Modeling coupled natural/human systems for environmental resource management

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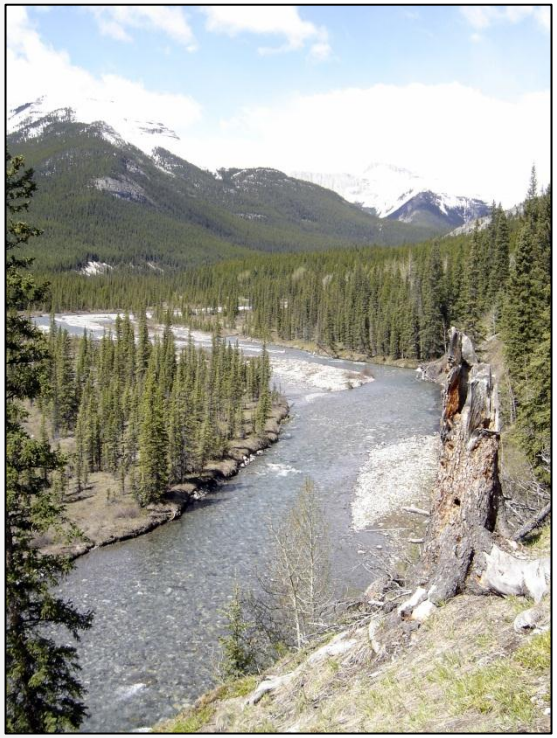
First Annual Environmental Modelling Workshop, CMO
University of Alberta, March 13-14, 2013

Research program objective

To develop spatial decision support systems using Geomatics technologies and simulation models to study complex coupled natural/human systems

- Coupled natural/human systems:
  - Systems in which human activities interact with natural landscape components, raising complex issues of environmental resource management
- Focus on (current projects):
  - Land-use change
  - Water resources
  - Spatial planning
  - Wildlife response to human disturbances
  - Disease propagation

The Elbow River watershed project



Dr. Danielle Marceau, Geomatics Eng., UofC

Nishad Wijesekara, Majeed Pooyandeh, Babak Farjad, Ph.D. students

Dr. Shawn Marshall, Geography, UofC

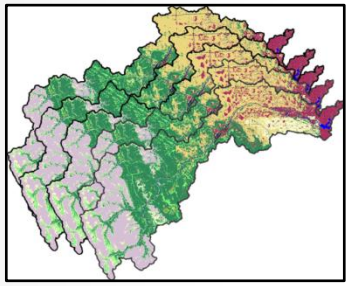
Dr. Anil Gupta, AESRD

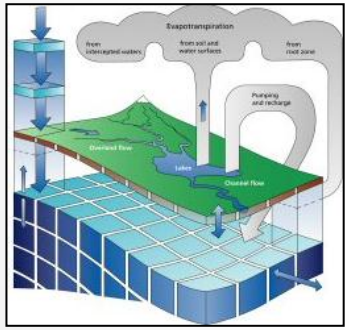
Patrick Delaney, DHI Water and Environment, Canada

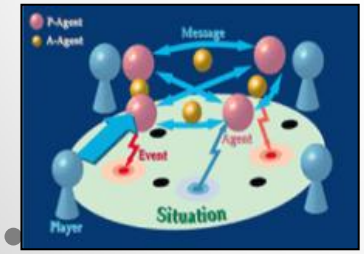
Several stakeholders

Objective

To study the impact of land-use and climate change on the hydrology of the watershed while considering the perspective of stakeholders

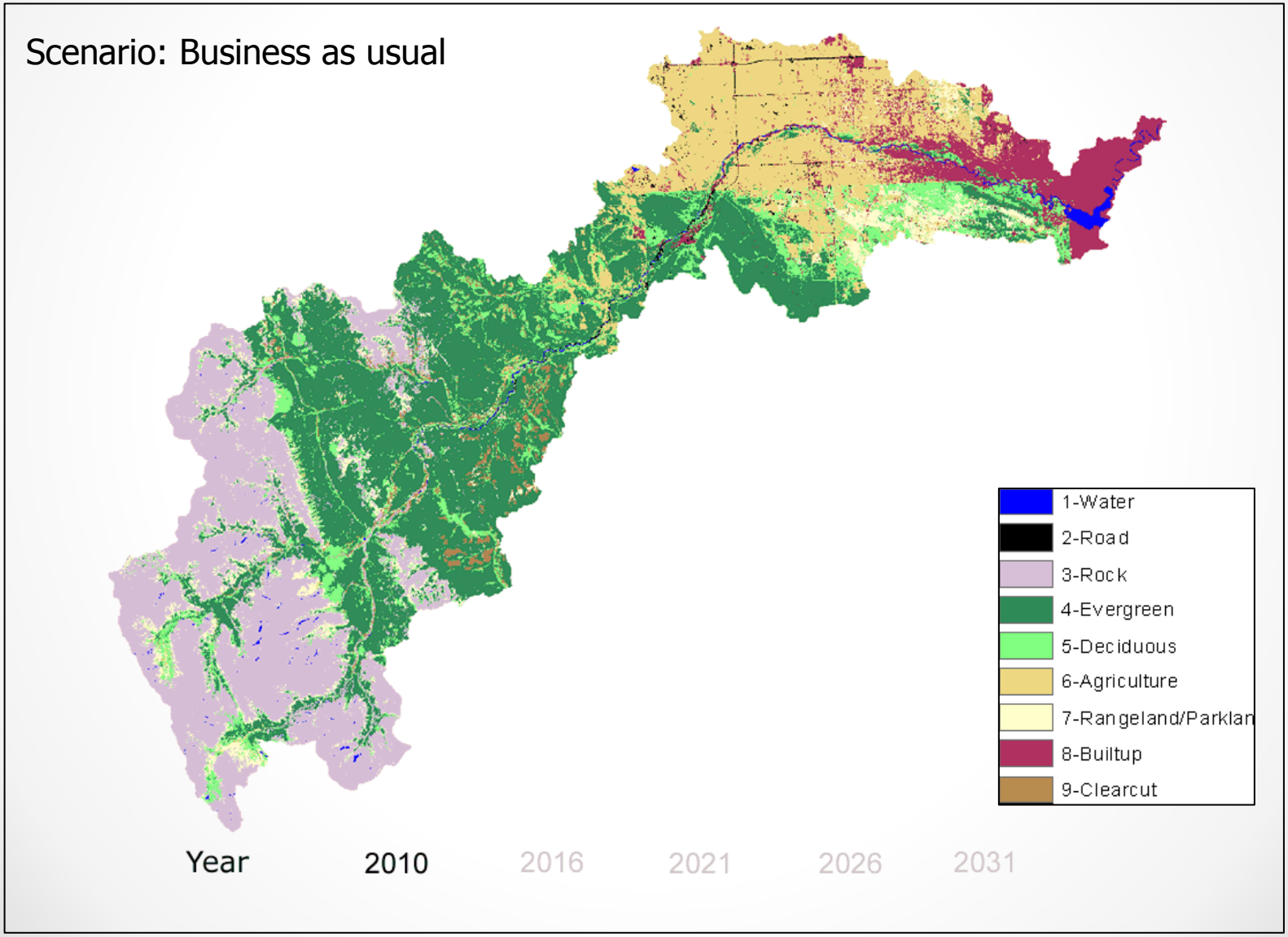


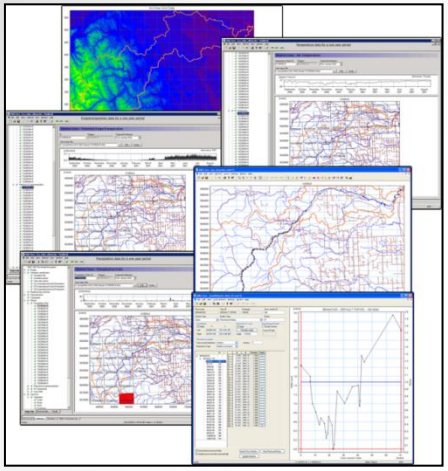




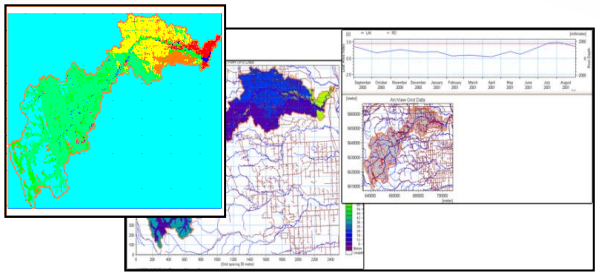
- This is achieved through the development of an integrated modeling system that includes:
  - A cellular automata (CA) to simulate scenarios of land-use change
  - A spatially-distributed hydrological/climate model (MIKE SHE)
  - A web-based agent-based model (ABM) to support the negotiation of stakeholders concerned by land development and water resources

Land-use change CA modeling

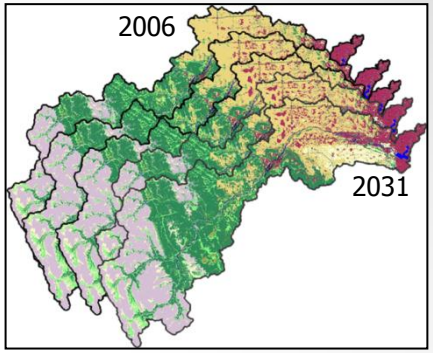




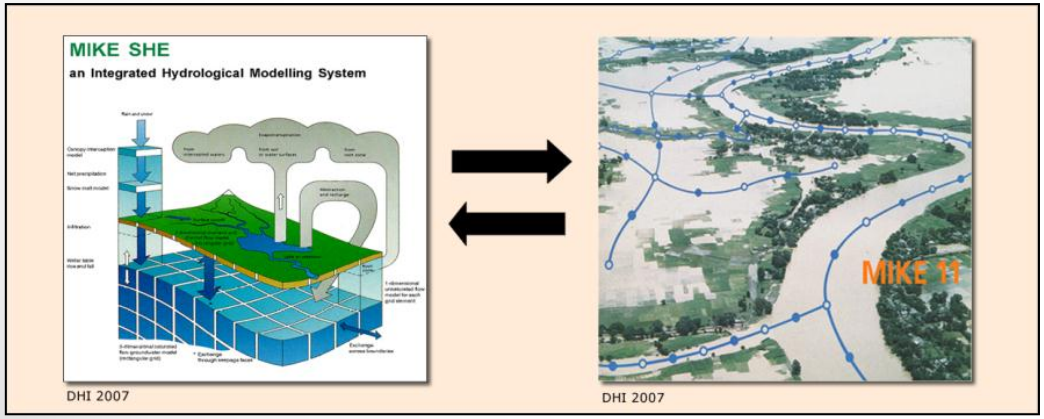
- Topography
- Climate data
- River channel data
- Ground water table

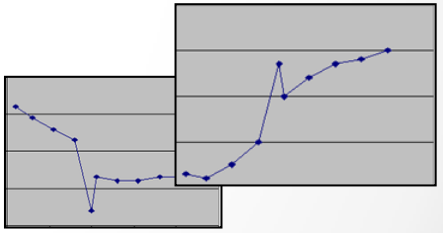


- Surface roughness
- Leaf area index
- Root depth



MIKE SHE simulations





- Total water balance
- Total overland flow
- Evapotranspiration

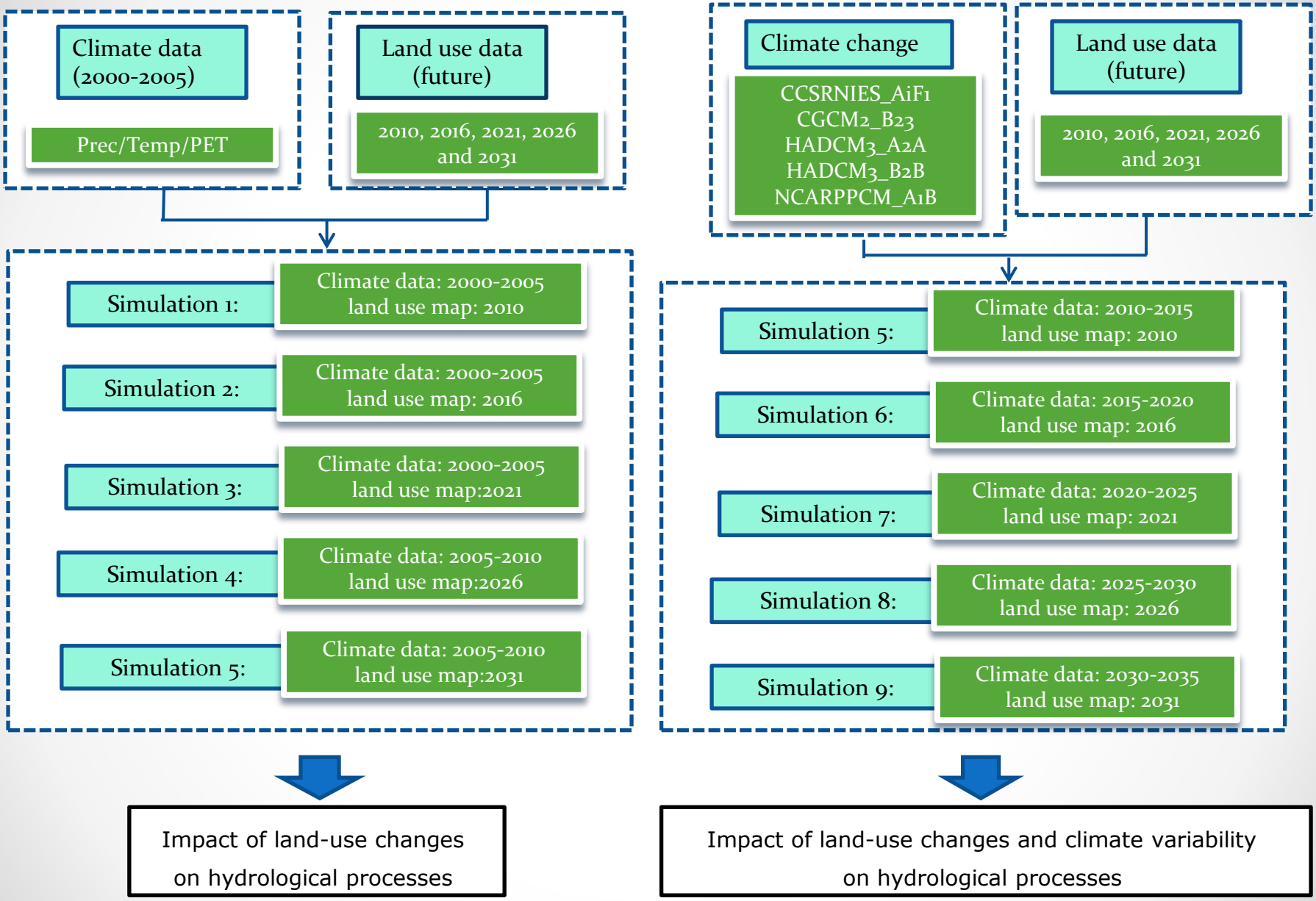
(Wijesekara and Marceau, 2012)

Impact of land-use scenarios on hydrology

Scenario	OL (mm)	BF (mm)	ET (mm)	Inf (mm)
BAU	454.0	110.0	1809.3	276.1
RV-LUC	445.4	109.9	1779.6	318.0
BC-LUC	440.3	115.7	1795.9	306.6
P-LUC	584.1	110.0	1669.4	243.3

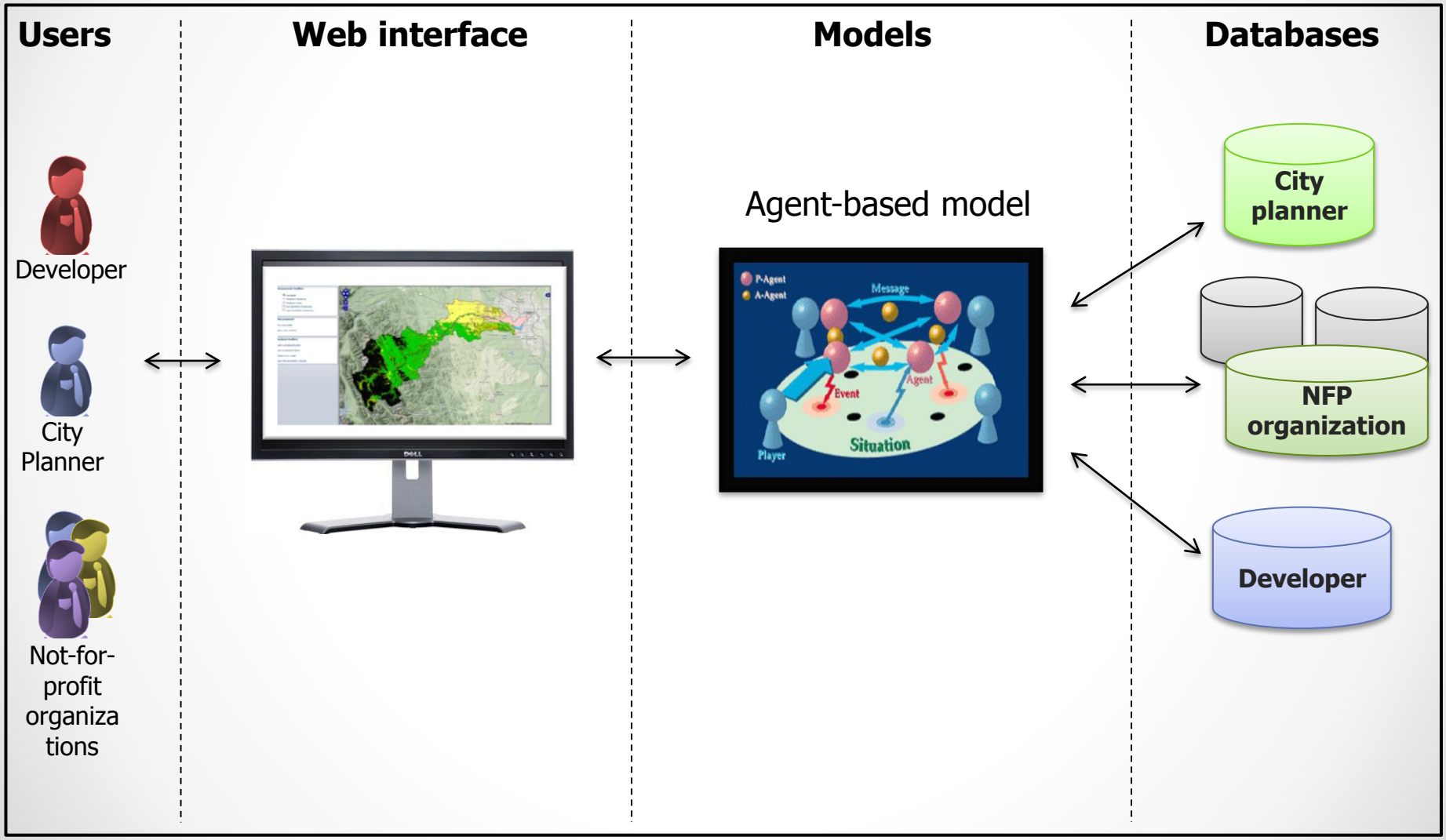
(Wijesekara et al., 2013)

- BAU: business as usual
- RV-LUC: new development concentrated in the Rocky View County
- BC-LUC: new development concentrated in Bragg Creek
- P-LUC: development based on projected population growth

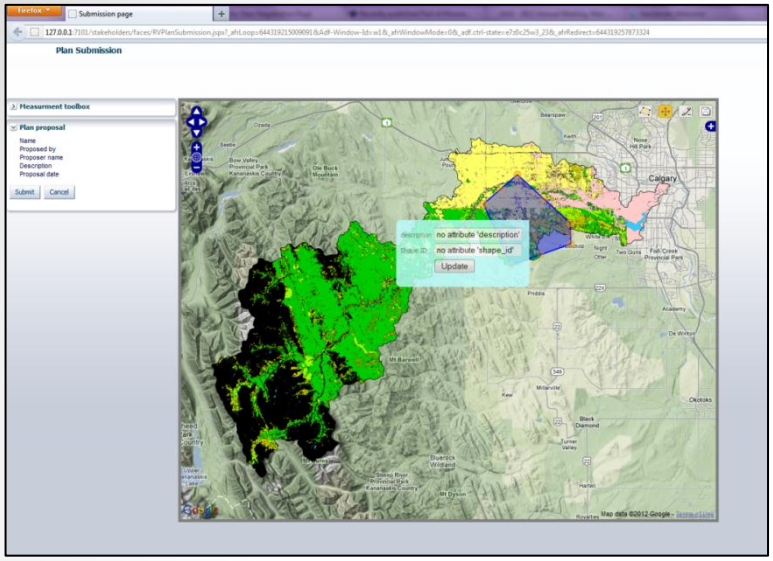

Climate data (2000-2005)
Prec/Temp/PET
Land use data (future)
2010, 2016, 2021, 2026 and 2031
Simulation 1:
Climate data: 2000-2005 land use map: 2010
Simulation 2:
Climate data: 2000-2005 land use map: 2016
Simulation 3:
Climate data: 2000-2005 land use map:2021
Simulation 4:
Climate data: 2005-2010 land use map:2026
Simulation 5:
Climate data: 2005-2010 land use map:2031
Impact of land-use changes on hydrological processes
Climate change
CCSRNIES_AiF1
CGCM2_B23
HADCM3_A2A
HADCM3_B2B
NCARPPCM_A1B
Land use data (future)
2010, 2016, 2021, 2026 and 2031
Simulation 5:
Climate data: 2010-2015 land use map: 2010
Simulation 6:
Climate data: 2015-2020 land use map: 2016
Simulation 7:
Climate data: 2020-2025 land use map: 2021
Simulation 8:
Climate data: 2025-2030 land use map: 2026
Simulation 9:
Climate data: 2030-2035 land use map: 2031
Impact of land-use changes and climate variability on hydrological processes

(Farjad, 2012)

Representing stakeholder' perspectives

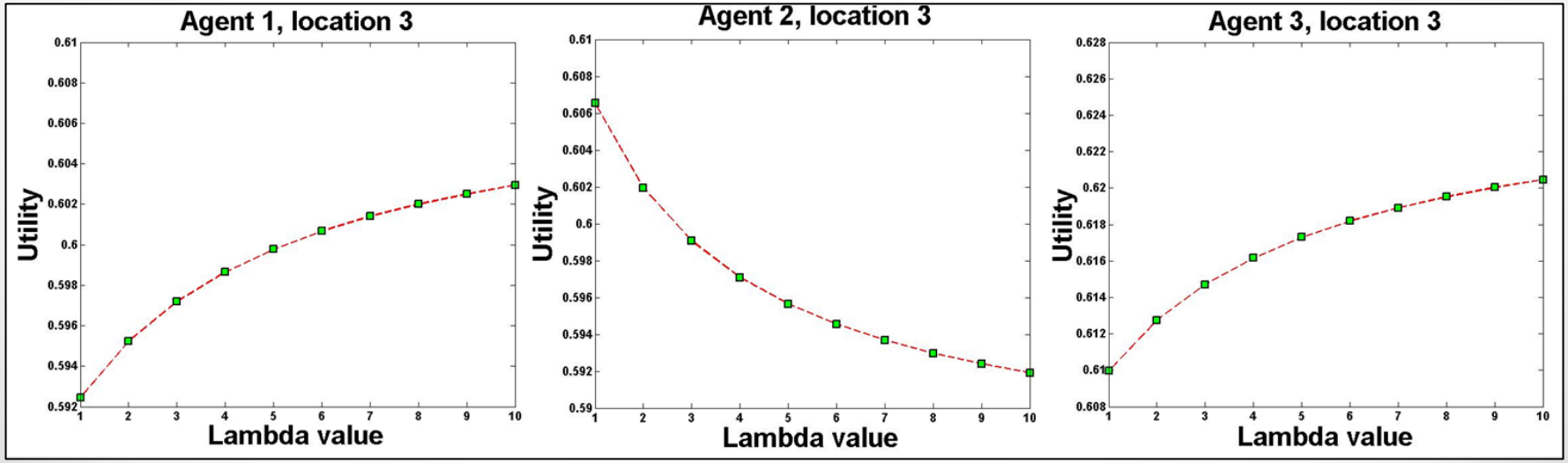


(Pooyandeh and Marceau, 2012)



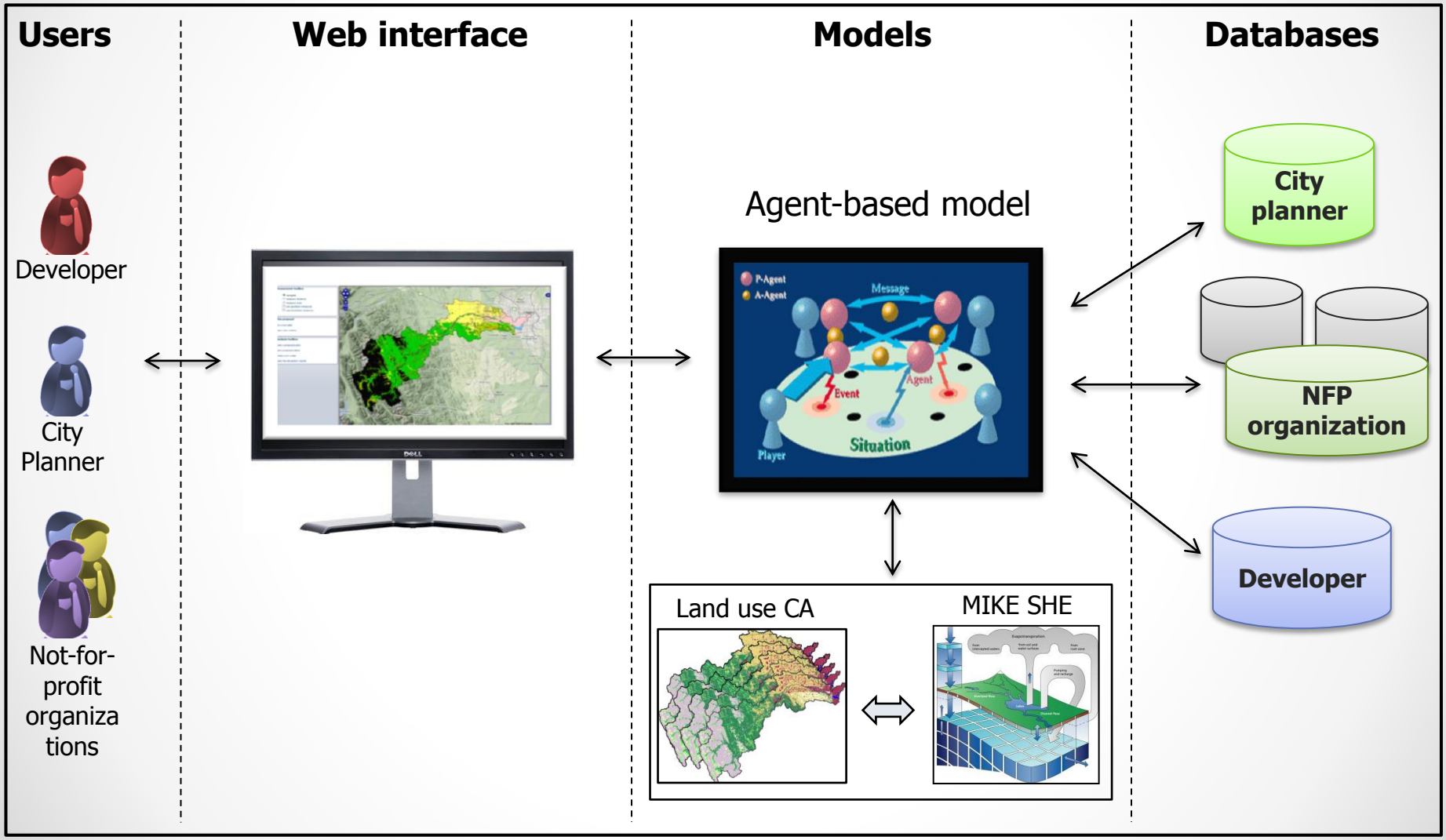
Agents' negotiation

- Utility: objective (satisfaction) of the agent
- Lamba value: weights adjusted by each agent during the negotiation
- An agreement is reached when each agent is satisfied at a minimum level of 0.6



(Pooyandeh and Marceau, 2013)

Representing stakeholder' perspectives

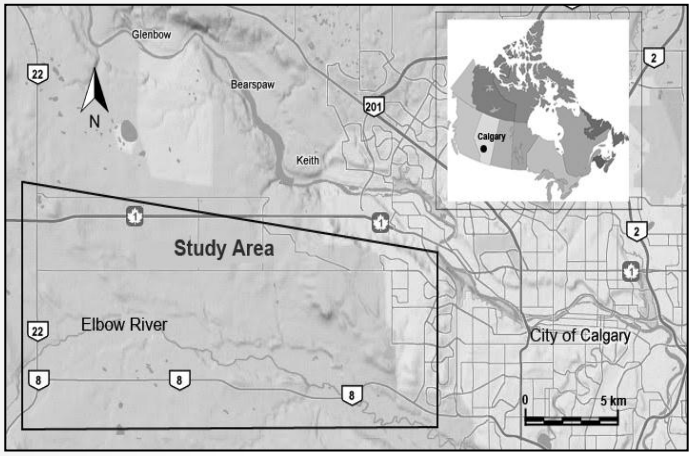


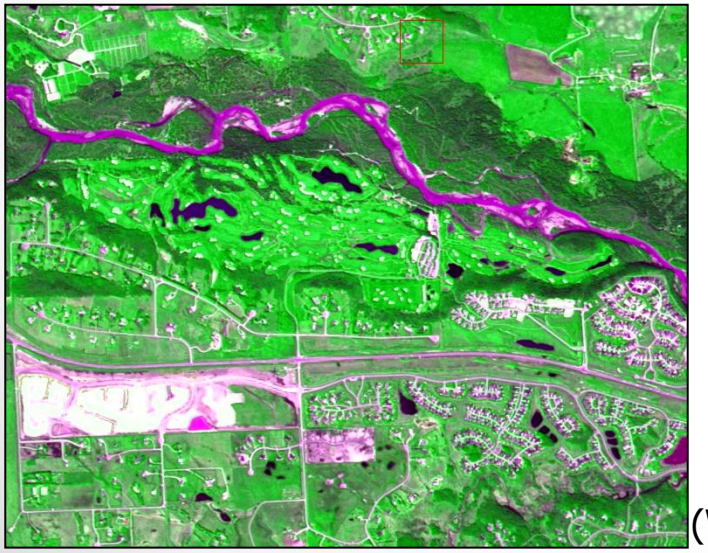
(Pooyandeh and Marceau, 2012)

Calgary/Rocky View land-use dynamics

Dr. Danielle Marceau, Geomatics Eng., UofC
Fang Wang, Ph.D. student
Colleen Sheppard, Calgary Regional Partnership
Rocky View County

Objective and Method

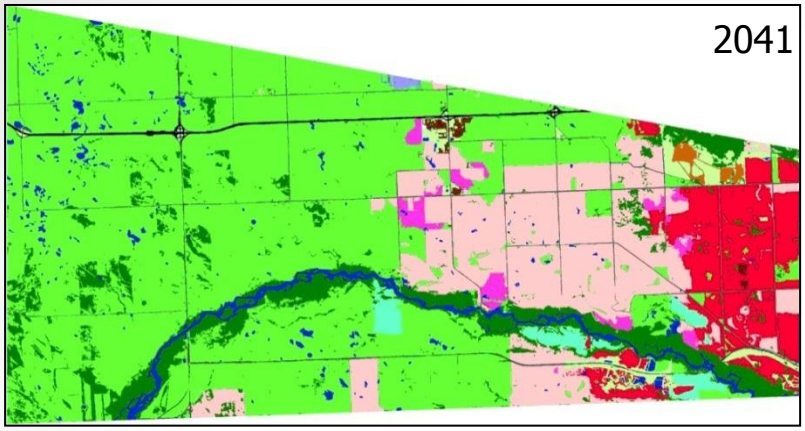


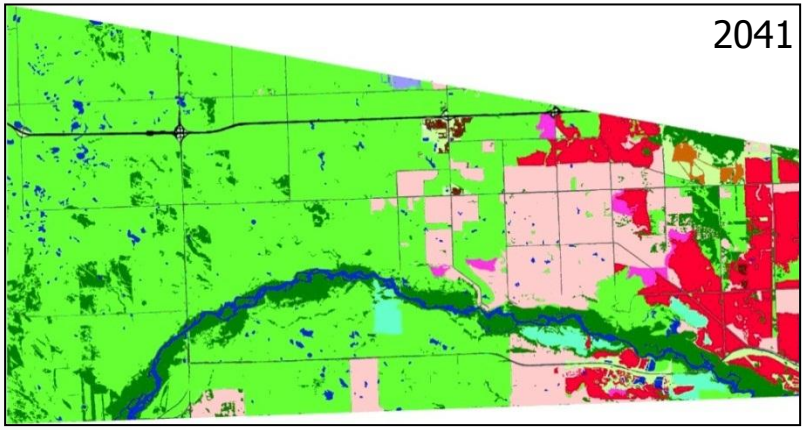


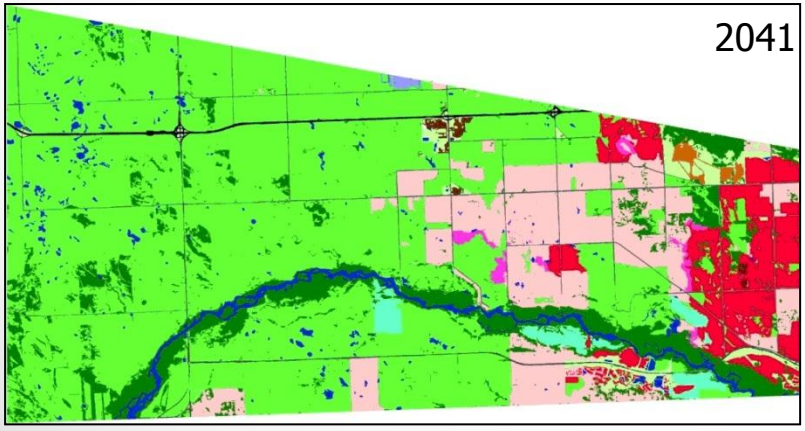
- Objective:
  - To explore scenarios of land-use change in a dynamic area of Calgary/Rocky View at very fine spatial scale (5 m)
- Method:
  - A patch-based CA model was developed to take into account the internal spatial heterogeneity of the land-use classes
  - e.g.: a residential area composed of houses, streets, and green spaces

(Wang and Marceau, 2012)

Simulated scenarios

1. 

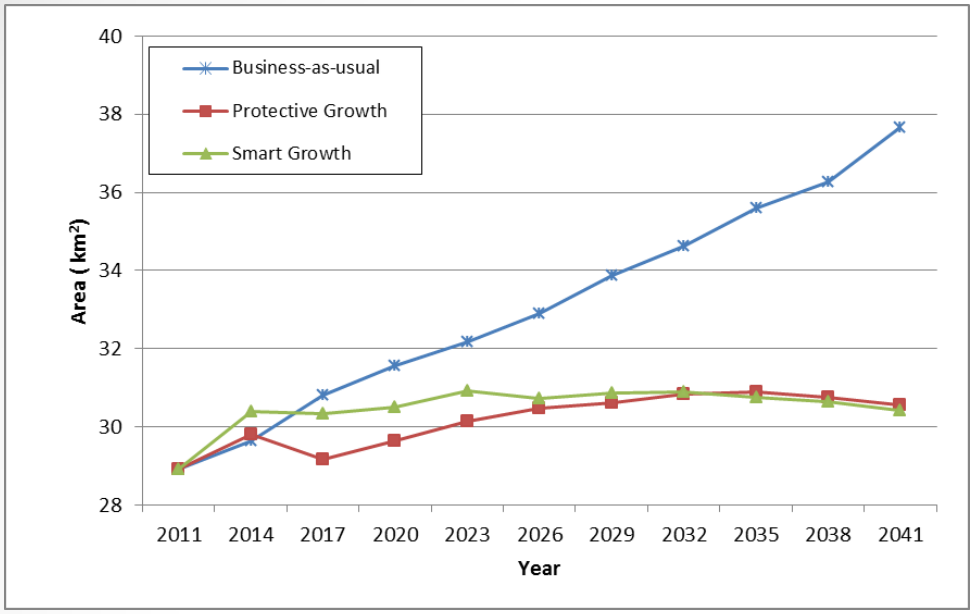
2. 

3. 

1. Business-as-usual Scenario
2. Protective Growth Scenario
3. Smart Growth Scenario

Result: Sustainability

1.



1. Projected area for country residential
2. Land consumption in 2041

2.

Class	Business-as-usual Scenario (km^2)	Protective Growth Scenario (km^2)	Smart Growth Scenario (km^2)
Country Residential	37.67	30.56	30.43
Urban Residential	18.69	19.83	16.55
Agriculture	139.13	144.42	148.13
Forest	25.05	27.13	27.16

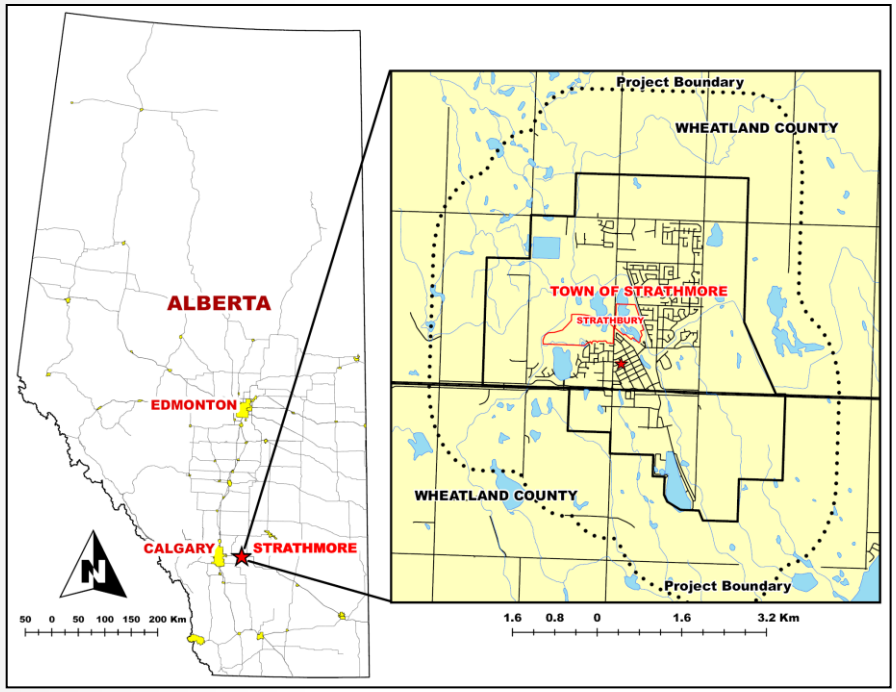
(Wang and Marceau, 2012)

Spatial planning in Strathmore

(Town of Strathmore web site)

Dr. Danielle Marceau, Geomatics Engineering, UofC
Michael Kieser, M.Sc. student
Stakeholders in Strathmore

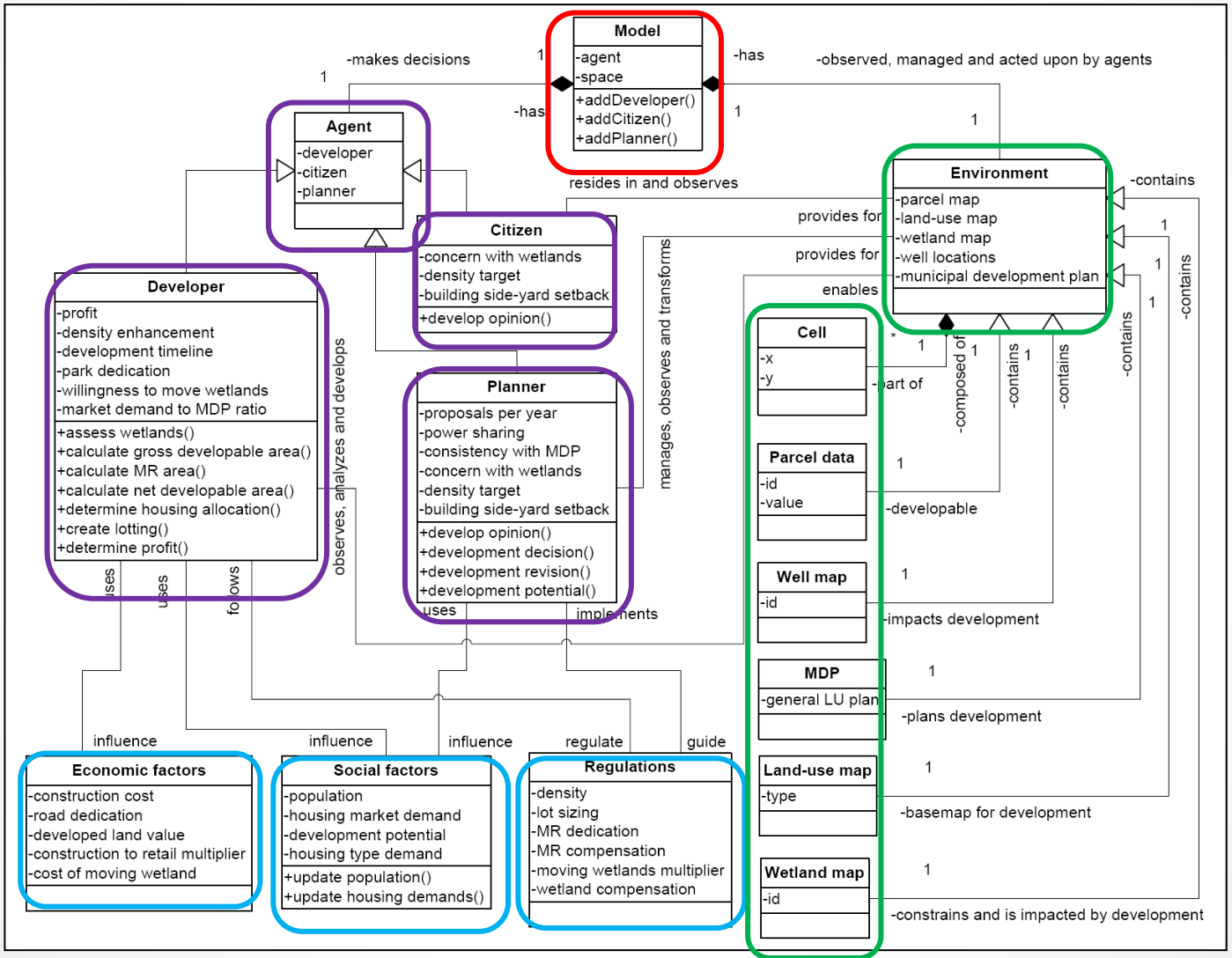
Objective and Method



(Kieser and Marceau, 2011)

- Objective:
  - To simulate the land development process in a proposed residential subdivision in Strathmore
  - To evaluate the impact of five scenarios over 10 years
- Method:
  - An agent-based model was developed to take into account the stakeholders' perspectives along with government regulations, planning policies and design standards

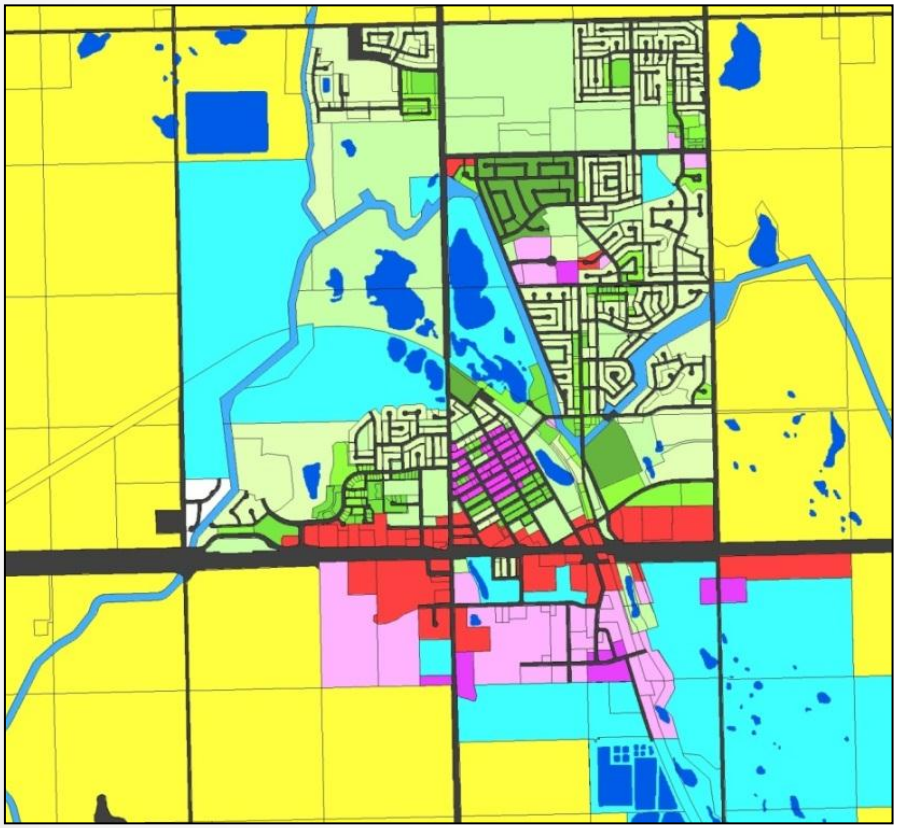
Conceptual model



(Kieser and Marceau, 2011)

Land use in 2007

Spatial resolution: 4 m



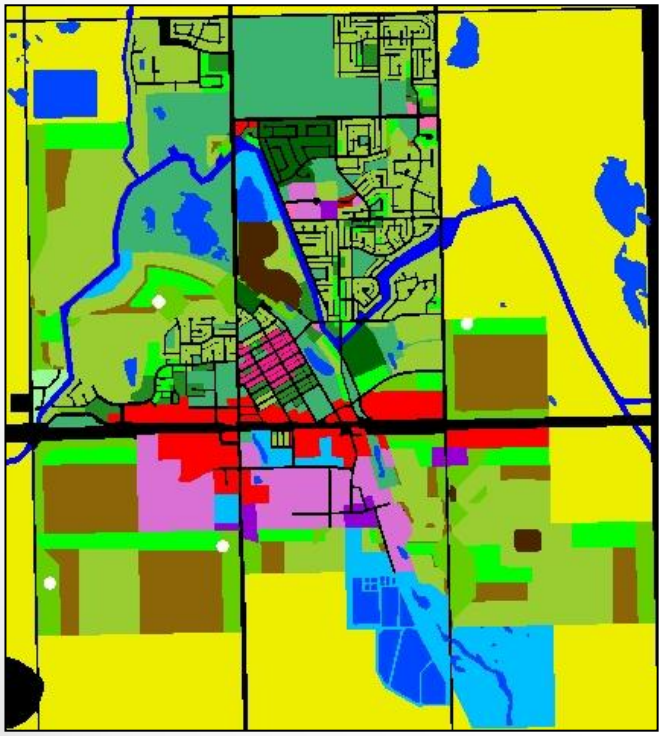
(Kieser and Marceau, 2011)

Legend

- Wetlands
- C1 - Commercial
- CB - Central Business
- CHWY - Highway Commercial
- DC3 - Direct Control
- P1 - Public Service
- M1 - Restricted Light Industrial
- M2 - Light Industrial
- CR1 - Country Residential
- R1 - Single Detached Residential
- R2 - Mixed Housing
- R2X - Medium Density Attached
- R3 - Apartment District
- MHP - Mobile Home Park
- MR - Municipal Reserve
- ER - Environmental Reserve
- OS - Open Space
- AG - Agriculture
- UR - Urban Reserve
- WID Canal
- Roads

Scenario 1: Business as usual

This scenario projects current development goals into the future

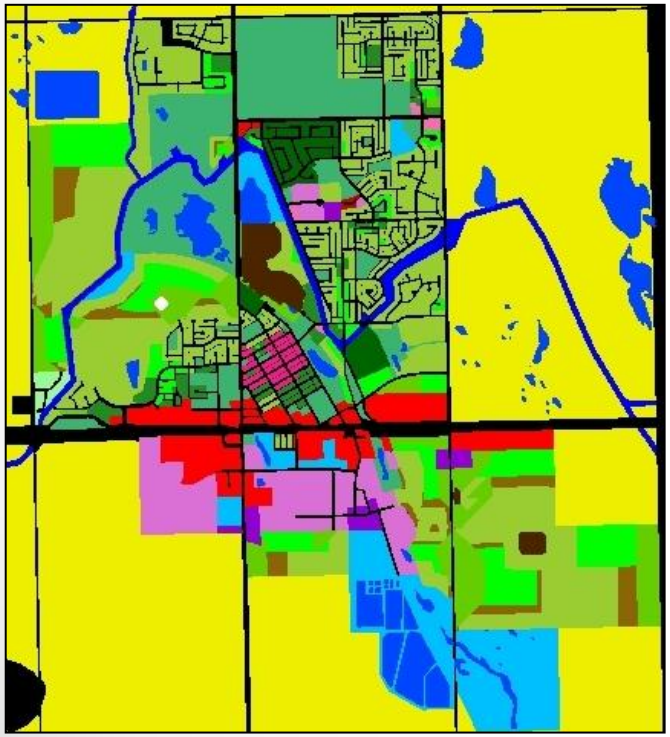


(Kieser and Marceau, 2011)

- By year 9, the development potential has surpassed the housing demand (170%)
- After 10 years, land-use change has occurred over 280 ha contained within 17 land parcels

Scenario 2: Change in the market

This scenario simulates an adaptation to the market demand for smaller housing types

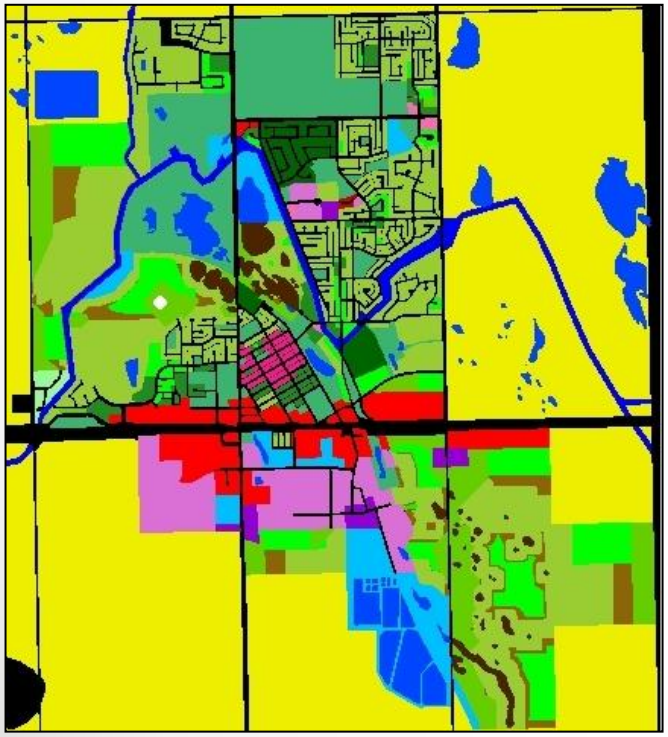


(Kieser and Marceau, 2011)

- This scenario results in the development potential being 30% greater than the housing demand
- After 10 years, land-use change occurs on 176 ha contained within 11 land parcels

Scenario 3: Sustainable development

This scenario controls development rate, gives preference to smaller housing types, decreases the road infrastructure, does not disturb wetlands



(Kieser and Marceau, 2011)

- Land-use change occurs on 198 ha contained within 11 land parcels
- This scenario creates more intricate patterns and presumably a more interesting community

The woodland caribou project
(*Rangifer tarandus caribou*)

Dr. Danielle Marceau, Geomatics Eng., UofC
Dr. Christina Semeniuk, PDF
David Birkigt, Researchc Associate
Dr. Marco Musiani, EVDS and Veterinary Medecine, UofC
Dr. Greg McDermid, Geography, UofC
Dr. Mark Hebblewhite, University of Montana
Scott Grindal, ConocoPhillips Canada

Objective

To determine how the industrial activities influence woodland caribou habitat selection and use in the study area

- An ABM/CA model was developed to:
  - Simulate and recreate the movement behaviors of caribou to explore how they select and use their winter habitat
  - Determine the relative impact of different industrial features on caribou habitat selection strategies in winter
  - Assess how caribou adapt to their changing environment

Modeling approach

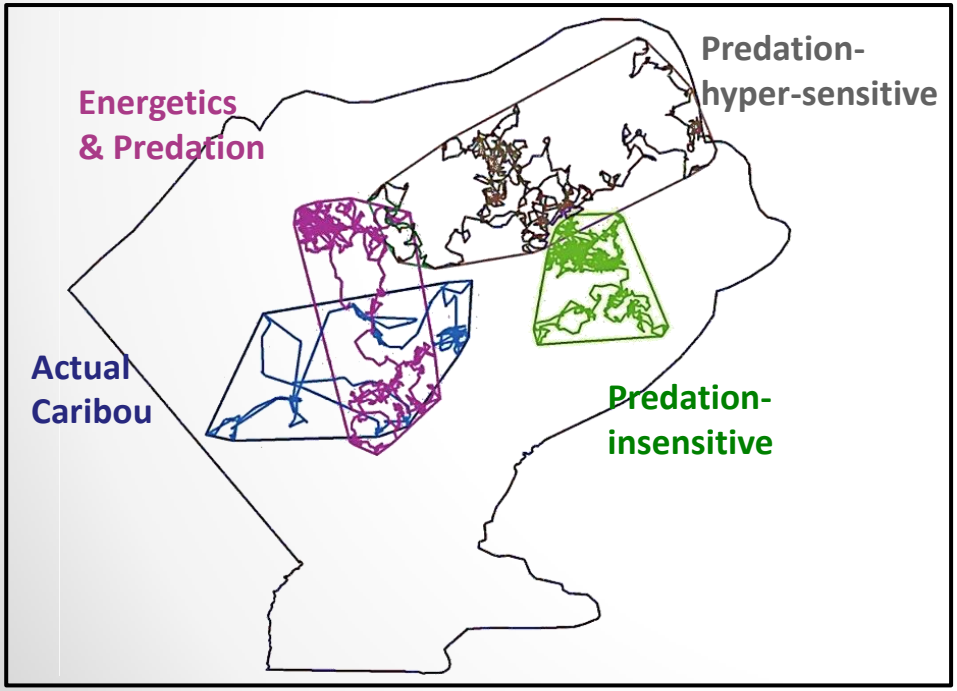
Our modeling approach combines movement ecology with behavioural ecology within an ABM/CA framework

- The ABM simulates caribou as individual agents that:
  - Are capable of making trade-off decisions to maximize their survival and reproductive success
  - Are spatially aware of their surrounding environment
  - Have a memory
  - Can learn where to forage, while concurrently avoiding predators and habitat disturbance

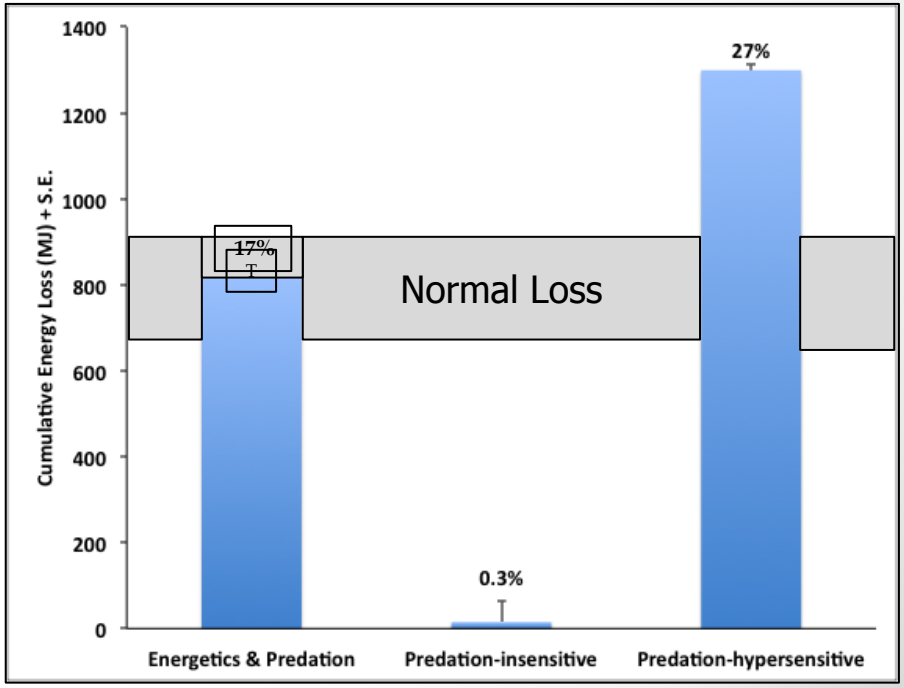
Result: Strategy for habitat use

The Energetics and Predation scenario in which the caribou agent must trade-off its daily energy requirement, minimize its reproductive energy loss, and minimize the predation risk is the best-fit scenario

Representative paths and home ranges



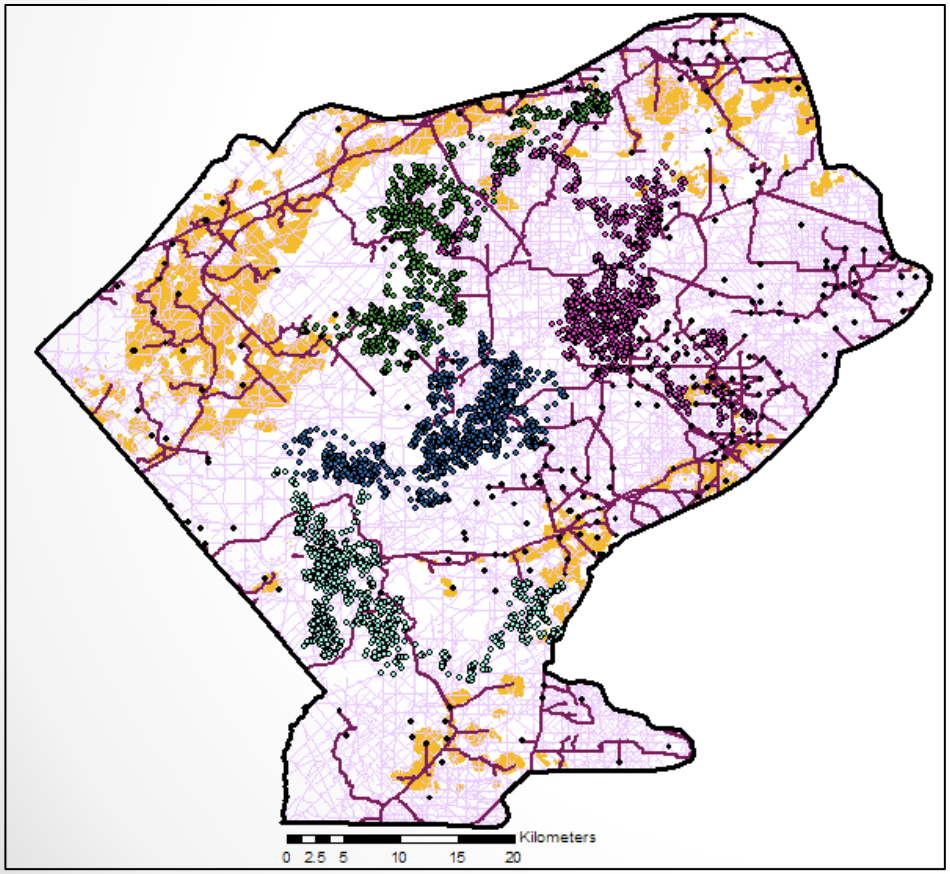
Cumulative energy loss



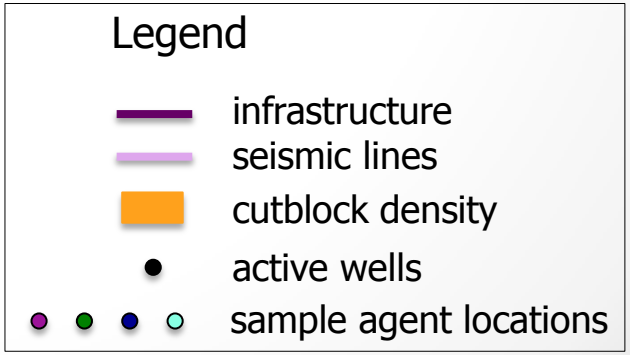
(Semeniuk et al., 2012)

Result: Sensitivity to industrial activities

Forestry and oil and gas features distinctly affect the spatial and energetic responses of caribou



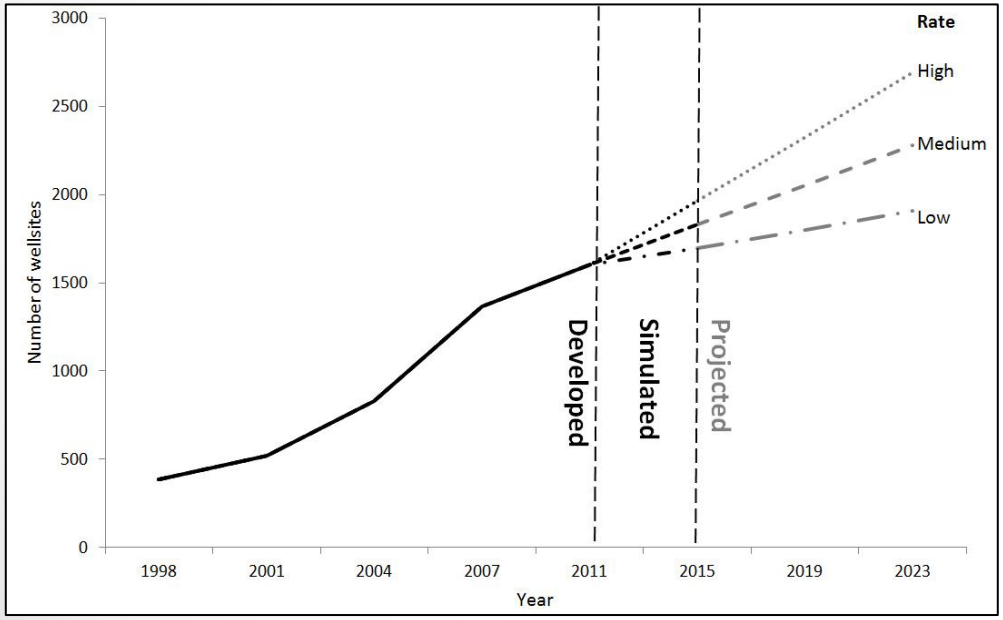
- Caribou are most sensitive to the presence of linear features
- They are sensitive to a minor extent to cutbloc density and active wellsites



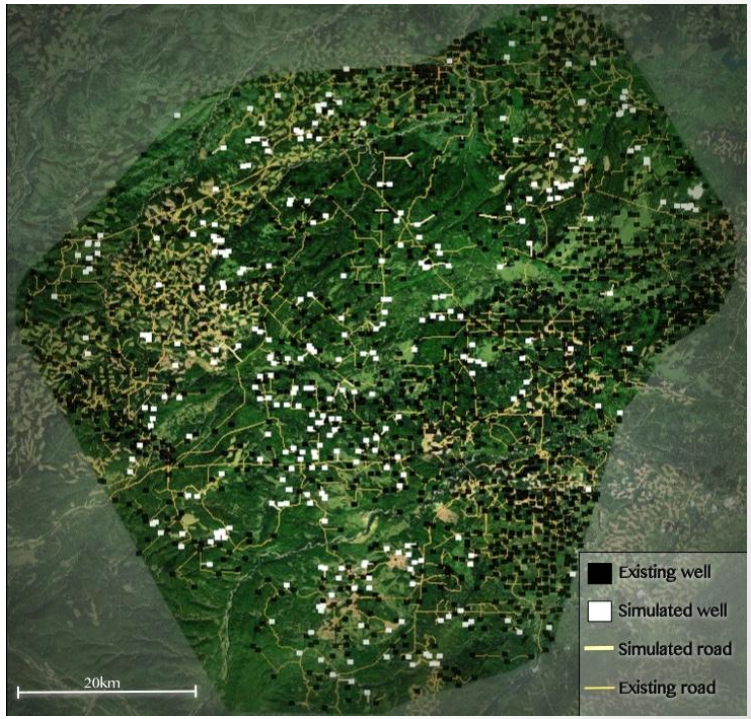
(Semeniuk et al., 2013)

Projecting in the future

A cellular automata was developed to simulate three scenarios of upstream development over the next 10 years



2015: medium development rate

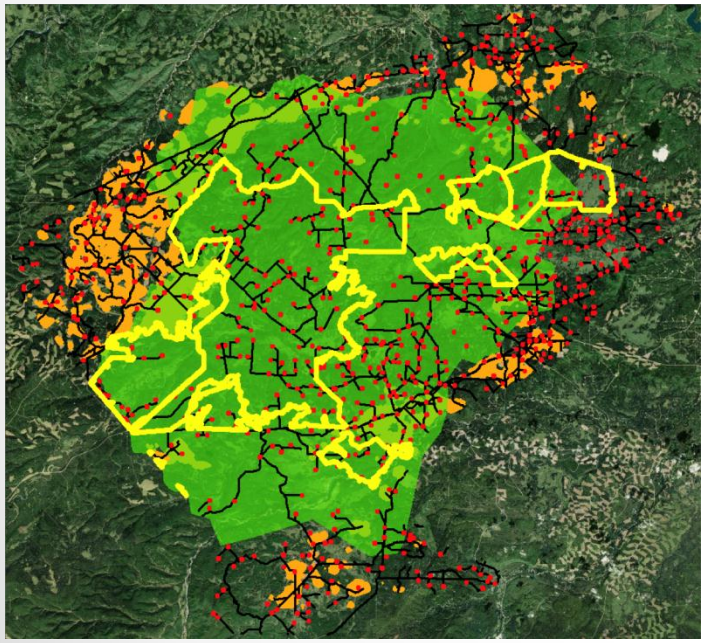


(Birkigt et al., 2013)

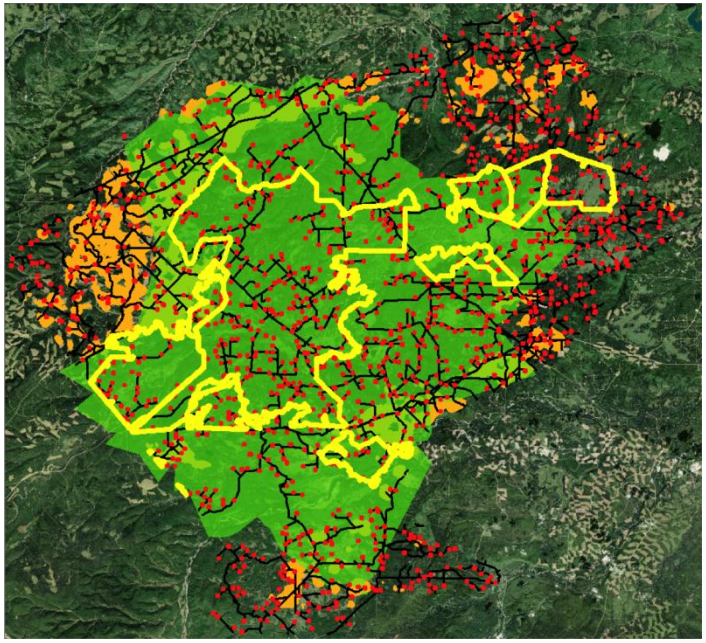
Result: Adaptation to projected conditions

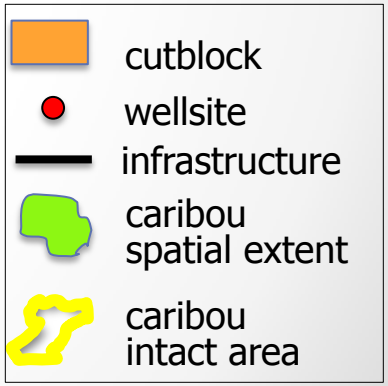
Projected environmental conditions up to 2023 using a cellular automata reveal how caribou adapt to the changes in their habitat

2011: Intact area: 63%



2023: Intact area: 53%





(Semeniuk et al., 2013)

Modeling disease propagation with ABMs

Wildlife - Cattle

Dr. Karen Orsel, Veterinary Medicine, UofC
Dr. Ale Massolo, Veterinary Medicine, UofC
Dr. Danielle Marceau, Geomatics Eng., UofC
Dr. Aaron Reeves, PDF
Mathieu Provost, Ph.D. Student
Ranchers

Coyote – Dog - Human

Dr. Ale Massolo, Veterinary Medicine, UofC
Dr. Danielle Marceau, Geomatics Eng., UofC
Ken Mori, M.Sc. Student, Geomatics Eng.
City of Calgary

Conclusion

Understanding the complex interactions between human and natural systems is essential for environmental resource management

- It requires an interdisciplinary scientific approach
- It requires a flexible and comprehensive modeling approach to investigate multiple scenarios
- It requires the involvement of stakeholders as they are key actors in the process of identifying and implementing sustainable management measures

Acknowledgements

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  - GEOIDE
  - MITACS
  - NSERC
  - ConocoPhillips Canada
  - Tecterra
  - Alberta Environment Sustainable Resource Development (AESRD)
  - DHI (in-kind)
  - Calgary Regional Partnership
  - Alberta Innovates (scholarship)
  - University of Calgary (Internal awards)

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