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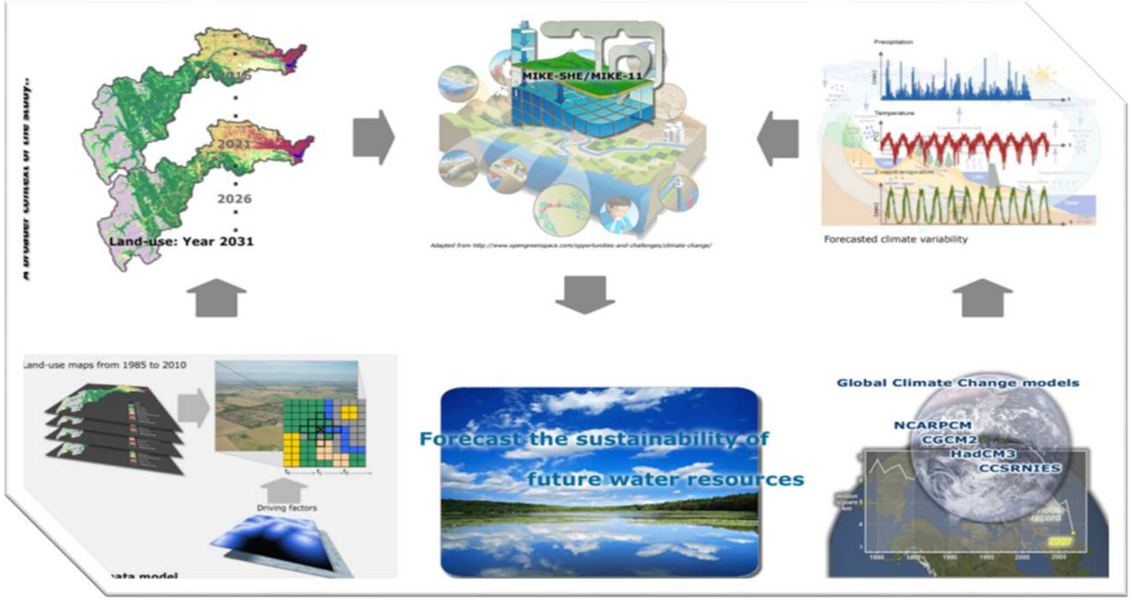


Investigating the impact of climate variability and land-use change on hydrological processes in the Elbow River watershed, Alberta, Canada

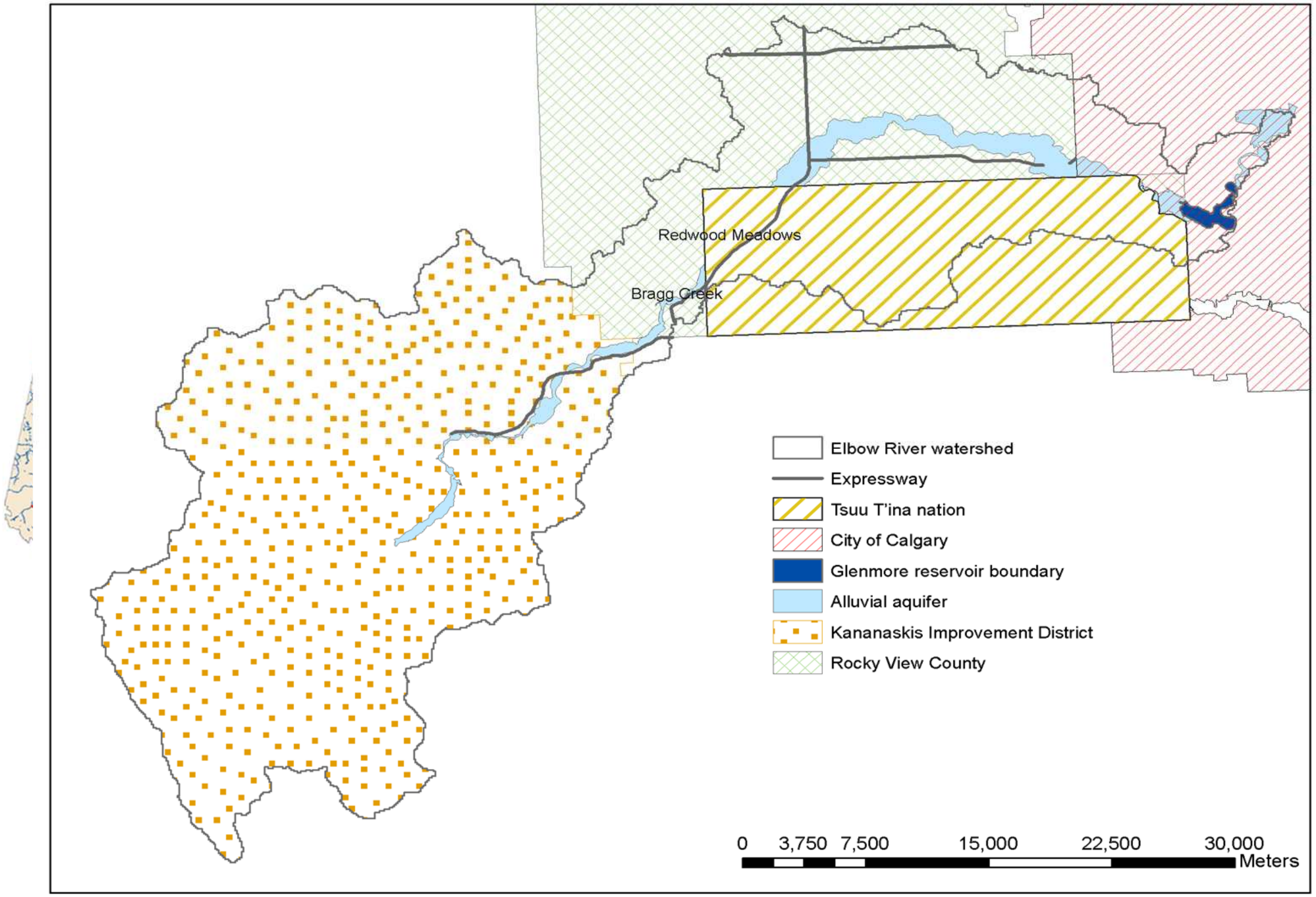
G. N. Wijesekara[1], B. Farjad[1] A. Gupta[2], P. Delaney[3], J. G. Hasbani[1], and D. J. Marceau[1]

([1]University of Calgary, [2]Alberta Environment, [3]Danish Hydraulic Institute)

HydroPredict – 2012

September 24 – 27, 2012, Vienna, Austria

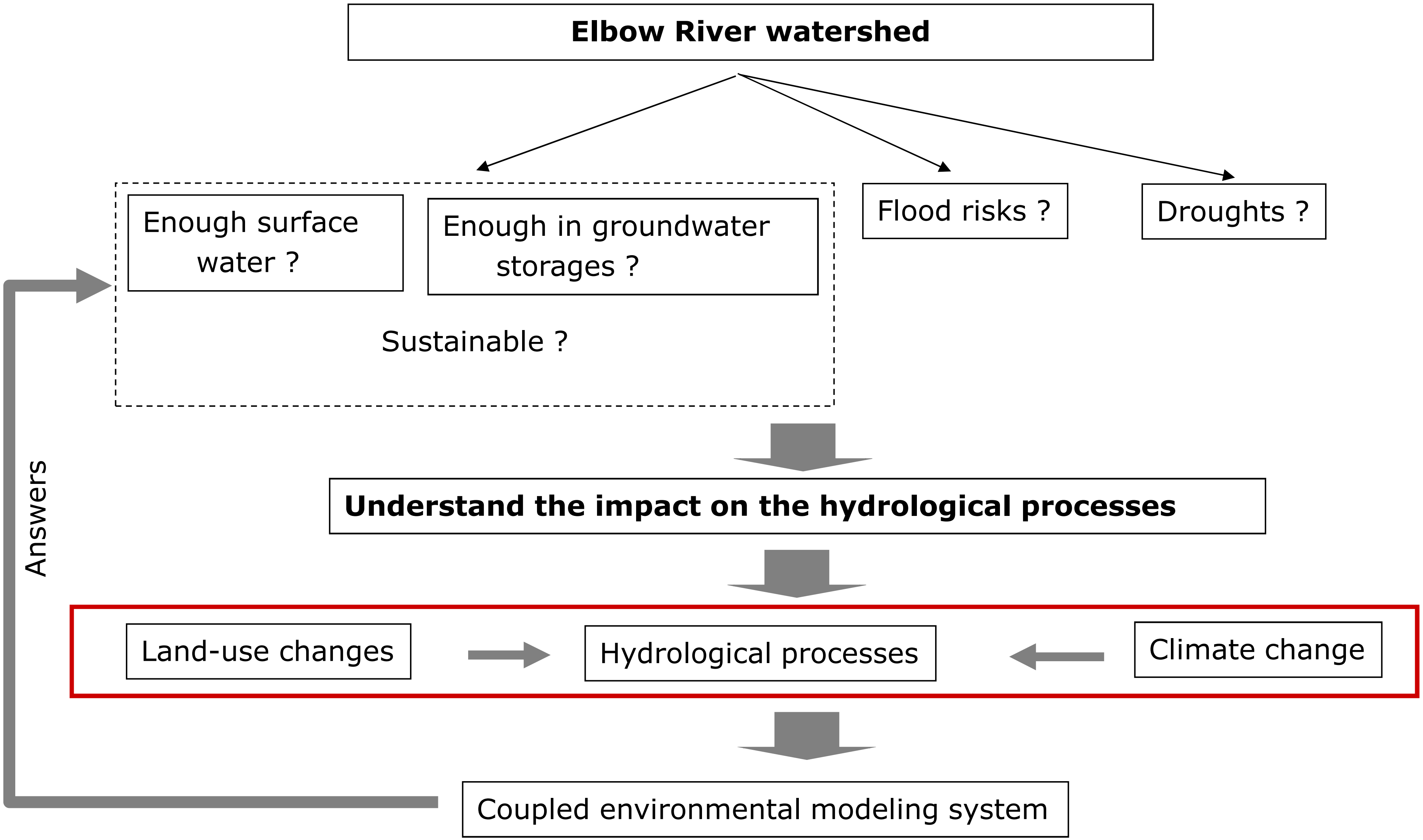
Study Area


Redwood Meadows
Bragg Creek
Elbow River watershed
Expressway
Tsuu T'ina nation
City of Calgary
Glenmore reservoir boundary
Alluvial aquifer
Kananaskis Improvement District
Rocky View County
0 3,750 7,500 15,000 22,500 30,000
Meters

Context of the study

- The Elbow River provides drinking water to 1 in 6 Albertans.
- Rapid population growth and urbanization in the Calgary region.
- Climate warming + its effect on glaciers + snow packs and evaporation + cyclic droughts + rapidly increasing human activity => a crisis in water availability (Schindler and Donahue 2006).

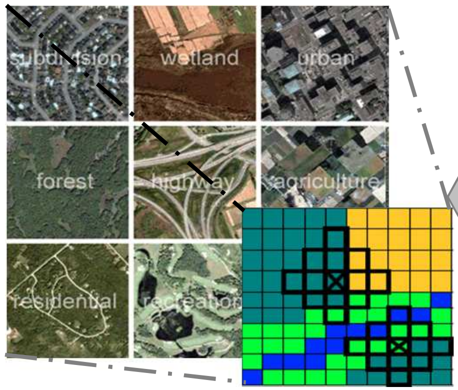
Context of the study(2)



Models

Land-use change model:

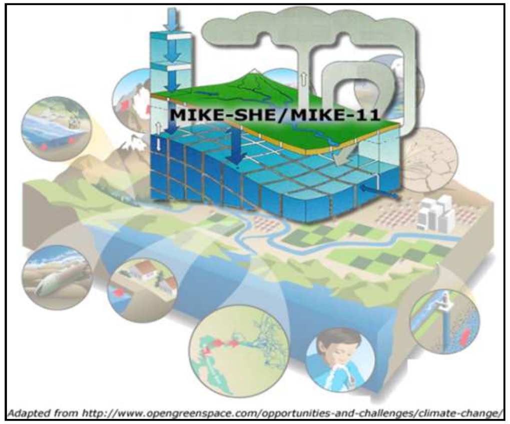
Cellular Automata



- Disaggregated
- Spatially explicit

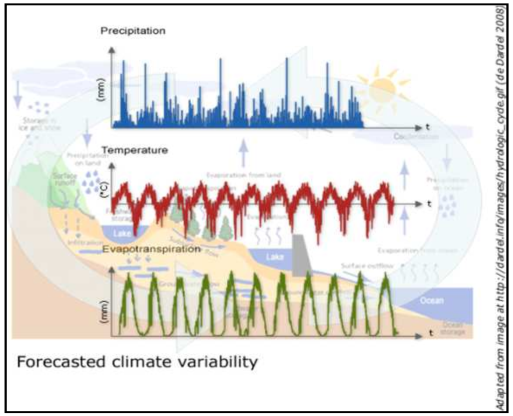
Hydrological model:

MIKE-SHE/MIKE-11



- Distributed
- Physically based

Climate variability

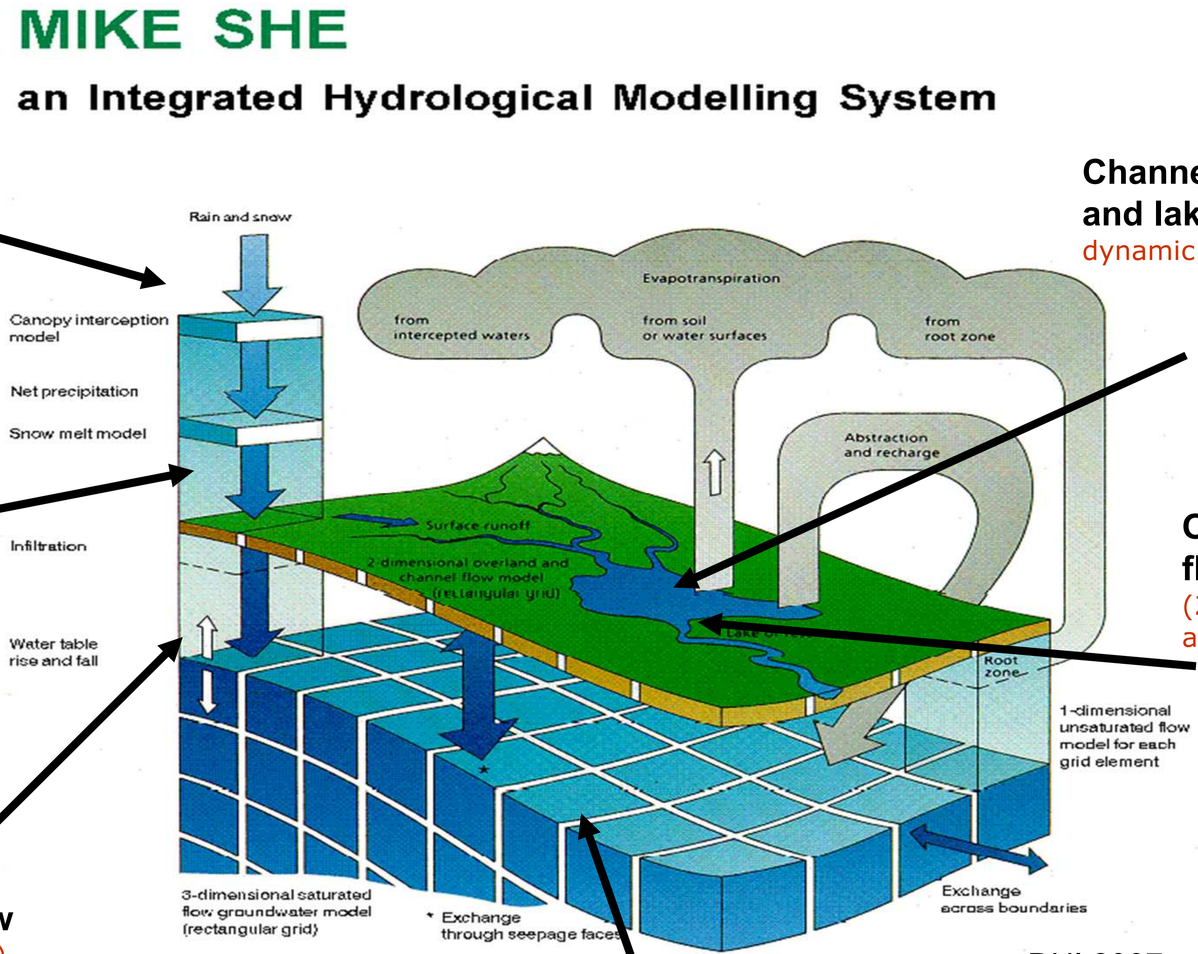


Elbow River watershed hydrology model (ERWHM)

Precipitation and snowmelt (Modified degree-day method)

Vegetation based evapotranspiration and infiltration (Simple water balance approach (two-layer UZ)

Unsaturated groundwater flow (Two-layer Water Balance Approach)



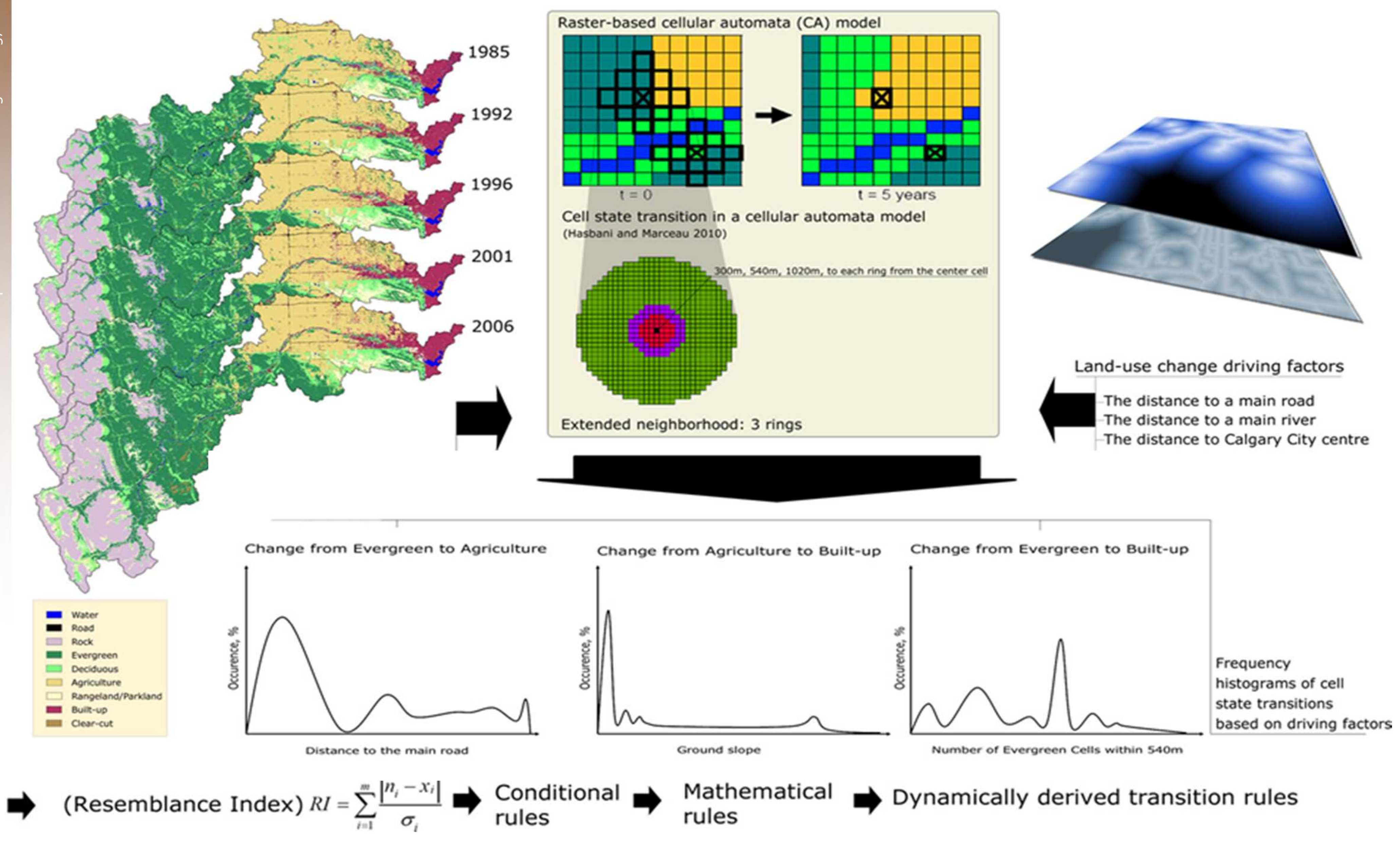
Channel flow in rivers and lakes - MIKE-11 (Fully dynamic wave approximation)

Overland surface flow and flooding (2D diffusion wave approximation)

DHI 2007

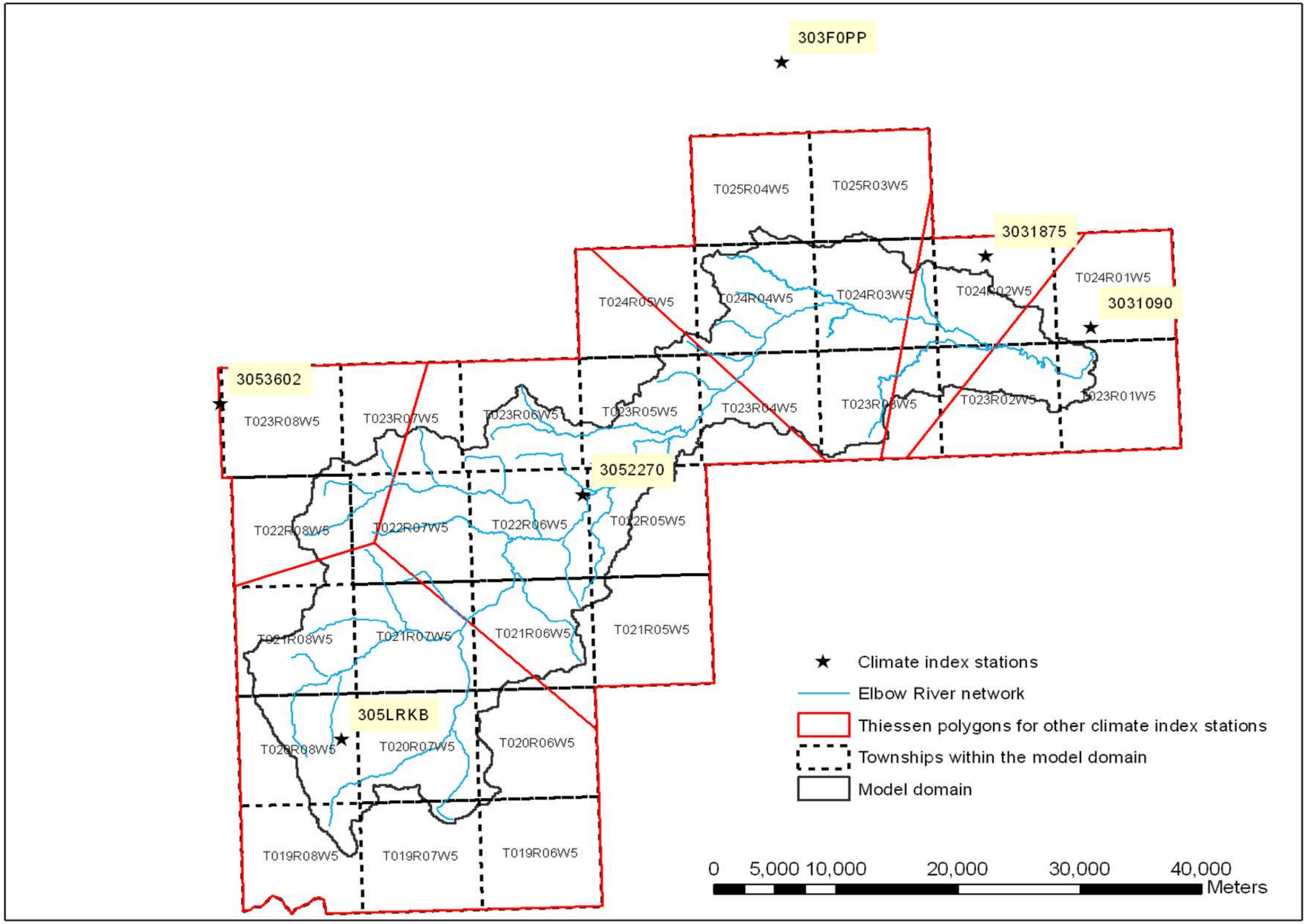
Saturated groundwater flow (3D Darcy equation)

Land-use Cellular Automata model



Climate variability

CCSRNIES_AiF1
CGCM
HADC
HADC
NCARP



n data
for the period: 2011 - 2035

Calibration and Validation

ERWHM:

- 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)
- Stream flow comparison - Nash and Sutcliffe coefficient of efficiency (NSE) at 4 hydrometric stations => Average of 0.63 (Calibration and validation) for daily data, 0.74 for monthly data
- Total snow storage comparison – Correlation coefficient at one station => average of 0.89 for calibration and 0.8 for validation
- Due to computational intensity, the model is calibrated at 200m grid.

Calibration and Validation (2)

- Land-use CA model

  - Considered land-use transitions:

    - ✓ Evergreen => Agriculture
    - ✓ Deciduous => Agriculture
    - ✓ Evergreen => Built-up
    - ✓ Deciduous => Built-up
    - ✓ Agriculture => Built-up
    - ✓ Rangeland/Parkland => Built-up
    - ✓ Rangeland/Parkland => Agriculture
    - ✓ Agriculture => Rangeland/Parkland

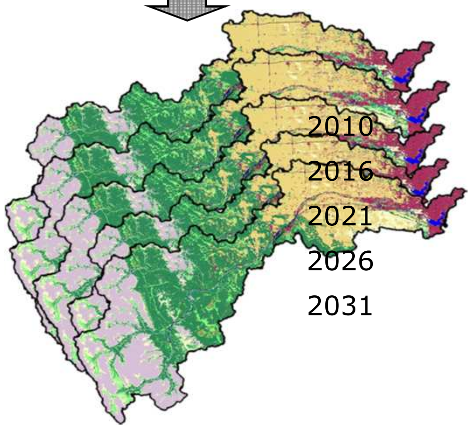
  - Calibrated using the data of 1985-2001, and land-use maps of 2006, 2010 were simulated using the base map of 2001.
  - Validated by comparing the simulated maps of 2006 and 2010 with the corresponding reference maps => 96% and 91% correspondence respectively.

Calibration and Validation (3)

- ET model
  - The Hargreaves- Samani, Thornthwaite, and Blaney-Criddle models were compared with the Priestley-Taylor model as a reference model provided by Alberta Environment.
  - The performances of the models were evaluated using linear regression analysis, Root Mean Square Error (RMSE), and Mean Bias Error (MBE)
  - The Hargreaves- Samani model was selected to calculate PET for the future
  - Hargreaves- Samani model:
    - calibration: 1961-1990: Coefficient of correlation of 0.89
    - Validation: 1990-2005 : Coefficient of correlation of 0.89

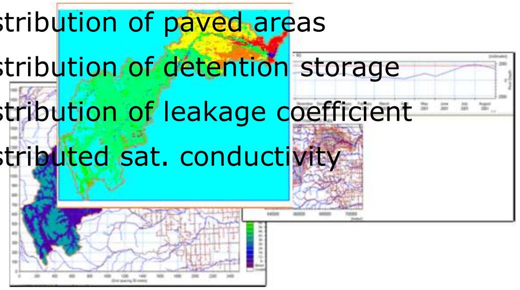
Simulations

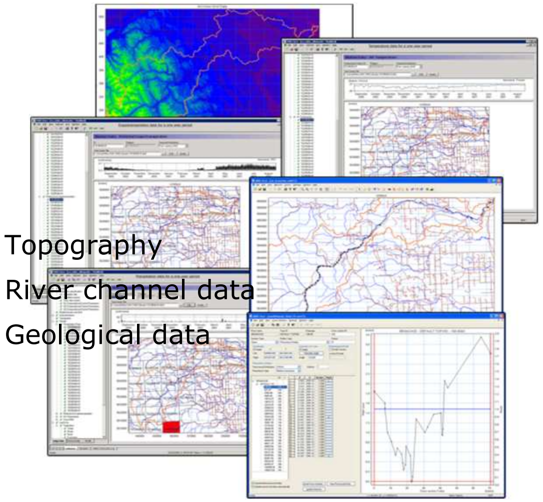
The land-use CA model (constrained)



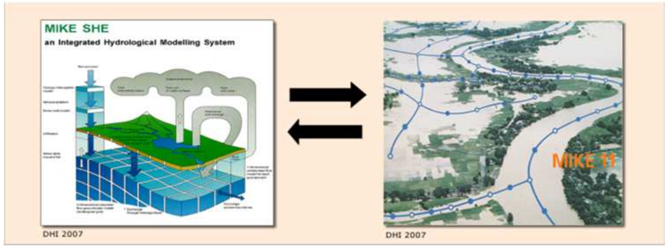
2010
2016
2021
2026
2031

Surface roughness
Distribution of LAI/RD
Distribution of paved areas
Distribution of detention storage
Distribution of leakage coefficient
Distributed sat. conductivity

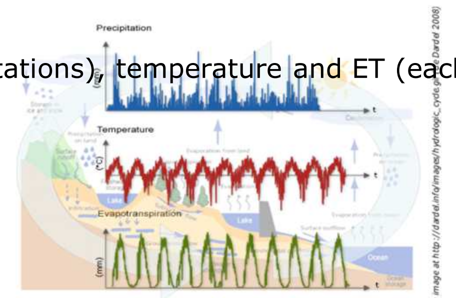




Topography
River channel data
Geological data

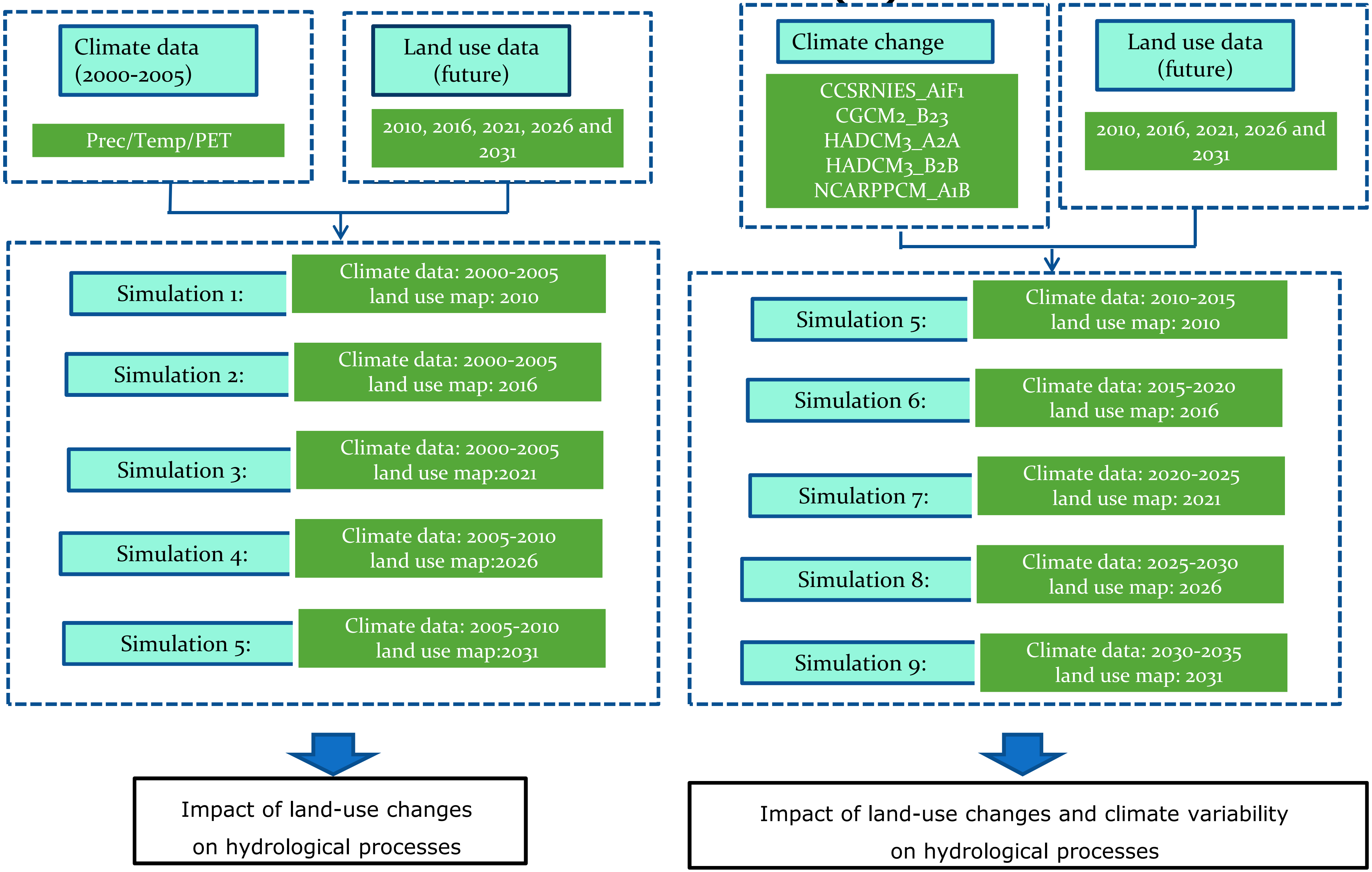


Forecasted prec (6 stations), temperature and ET (each township):
2010 – 2015
2015 – 2020
2020 – 2025
2025 – 2030
2030 - 2035



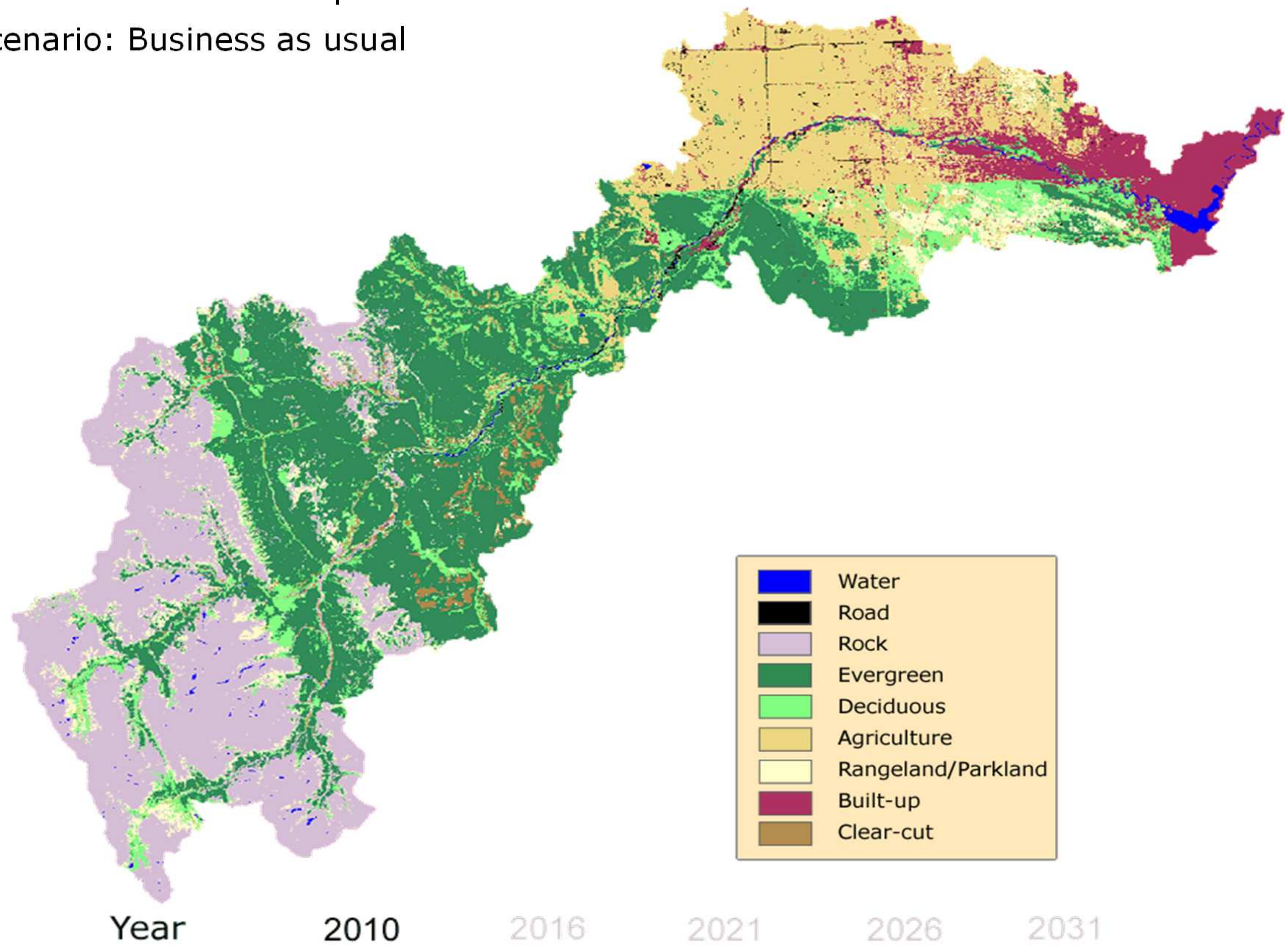
Forecasted climate variability

Simulations (2)



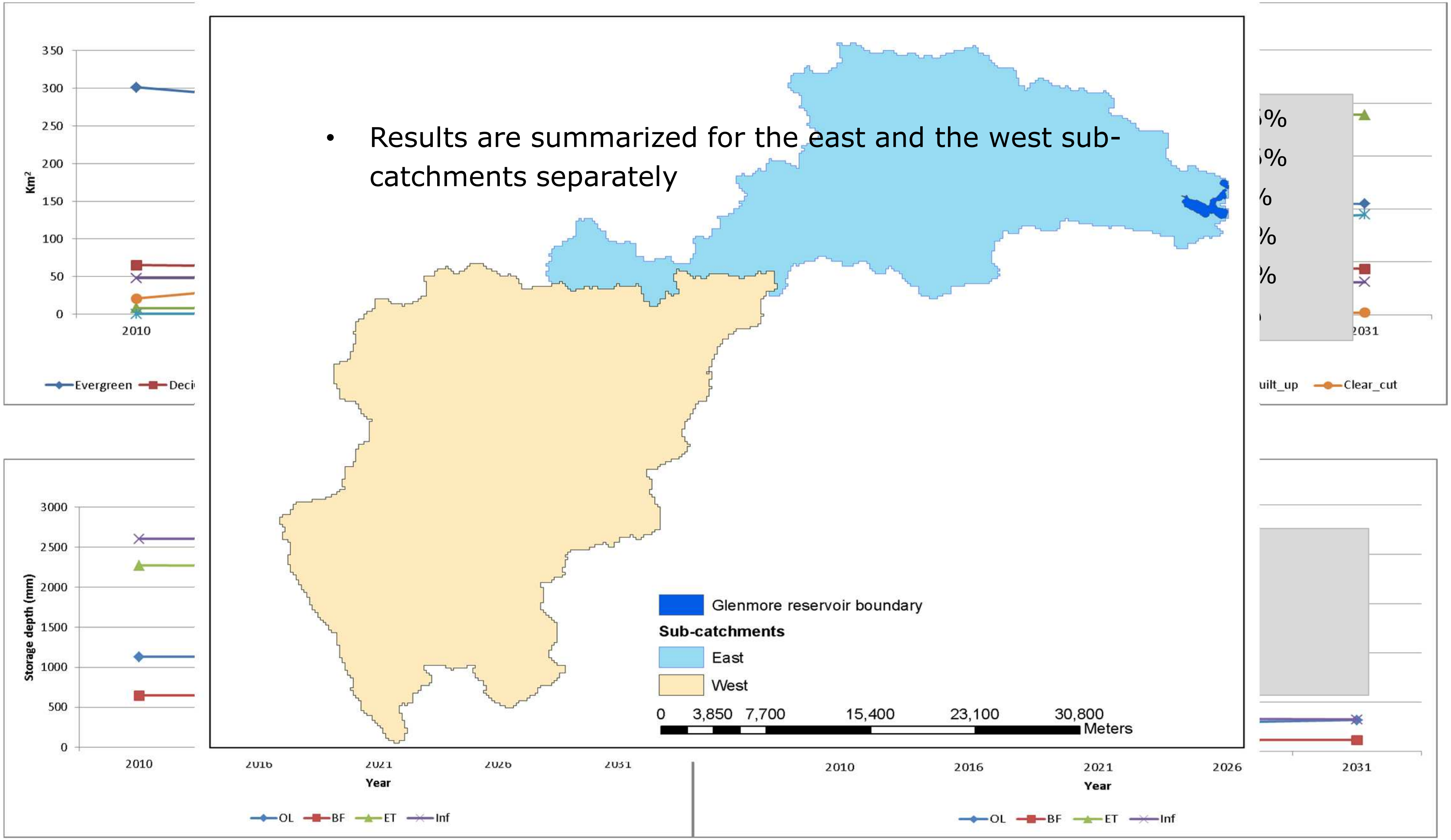
Simulated land-use changes

- Simulated land-use maps from 2010 to 2031
- Scenario: Business as usual



Impact of land-use changes on hydrological processes

- Results are summarized for the east and the west sub-catchments separately



OL – overland flow; Inf- Infiltration; ET – evapotranspiration; BF - baseflow

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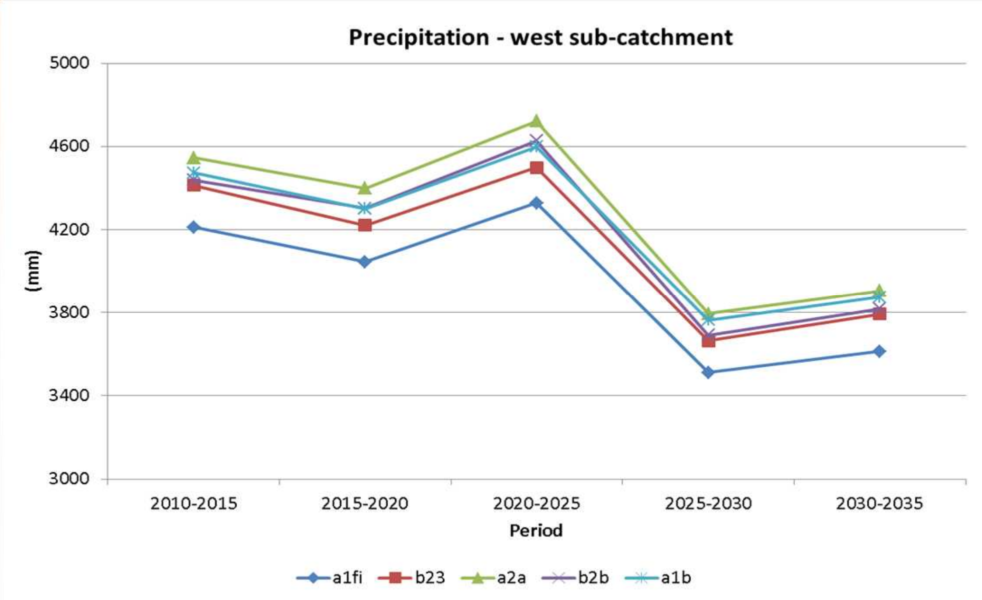
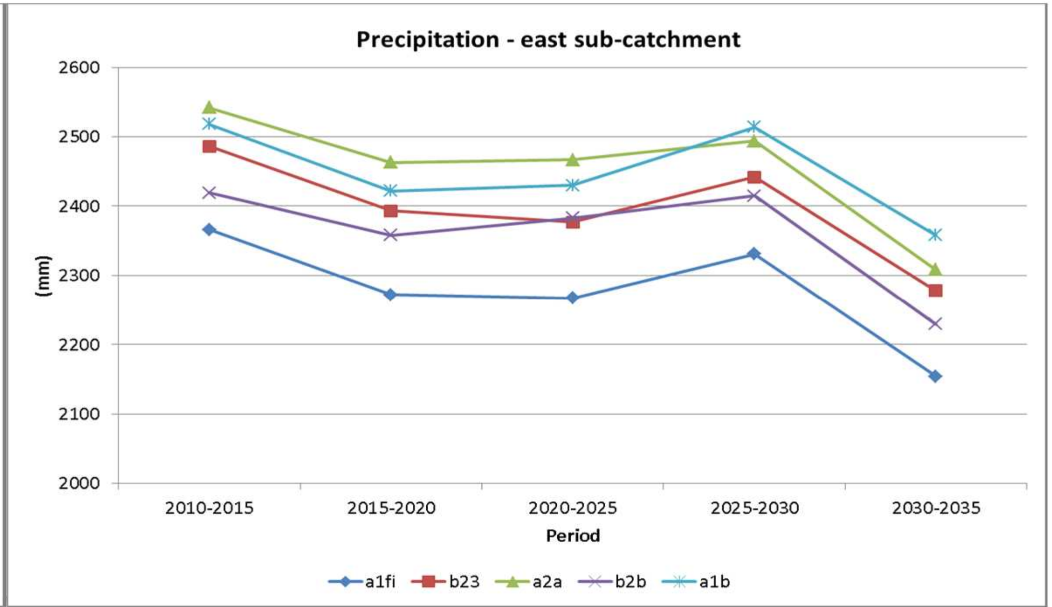
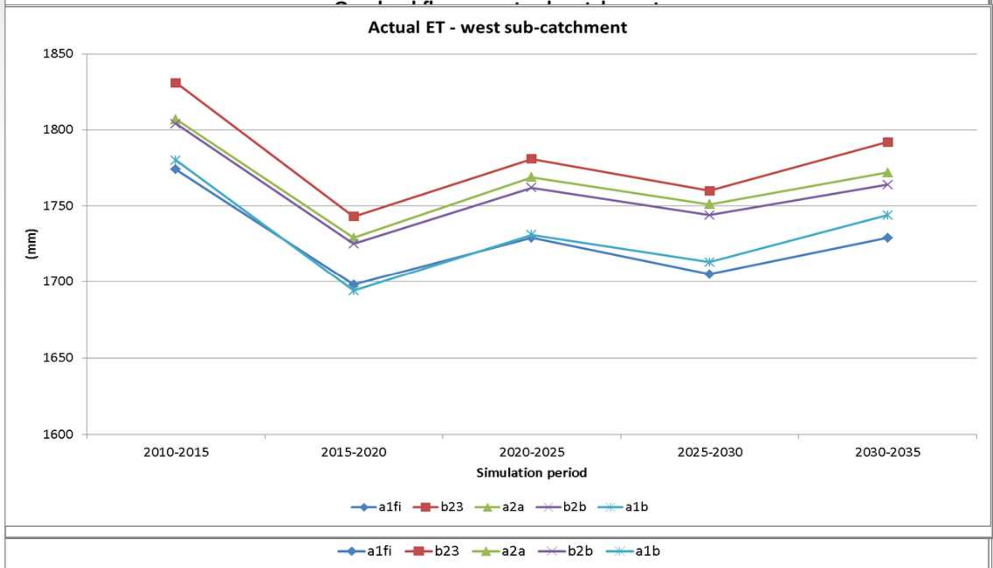
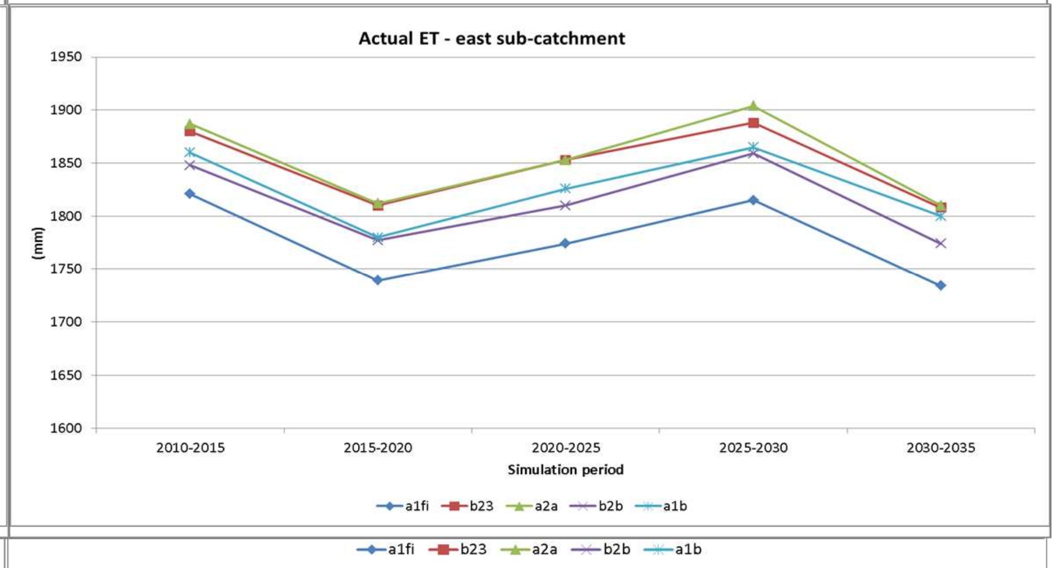
Impact of land-use changes and climate variability on hydrological processes









OL – overland flow; Inf- Infiltration; ET – evapotranspiration; BF - baseflow

Conclusion

- The impact of land-use changes on hydrological processes is:
  - ✓ Increase of OL, and decrease of Inf, BF, and ET
  - ✓ Due to considerable growth of urbanization and reduction forest areas
  - ✓ Considerable impact occur in the east sub-catchment

- The impact of land-use changes and climate variability on hydrological processes is:
  - ✓ West sub-catchment: impact of climate variability is dominant
  - ✓ East sub-catchment: impact of climate variability and land-use changes
  - ✓ East sub-catchment: generally the impact of land-use changes on the hydrological processes is accelerated due to the changes of climate variability

- The coupled model environment serves as a smart tool => analysis of lu-change/climate change scenario => more understanding
- This understanding is crucial for decision makers to ensure water resource sustainability of the Elbow River watershed.

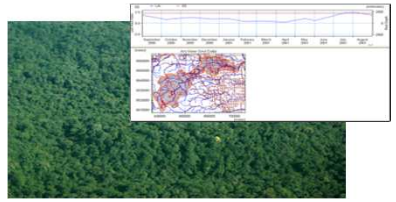
OL – overland flow; Inf- Infiltration; ET – evapotranspiration; BF - baseflow

Acknowledgements

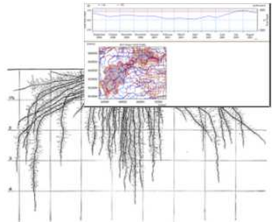
- This research is funded by several agencies:
  - Alberta Environment
  - GEOIDE (Network of Centres of Excellence in Geomatics)
  - Tecterra
  - DHI (in-kind contribution)
  - University of Calgary

Data collection (1)

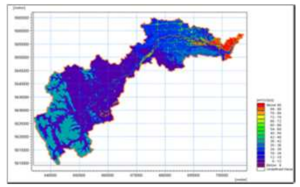
1. Leaf Area Index (LAI) – Spatially and temporally distributed



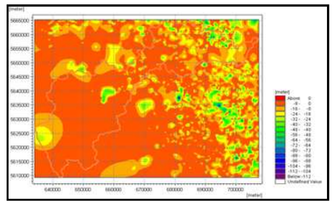
2. Root depth (RD) - Spatially and temporally distributed



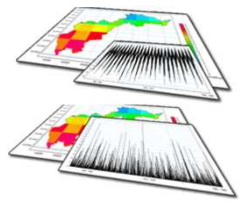
3. Manning number M (Surface roughness coefficient) – Spatially distributed



4. Ground water table – Spatially distributed

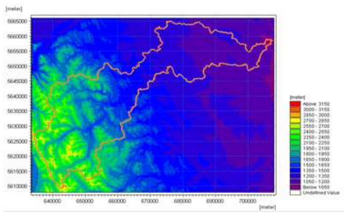


5. Climate data - Spatially and temporally distributed

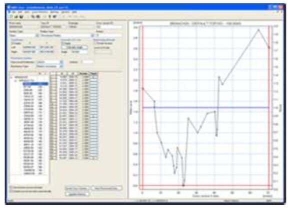


Data collection (2)

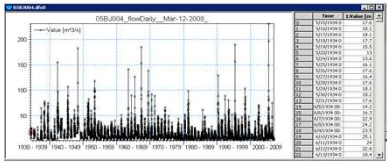
6. Topography - Spatially distributed



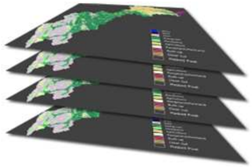
7. Cross sections of the river network



8. Water flow/level – Temporally distributed point data

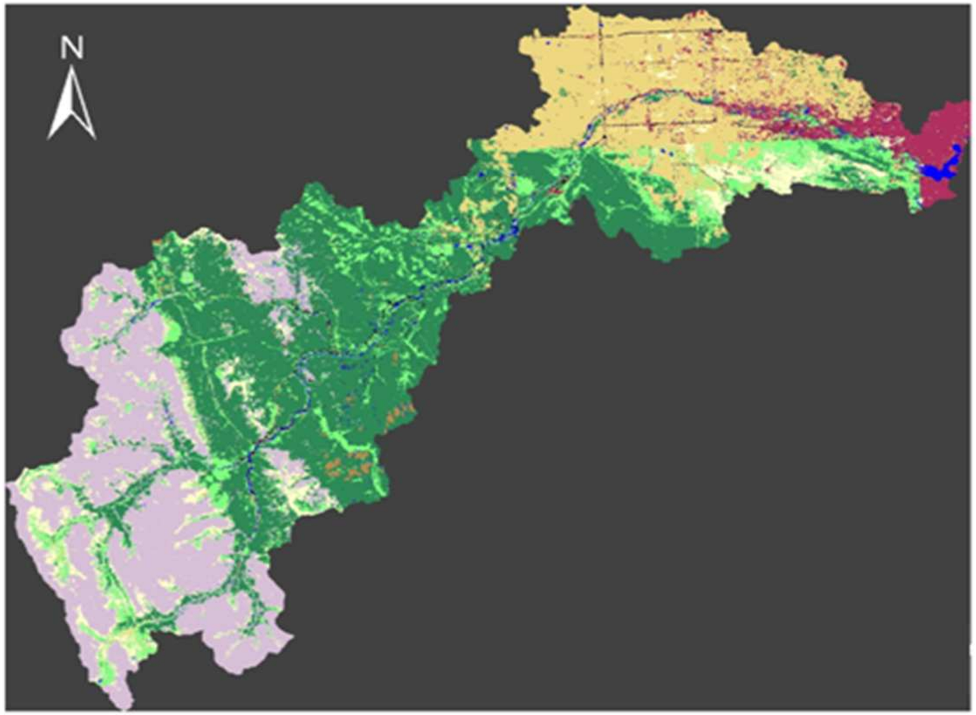


9. Land-use maps - Spatially and temporally distributed

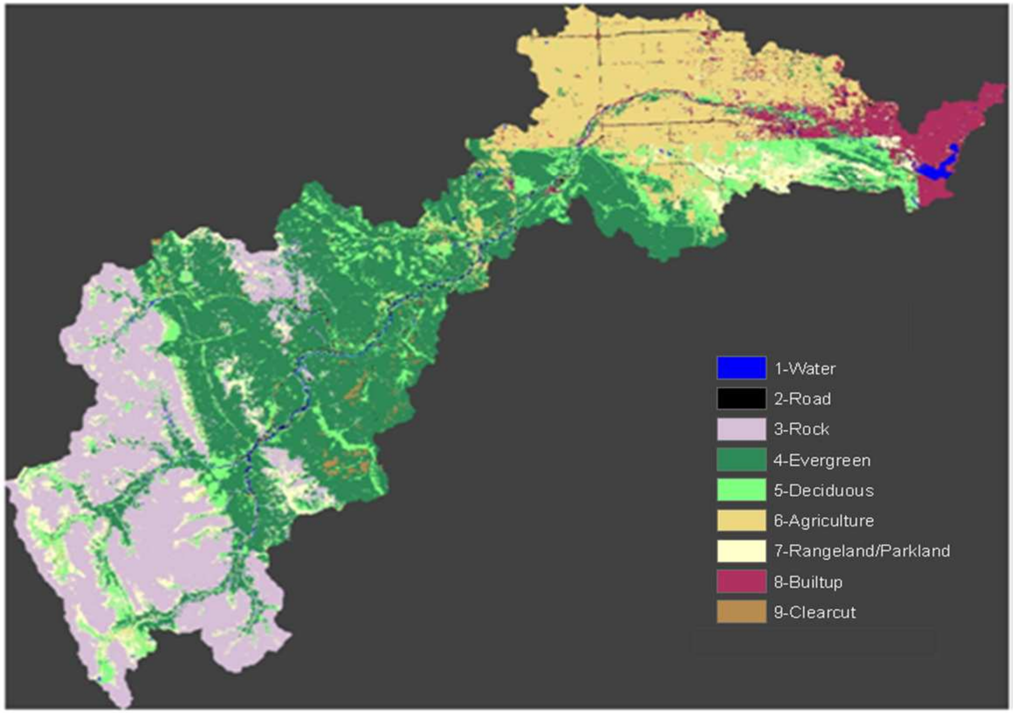


Results (1)

Simulated land-use map of 2006



Reference land-use map of 2006



- Kappa Index: 0.89

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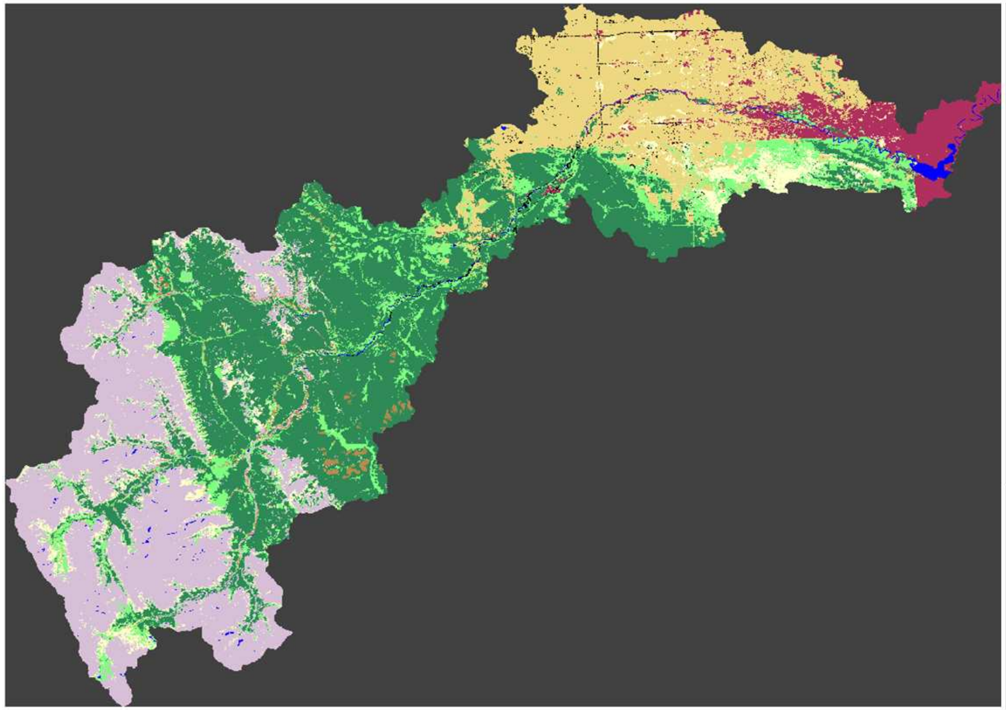
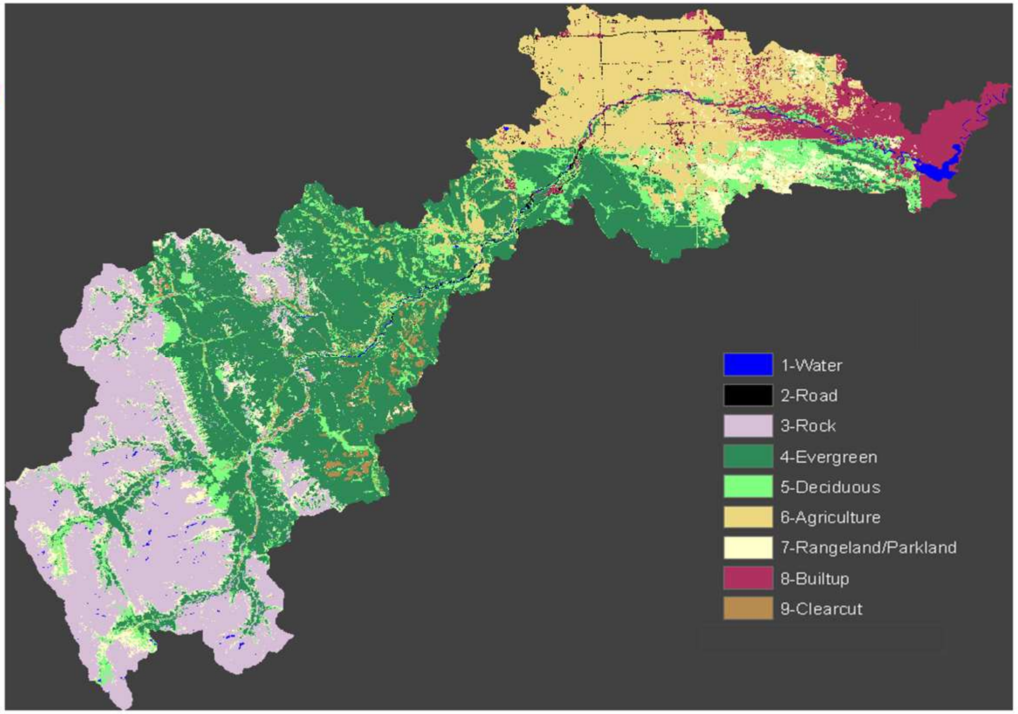
Results (2)

Simulated land-use map of 2010



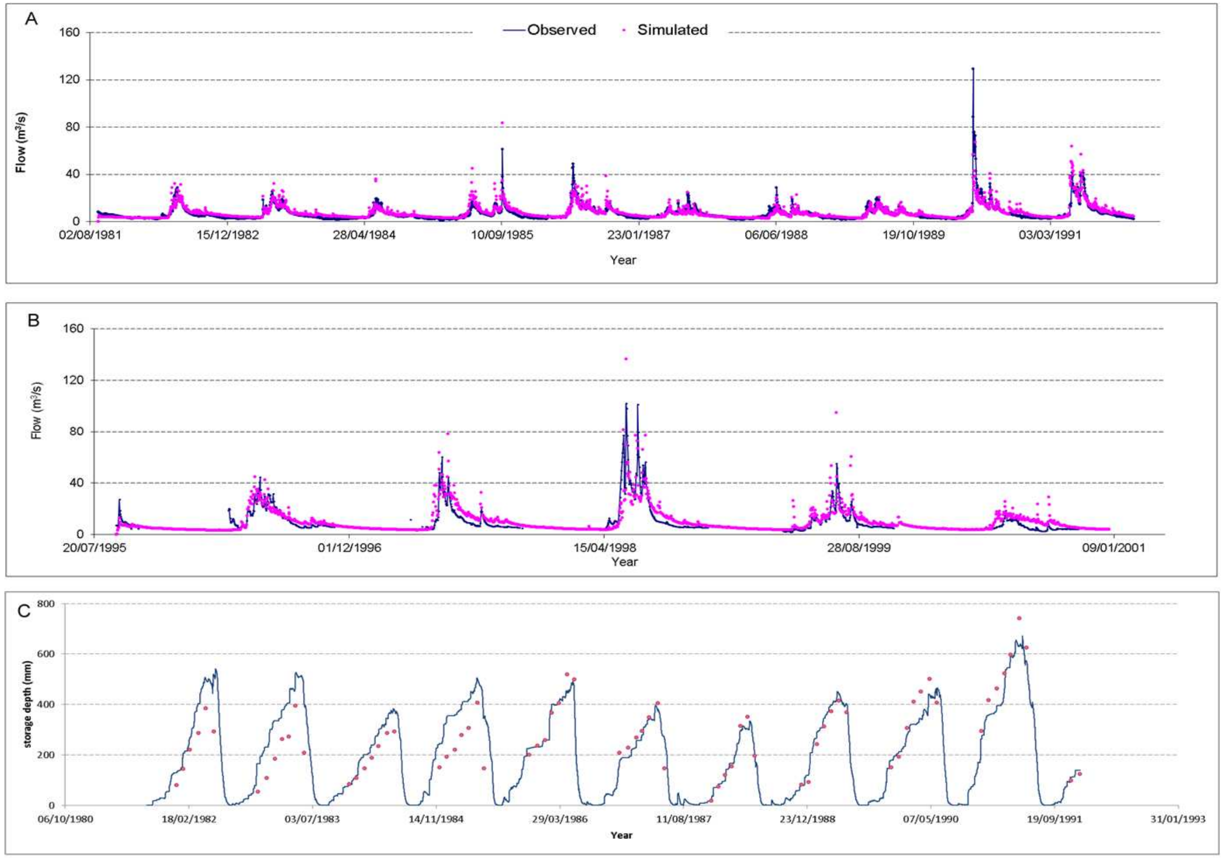
Reference land-use map of 2010



- Kappa Index: 0.81

	Calibration/Validation period	Correlation coefficient Little Elbow
Calibration	Sept. 1981 to Dec. 1991	0.86
Validation	Sept. 1991 to Dec. 1995	0.77
	Sept. 1995 to Dec. 2000	0.70
	Sept. 2000 to Dec. 2005	0.84
	Sept. 2005 to Dec. 2008	0.86

	Calibration/Validation period	WB error (%)	NSE - daily				NSE - Monthly			
			004	006	009	010	004	006	009	010
Calibration	Sept. 1981 to Dec. 1991	0.04	0.72	0.63	0.53	0.63	0.83	0.75	0.63	0.75
Validation	Sept. 1991 to Dec. 1995	0.06	0.75	0.63	0.25	0.75	0.90	0.69	0.23	0.86
	Sept. 1995 to Dec. 2000	0.08	0.77	N/A	N/A	0.64	0.87	N/A	N/A	0.79
	Sept. 2000 to Dec. 2005	0.05	0.72	N/A	N/A	0.64	0.83	N/A	N/A	0.82
	Sept. 2005 to Dec. 2008	0.04	0.53	N/A	N/A	0.60	0.69	N/A	N/A	0.77



Observed and simulated stream flow at station 05BJ004 during 1981-1991 (A), 05BJ010 during 1995-2000 (B), and total snow storage data at station Little Elbow during 1981-1991 (C)