Forecasting Hydrological Processes under Combined Climate and Land-Use/Cover Change Scenarios

Babak Farjad [1], Anil Gupta [2], and Danielle Marceau [3]

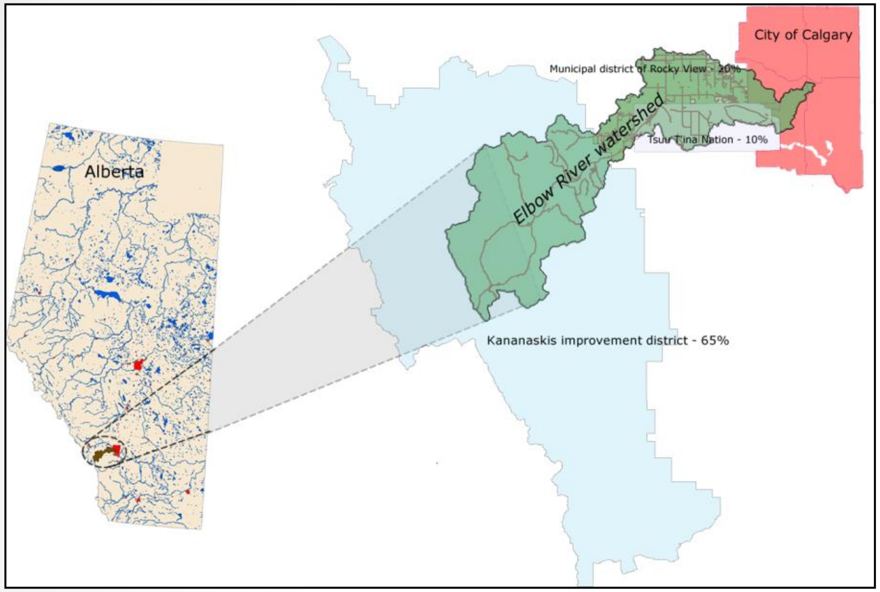
[1,3] Department of Geomatics Engineering, University of Calgary, 2500 University Drive NW, Calgary, AB, Canada T2N 1N4

[2] Alberta Environnent and Parks, Calgary, AB, Canada AB T3L 1S4

bfarjad@ucalgary.ca

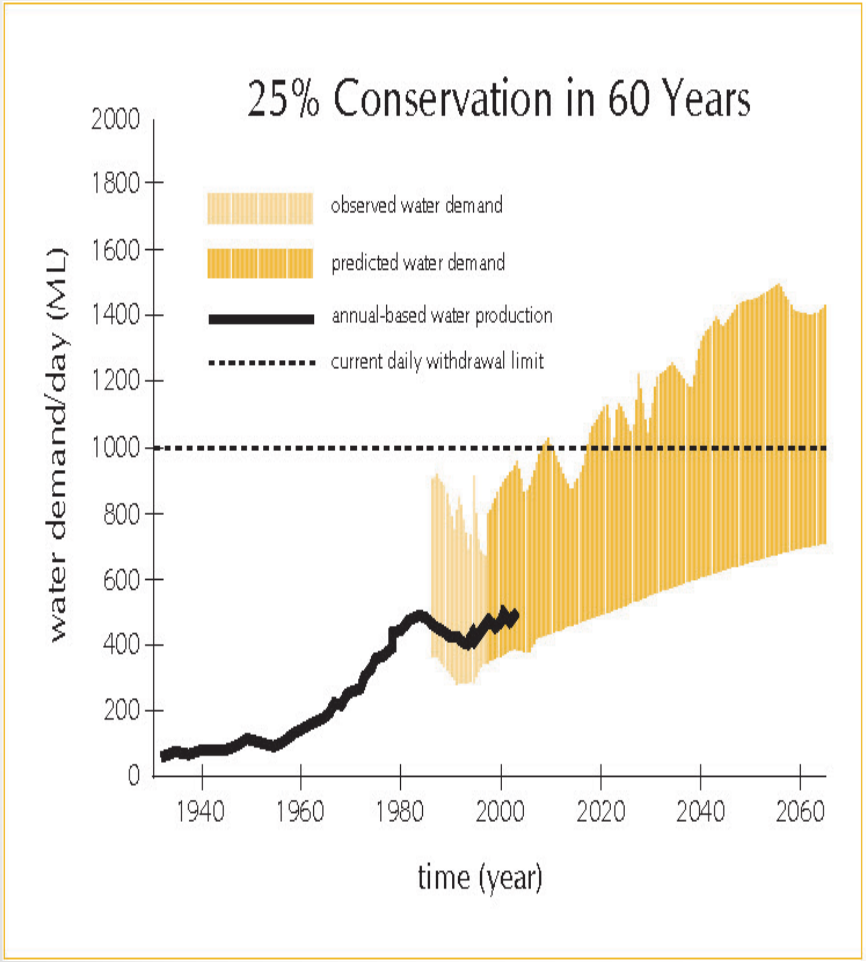
November 10, 2016

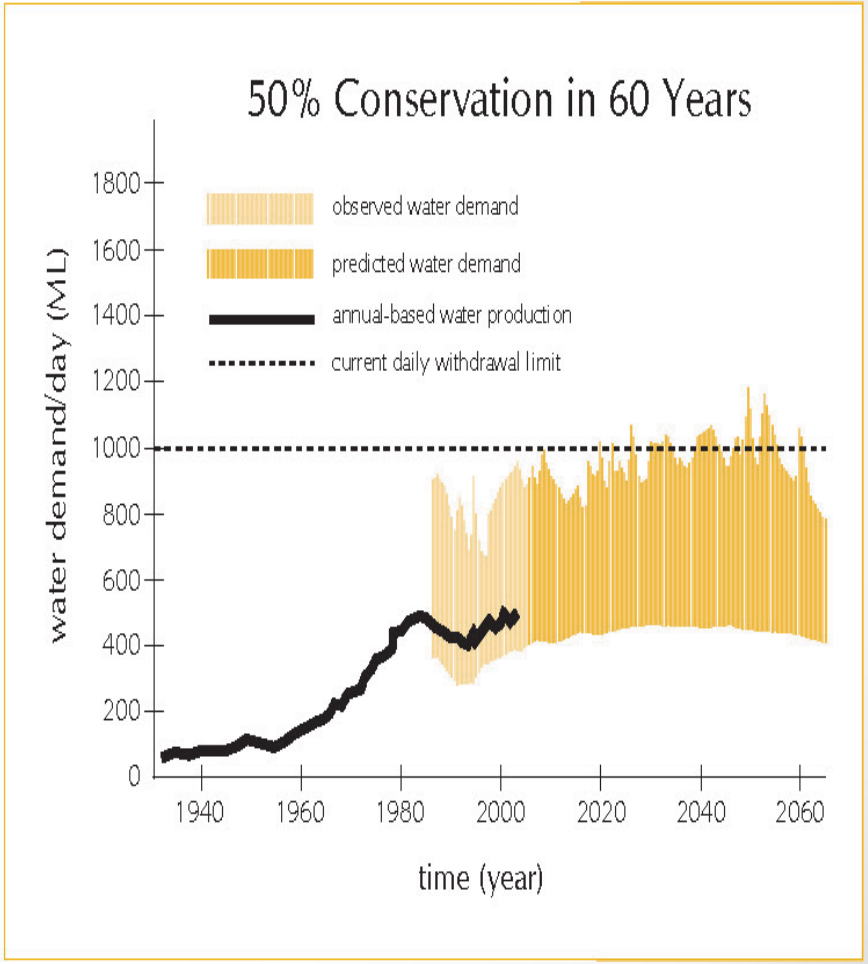
The Elbow River watershed



- The Elbow River watershed in southern Alberta covers 1,200 km^2.
- It supplies the Glenmore Reservoir that provides water to nearly half of Calgary.
- it is subjected to considerable pressure for land development due to the rapid population growth in the City of Calgary.
- The spatial heterogeneity of the land surface and geomorphological characteristics of the watershed such as shape, topography, stream patterns, and density varies substantially from west to east.

The Elbow River watershed: Issue (1)





Source: Natural Resources Canada

The Elbow River watershed: Issue (2)

- Heavy rainfall along with snowmelt contributed to the flood peaks in the Elbow River watershed and flooding in Calgary in 2005 and 2013.

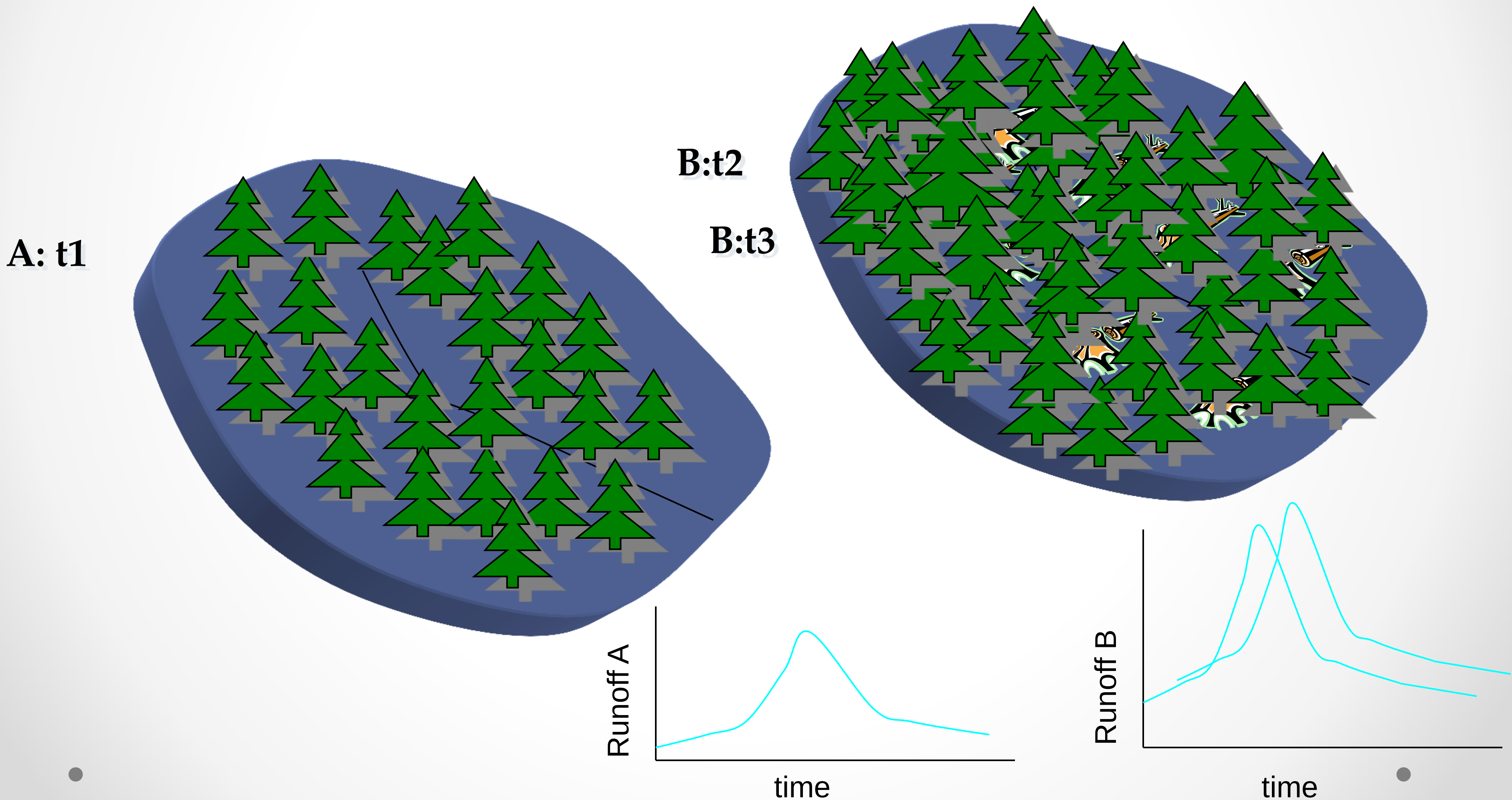
Photos by CTV news

- The 2005 flood in Calgary resulted in $17.2 million damage; approximately 1,500 Calgarians were evacuated.

- In 2013, the Elbow River was flowing through Calgary at 12 times the regular rate causing $400 million of damages, and the evacuation of 100,000 people.

(City of Calgary)

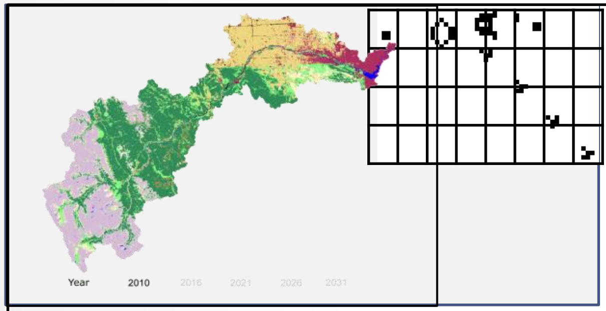
Land-use/cover change impacts



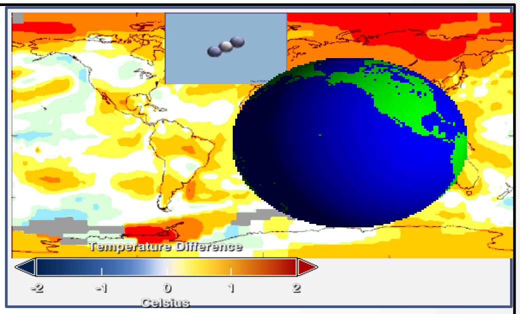
Objective

- The objective of this research is to understand the responses of hydrological processes to climate and land-use/cover (LULC) change in the Elbow River watershed using an integrated modeling framework approach.

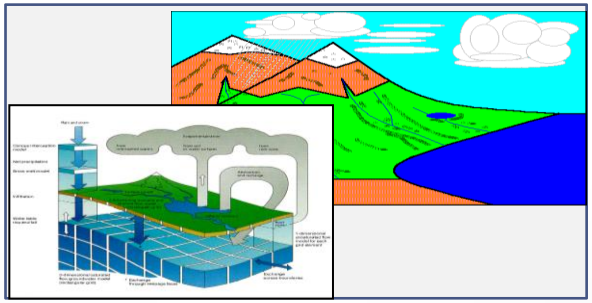
CA land-use/cover model



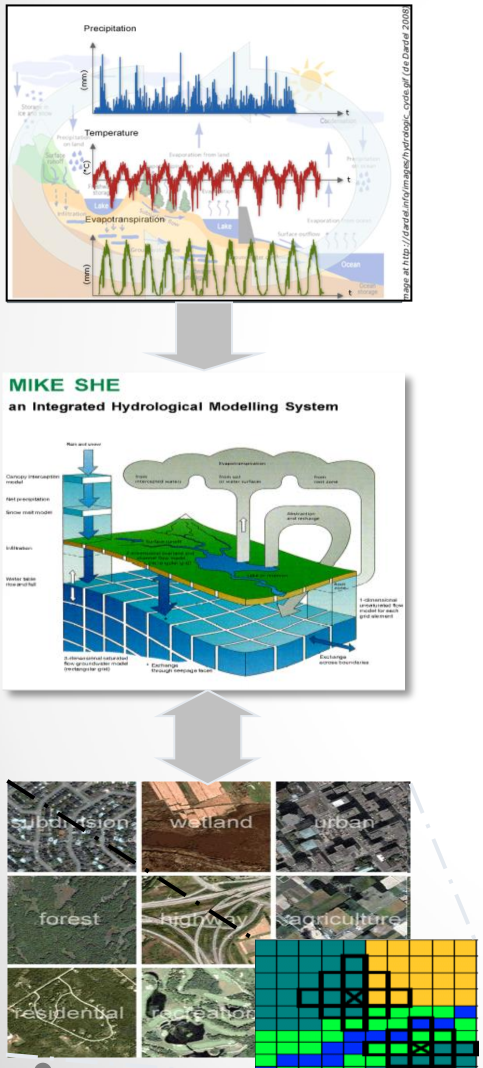
GCMs



MIKE SHE/MIKE 11 model



Objective



- ❑ The following steps are performed:

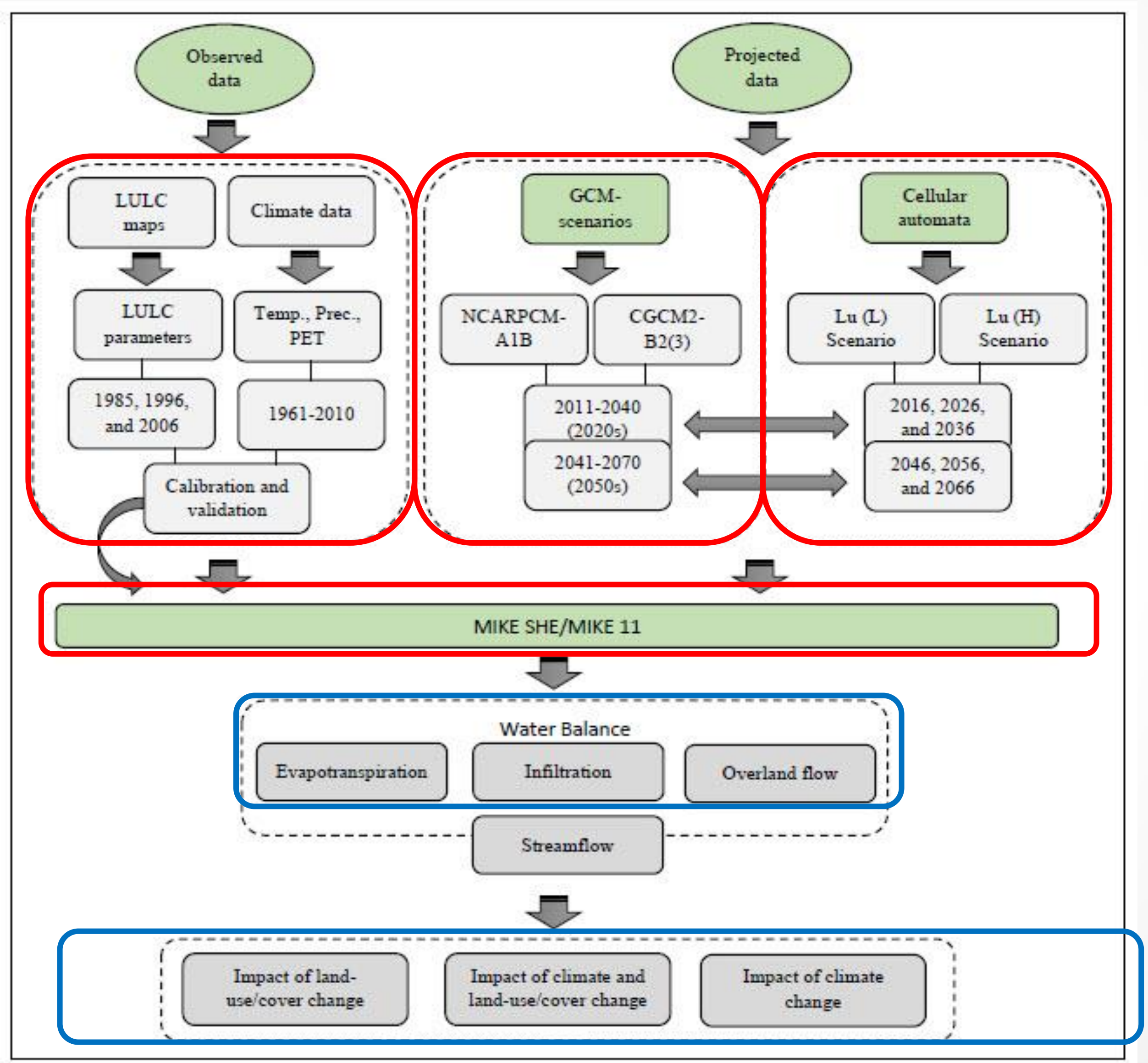
- ❑ Investigate hydrological responses due to climate change in the 2020s and 2050s, relative to the period of 1961-1990.

- ❑ Project LULC changes in the watershed for the period of 2020s and 2050s.

- ❑ Investigate the combined and separate impact of climate and LULC change on hydrological processes.

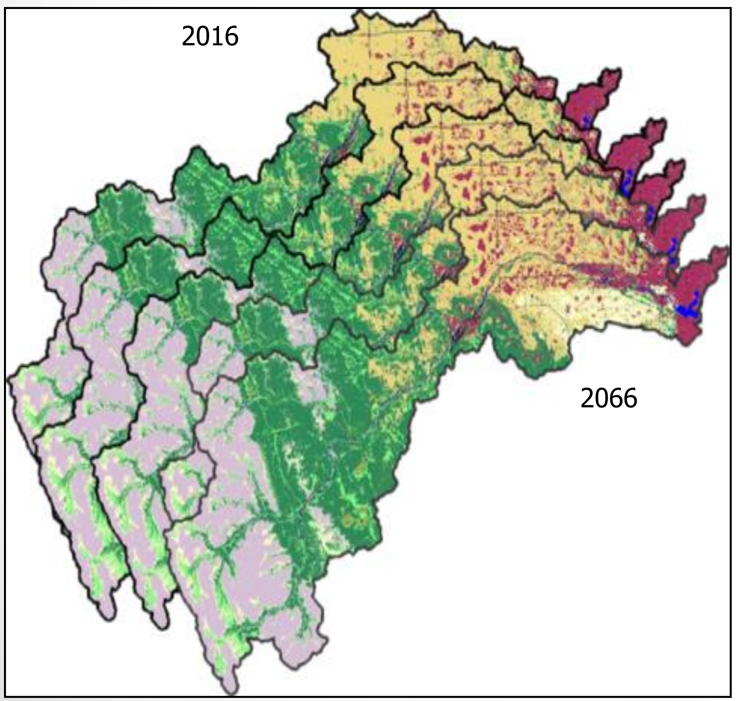
Methodology

Methodological framework



Cellular Automata model: approach

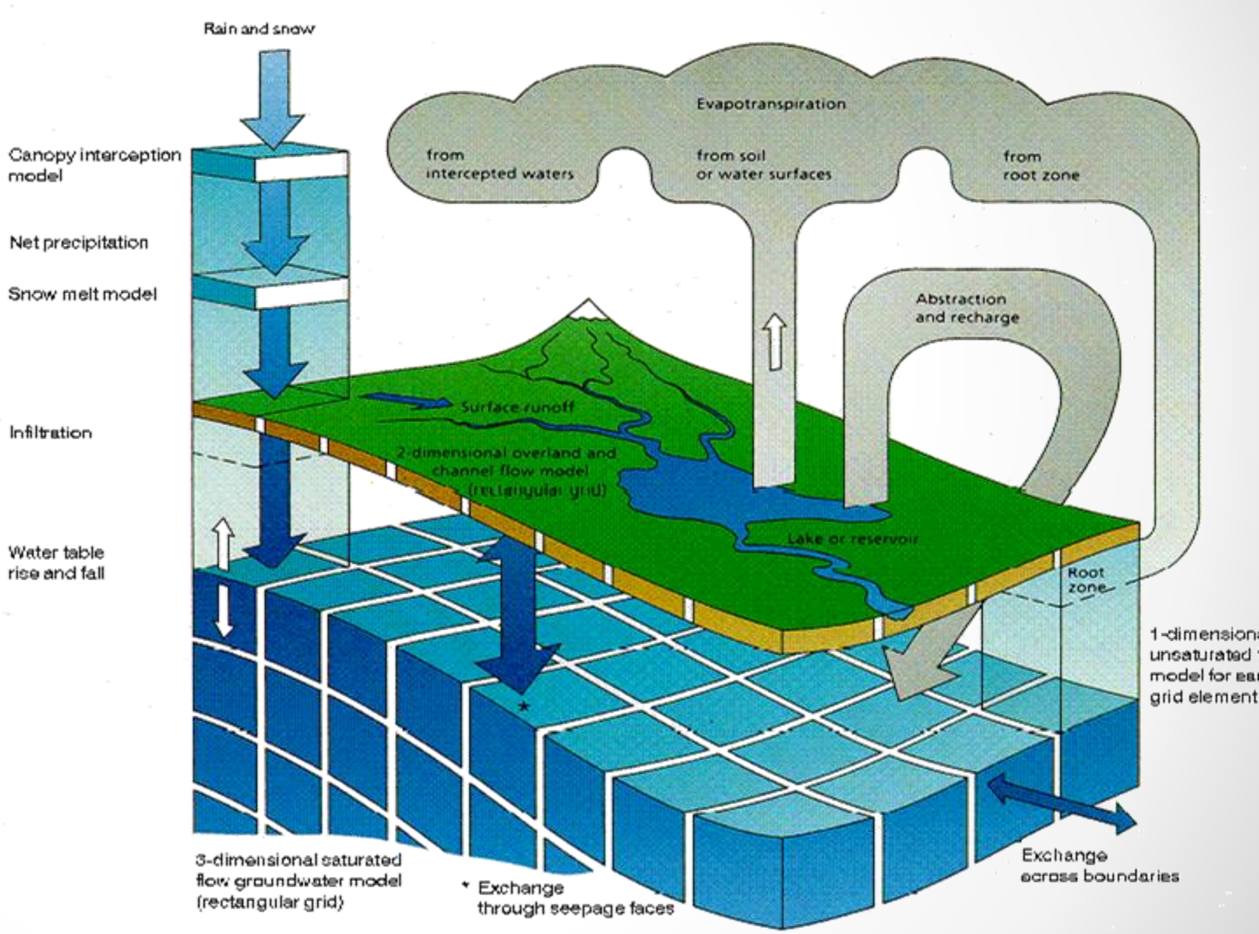
- LULC maps of 1985, 1992, 1996, 2001, 2006 were used for calibration; LULC map of 2010 was used for validation
- The CA model was used to produce LULC maps for the years: 2016, 2026, 2036, 2046, 2056, and 2066.



- Detention storage – Spatially distributed
- Manning M (Surface roughness coefficient) – Spatially distributed
- Leaf Area Index (LAI) – Spatially and temporally distributed
- Root depth (RD) – Spatially and temporally distributed

The hydrological model: MIKE SHE/MIKE 11

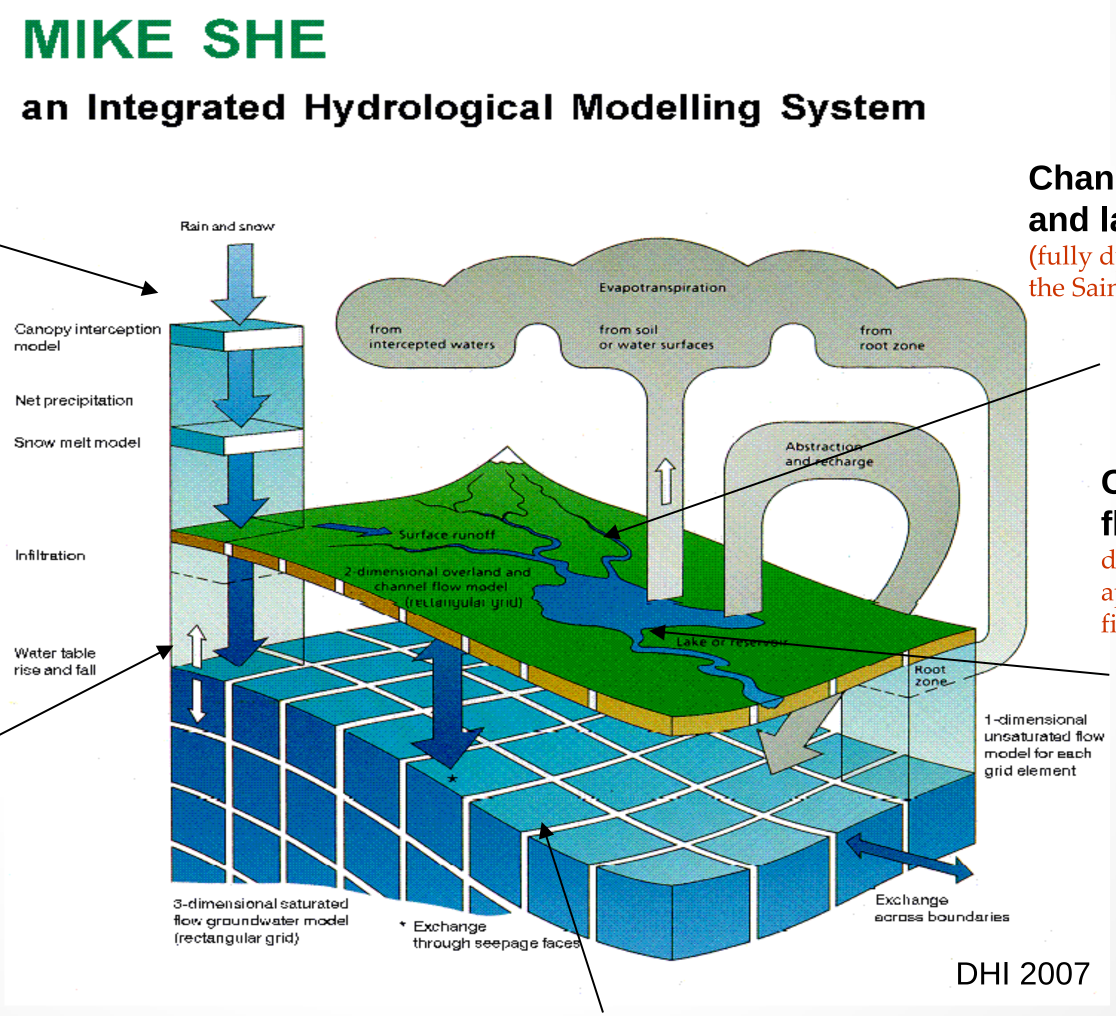
- Fully-coupled groundwater and surface water models
- Represents all of the major processes of the land-based portion of the hydrologic cycle
- Fully distributed in space and time



The hydrological model: MIKE SHE/MIKE 11

Snowmelt (degree-day method)

Channel flow in rivers and lakes - MIKE-11 (fully dynamic wave version of the Saint-Venant equations)



Overland surface flow (two-dimensional diffusive wave approximation by the finite-difference method)

Evapotranspiration (coupled Simple water balance approach and Kristensen and Jensen model)

Unsaturated zone (Two-layer Water Balance Approach)

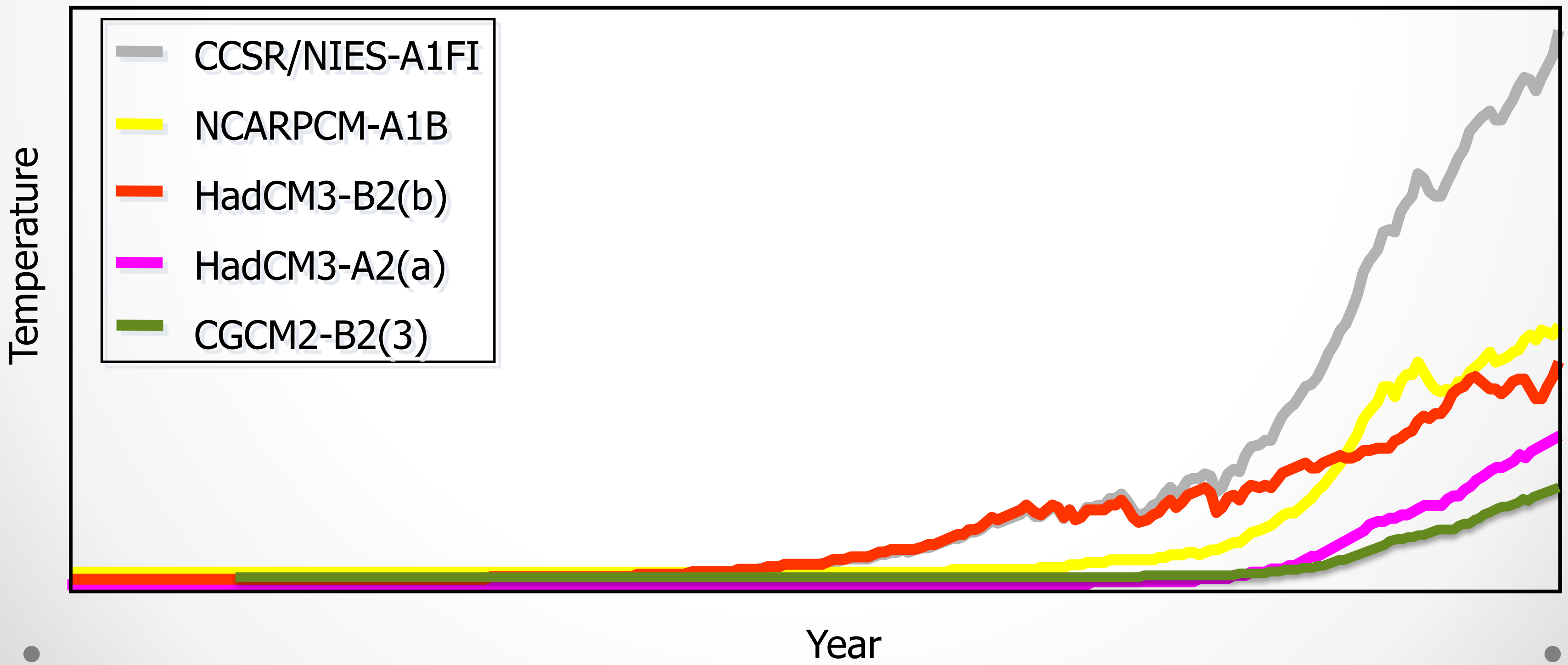
Saturated Zone (3D Darcy equations solved using a numerical finite-difference)

Hydrological modeling

- Calibration: 1981 – 1991 (land-use map of 1985)
- Validation:
  - 1991-1995 (land-use map of 1992)
  - 1995-2000 (land-use map of 1996)
  - 2000-2005 (land-use map of 2001)
  - 2005-2008 (land-use map of 2006)
- The goodness-of-fit was evaluated by comparing simulation results with observed data with:
  - Stream flow at four hydrometric stations
  - Groundwater levels
  - Total snow storage

Climate change scenarios

- Projected temperature and precipitation were obtained from AESRD for the 2020s and 2050s.
- The scenarios represent extreme changes in temperature and precipitation.

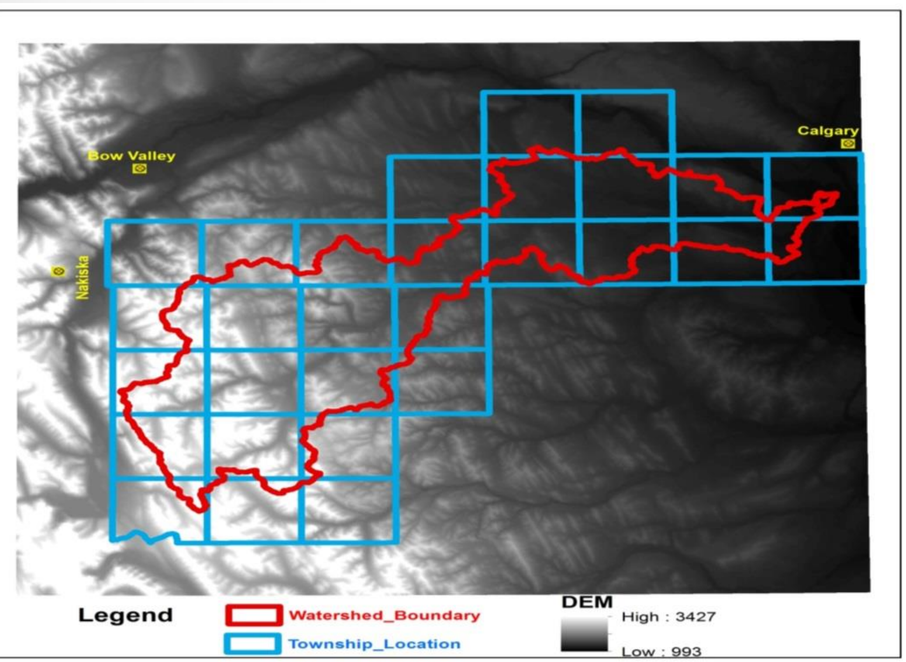


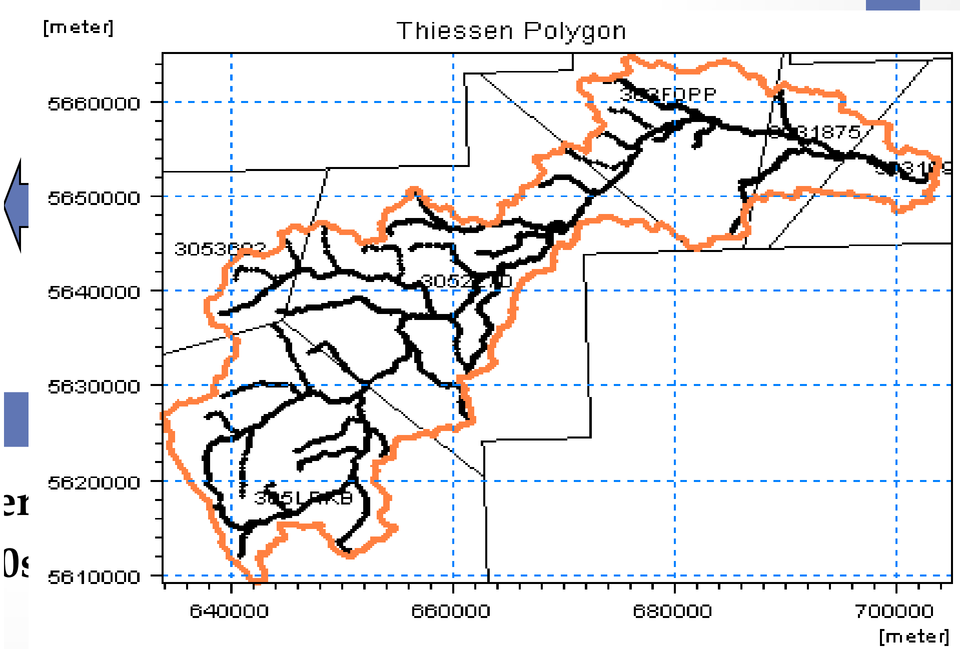
Climate variables

CCSRNIES_A1FI
CGCM2_B23
HADCM3_A2A
HADCM3_B2B
NCARPPCM_A1B

Temperature: 3 stations → Temp calculated for each township based on temp lapse rate

Precipitation : 6 stations → Distribution based Thiessen polygon



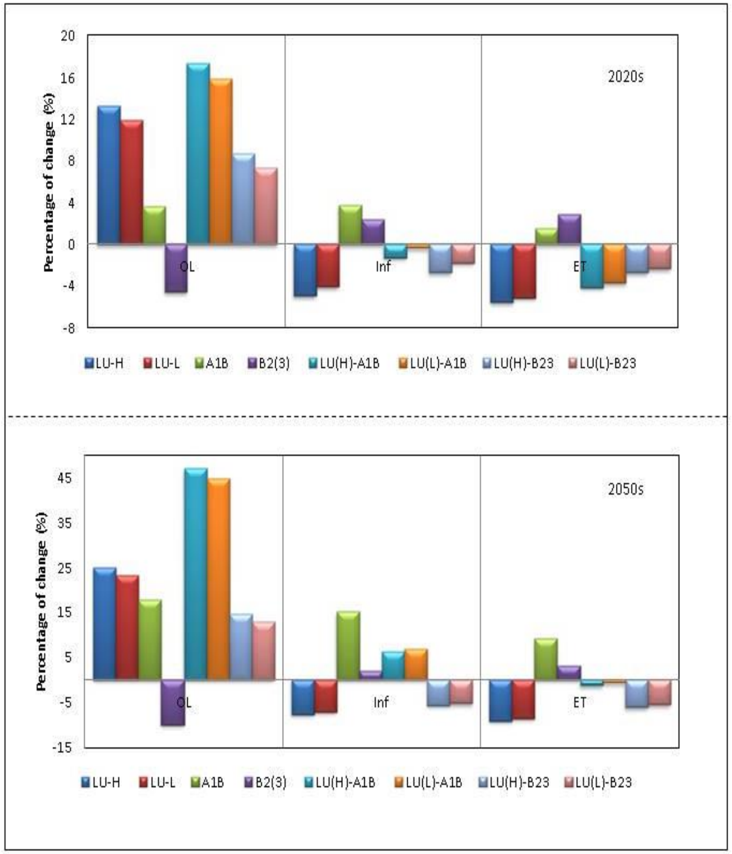


Results

Climate and LULC change impact: Annual variations

- In the 2020s, the impact of LULC change on evapotranspiration, infiltration, and overland flow is more significant than the impact of climate change

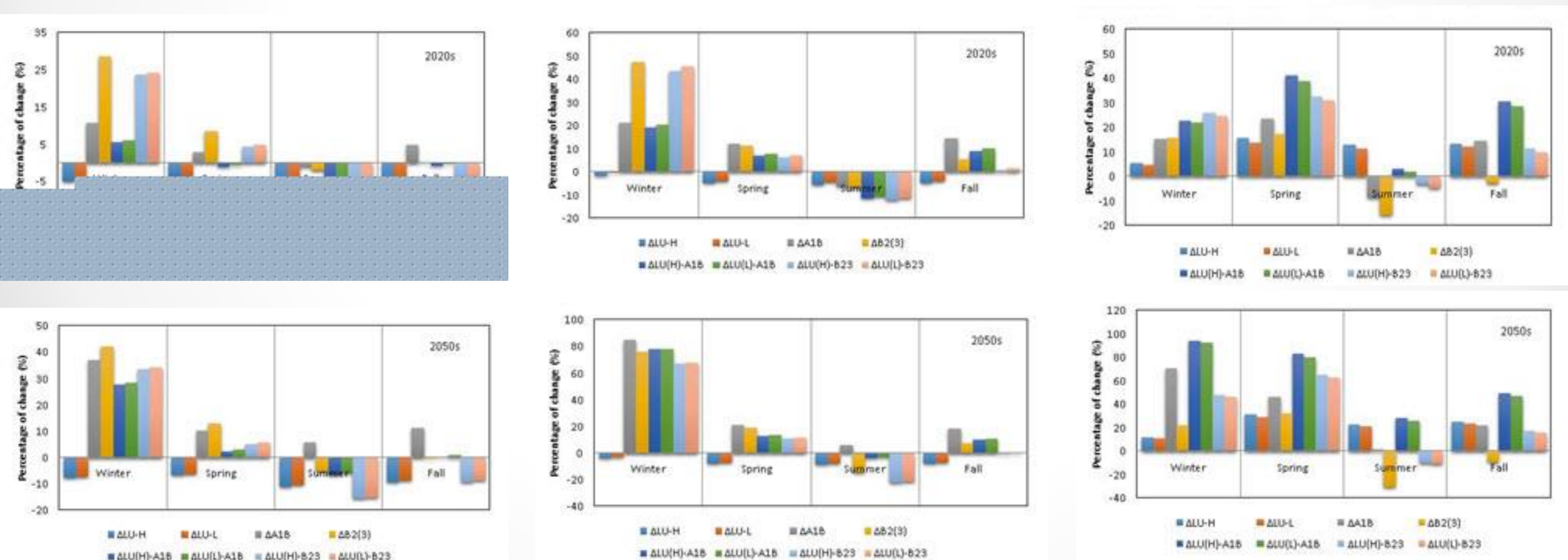
- In the 2050s, LULC change is also the dominant factor that impact evapotranspiration, infiltration, and overland flow, except with the A1B climate scenario



Climate and LULC change impact: Seasonal variations

- Evapotranspiration and infiltration are more strongly affected by both climate and LULC change in winter while overland flow is more impacted in the spring.
- The separated impacts of climate and LULC change on streamflow are positively correlated in winter and spring, which intensifies their combined influence.

AET Inf OL



Conclusion (1)

- Both land-use/cover and climate change are expected to substantially modify the hydrological regime of the watershed over the next 60 years annually and seasonally.

- The induced changes in hydrological processes under climate scenarios are proportionally more perceptible in the east sub-catchment compared to the west sub-catchment. However, the west sub-catchment governs the watershed behaviour and determines the future changes, over-riding the stronger climate change signal in the east.

- The shift in high streamflow from late spring-early fall to the middle of spring-summer could increase the risk of flooding, particularly in the lowlands in the east sub-catchment.

- The risk of flooding will be enhanced in mid-late spring, due to an increase in rain-on-snow events coinciding with the highest increase in spring freshet.

Conclusion (2)

- The decline in the east sub-catchment groundwater recharge can result in groundwater depletion, which is a concern when about 90% of licensed groundwater extractions are located in the east sub-catchment.
- The separated impacts of climate and LULC change on streamflow are positively correlated in winter and spring, which intensifies their combined influence.
- This is particularly the case in spring when the combined impact of climate and LULC results in a significant rise in streamflow, which may increase the vulnerability of the watershed to floods in this season.
- This study provides a comprehensive integrated modeling framework to understand the impact of both climate and land-use/cover change on the hydrology in the watershed. This could become a powerful analytical tool for decision makers.

References

- Farjad, B., Gupta, A., & Marceau, D. J. (2016). Annual and Seasonal Variations of Hydrological Processes Under Climate Change Scenarios in Two Sub-Catchments of a Complex Watershed. Water Resources Management, 30(8), 2851-2865.

- Farjad, B., Gupta, A., & Marceau, D. J. (2015). Hydrological Regime Responses to Climate Change for the 2020s and 2050s Periods in the Elbow River Watershed in Southern Alberta, Canada. In Environmental Management of River Basin Ecosystems (pp. 65-89). M. Ramkumar, K. Kumarasamy, and R. Mohanraj, Eds, Springer International Publishing.

- Wijesekara, G. N., Farjad, B., Gupta, A., Qiao, Y., Delaney, P., & Marceau, D. J. (2014). A Comprehensive Land-Use/Hydrological Modeling System for Scenario Simulations in the Elbow River Watershed, Alberta, Canada. Environmental Management, 53(2), 357-381.

Thanks for your attention!