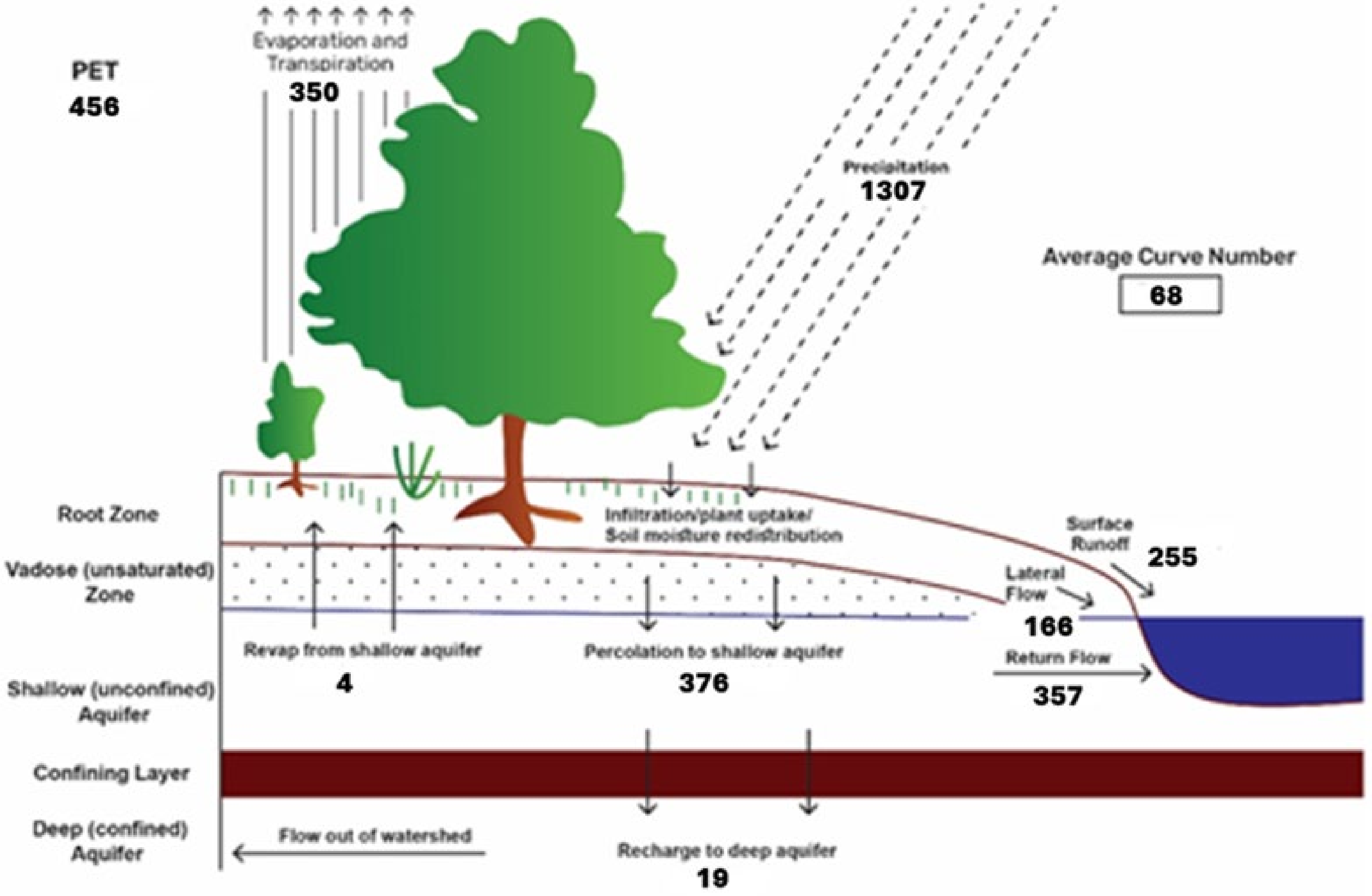
RCP 8.5, this is projected to be **13%** higher for the 2051-2075 period and **17%** higher for the last 25 years of this century.

Precipitation Variation



Watershed hydrological components value

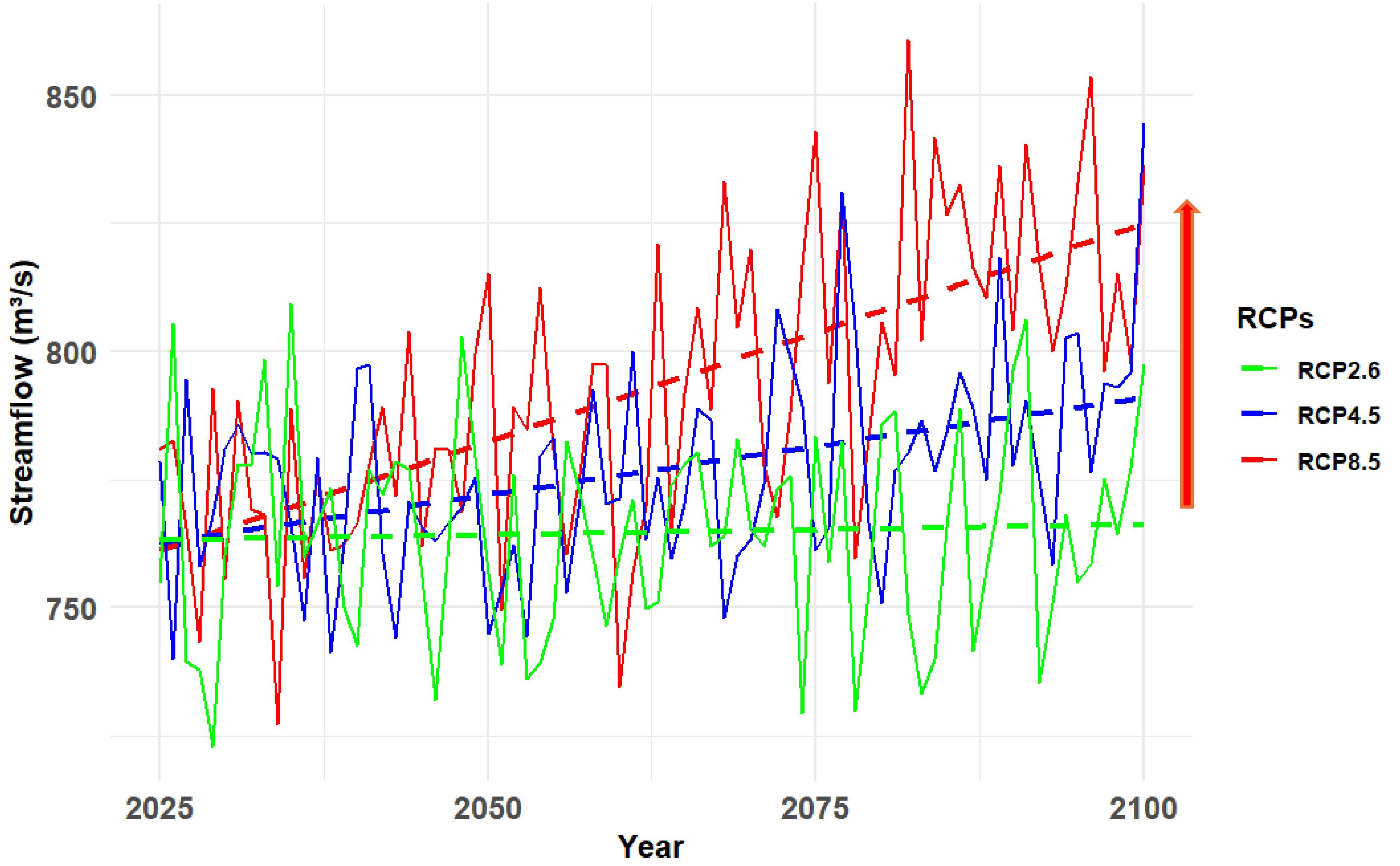
Component	Value (%)
Precipitation	100% (baseline)
Surface Runoff	**28%**
Evapotranspiration	**25%**
Percolation	**23%**
Others (losses, deep seepage, residuals)	**24%** (includes vadose zone infiltration, baseflow)



All data in millimeter

Projected Streamflow Trends under RCP Scenarios

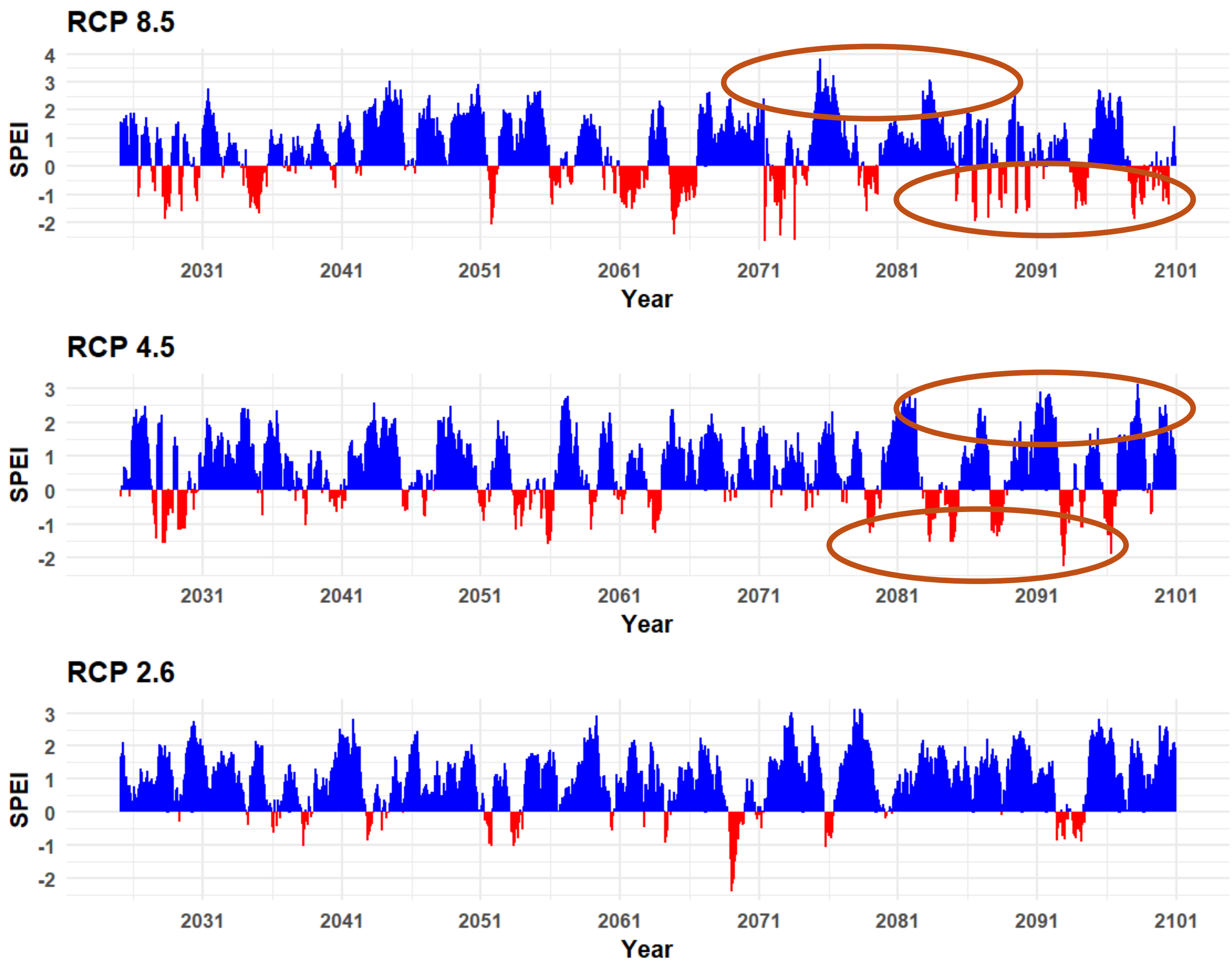
Overall Trend: Increased streamflow across all scenarios, RCP8.5 showing the highest.



RCP8.5 - highest increase, variation +20.27% by 2075s
RCP4.5 - moderate increase, variation +16.33% by 2075s
RCP2.6 - smallest increase. All scenarios indicate an upward trend in flow over time

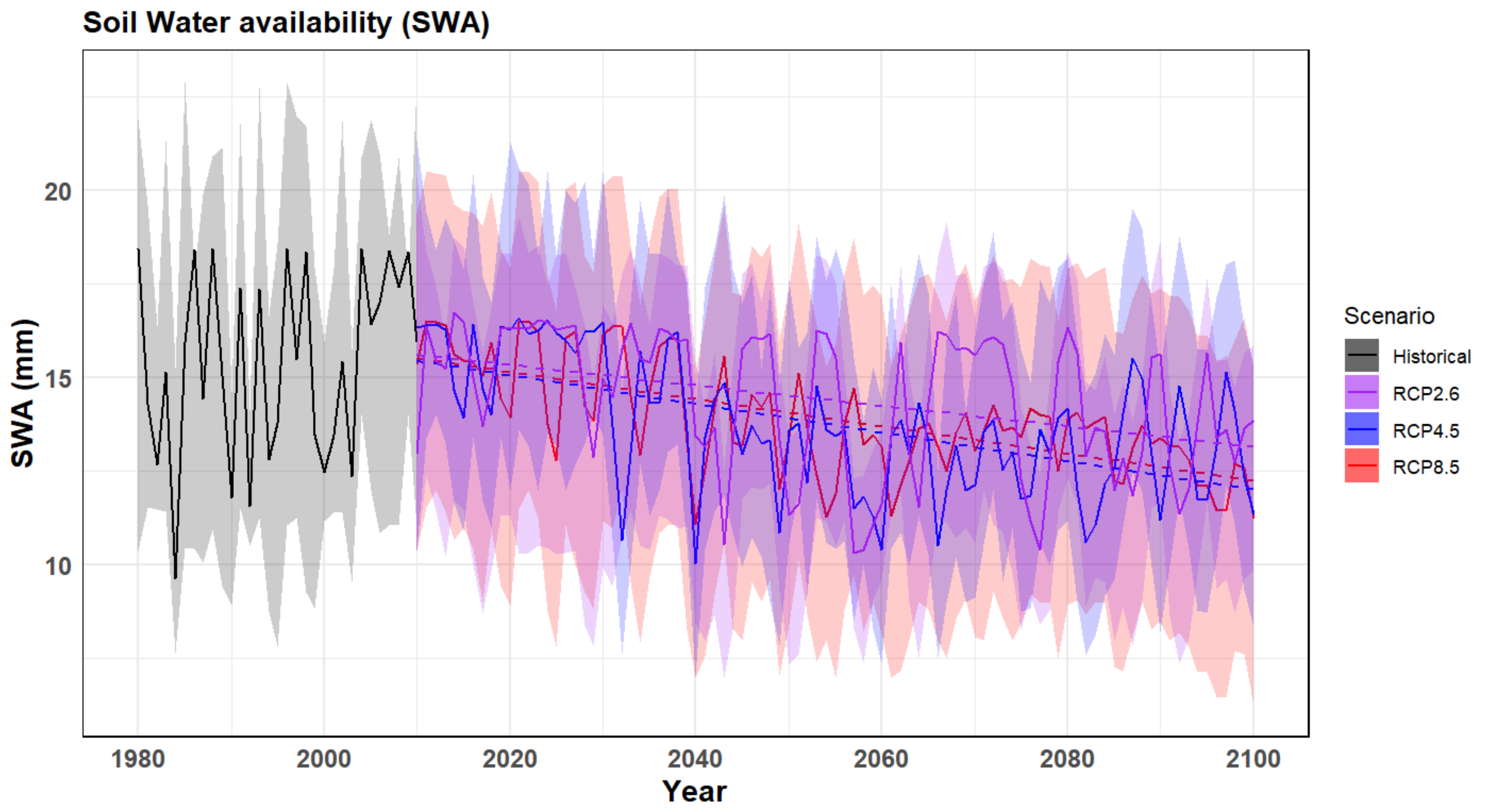
Drought Risk Assessment using SPEI

Annual SPEI from 2025 to 2100 under RCP 2.6, RCP 4.5, and RCP 8.5 scenarios



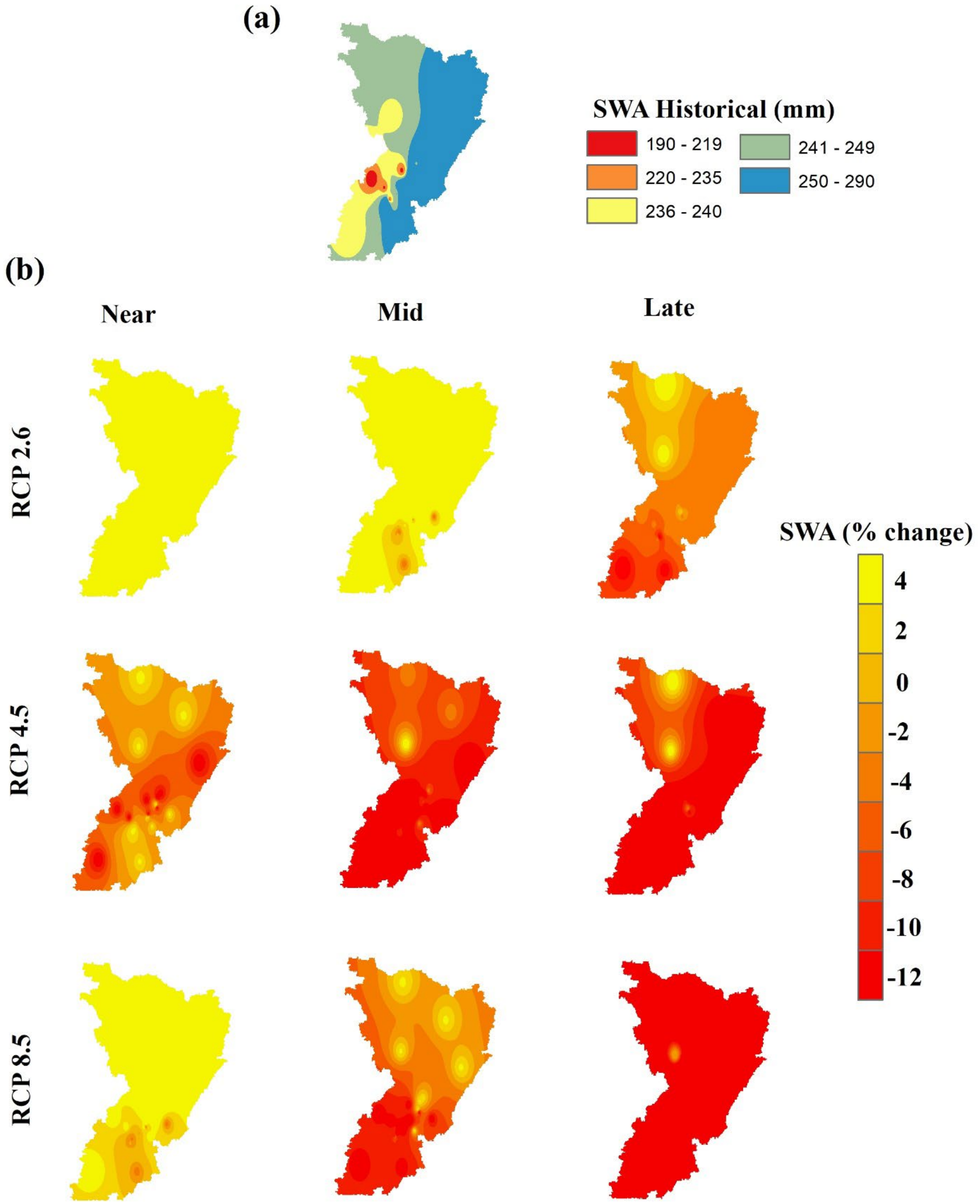
SPEI Values	Category
≥ 2.0	Extremely wet
1.5 to 1.99	Severely wet
1.0 to 1.49	Moderately wet
0.0 to 0.99	Mild wet
-0.99 to 0.0	Mild dry
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
≥ -2.0	Extremely dry

Time series plot of SWA



- SWA within a soil depth of 1.0 m from 1980 to 2100

Spatial Trends - SWA



Annual spatial distribution of SWA during the

- **historical (1980–2010)**
- **the near-future (2025–2049)**
- **mid-century (2050–2074)**
- **late-century (2075–2100)**

under RCP 2.6, RCP 4.5, and RCP 8.5 scenarios

Efficiency Analysis

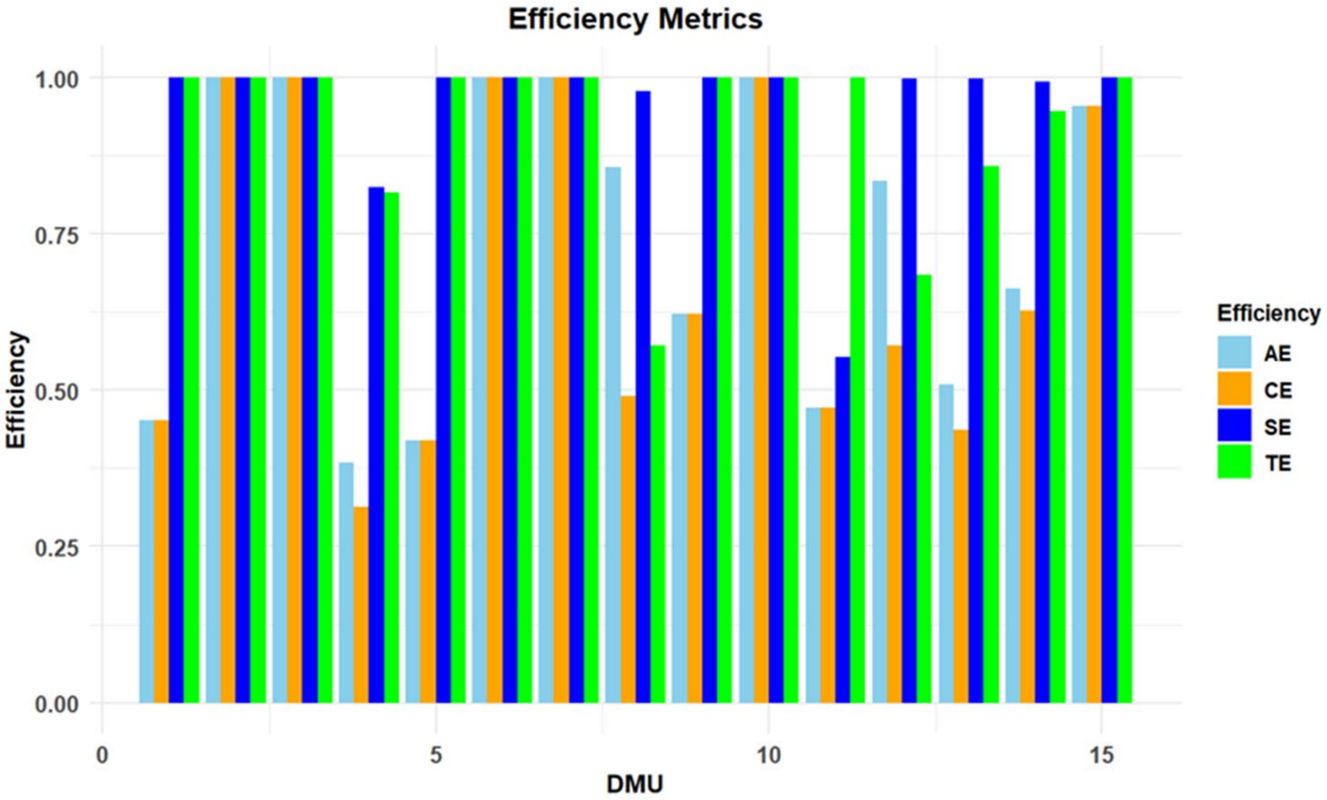
Surveyed **37 farms** and conducted **Data Envelopment Analysis (DEA)** to evaluate their:

- Technical efficiency (TE),
- Allocative and cost efficiency,
- Environmental and scale efficiency.

Most farms had **high TE (~95%)**, but lagged in **allocative and environmental efficiency**, often due to fertilizer overuse, poor irrigation practices, and scaling issues.

Efficiency Metrics shows Technical Efficiency (TE), Cost Efficiency (CE), Allocative Efficiency (AE), and Scale Efficiency (SE).

Value ranges from 0 to 1



Conclusion and Future Direction

This integrated assessment of the Upper Humber River Watershed (UHRW) reveals that climate change will have significant implications for both hydrological dynamics and agricultural sustainability in boreal regions.

- **Hydrological Findings:** SWAT model calibration and validation showed strong performance, supporting reliable projections. All RCP scenarios project increases in both **precipitation and temperature**, with **RCP 8.5** showing the most pronounced changes. Correspondingly, **streamflow is projected to increase**, particularly during snowmelt seasons.
- **Decline in Soil Water Availability:** Despite higher precipitation, **soil water availability is projected to decrease** under all RCP scenarios driven largely by rising temperatures and increased evapotranspiration. This trend poses a substantial challenge for water retention and agricultural resilience.
- **Farm Efficiency and Sustainability:** Data Envelopment Analysis indicates **high technical efficiency** among local farms. However, **cost, scale, and environmental efficiencies** vary significantly, highlighting the need for optimized resource use and adoption of climate-resilient practices.
- **CMIP6 climate data** to study impacts on specific crops, analyze effects of extreme weather events on agricultural productivity

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- SGS-MUN

PhD Supervisory Committee members

External Partner :

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Thank You

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