Alberta Government

Session 2

Day 1 – Session 2

Stefan Kienzle – Univesity of Lethbridge

BIOGRAPHY

Stefan is a hydrologist and GIS analyst at the Department of Geography, University of Lethbridge, with over 25 years of experience in watershed modelling. Stefan is also Adjunct Professor at the University of Regina (Saskatchewan, Canada) and the University of South Africa (Pretoria, South Africa). He has worked in government research institutes, consulting, and various Universities in Africa, Europe, and Canada. Stefan has been working with, and further developing, the ACRU agro-hydrological modelling system since 1990, and applied the model for watershed impacts analysis in South Africa, New Zealand, the USA and Canada. His current research focus is using the ACRU agro-hydrological modelling system to simulate the impacts of environmental change on watershed hydrology in many watersheds in the Province of Alberta.

In order to enable his work, Stefan is in the process of establishing a digital hydro-climatological Atlas of Alberta with a high spatial resolution. Dr. Kienzle maintains a strong research lab with research assistants and graduate students, and has published widely in international journals, including Journal of Hydrology, Hydrological Processes, Water Resources Management, Climatic Change, and the Hydrological Sciences Journal. Stefan is co-author of several book chapters. He was expert witness on hydrological issues in numerous court cases, including oil sands hearings in 2003 and 2006.

Day 1 – Session 2

Stefan Kienzle – Univesity of Lethbridge

ABSTRACT

Sustainable environmental management requires the knowledge of the envelope of expected water availability, both in rivers and in the soil. The ACRU agro-hydrological modelling system is a model than can provide this information under a range of environmental conditions.

ACRU is a multi-purpose, multi-level, integrated physical-conceptual model that is designed to simulate total evaporation, soil water and reservoir storages, land cover and abstraction impacts, snow water dynamics and streamflow at a daily time step. As is the case with every integrated/multipurpose hydrological modelling system applied to simulate hydrological responses in large and heterogeneous watersheds, ACRU requires considerable spatial information, inter alia, on topography, a wide range of climatic parameters, soils, land cover, reservoirs, and streams. The spatial organization of sub-units in ACRU is flexible, and includes sub-watersheds, square grid cells, and hydrological response units (HRUs). For example, the 20,000 km2 upper North Saskatchewan River watershed was subdivided into 1528 HRUs, each having a unique combination of elevation, land cover, and climate. The output of the ACRU model consists of daily time series of 52 variables for each spatial modelling unit, including streamflow, groundwater flow, groundwater recharge, soil water deficit and surplus, irrigation requirements, water use by vegetation, and evaporation from wet surfaces. From the time series, risk analyses on any variable can be carried out using exceedance probability plots, which provide information on the percentage of time a certain value, e.g. flood, soil moisture, or low flow is exceeded.

Current work on the Hydro-Climatological Atlas of Alberta is also briefly presented, including the calculation of climate trends based on the instrumental record 1950 – 2010.

Environment and Sustainable Resource Development

Environmental Modelling Workshop 2013

Simulating Hydrological Behaviour Under Environmental Change in Alberta

Stefan W Kienzle

University of Lethbridge

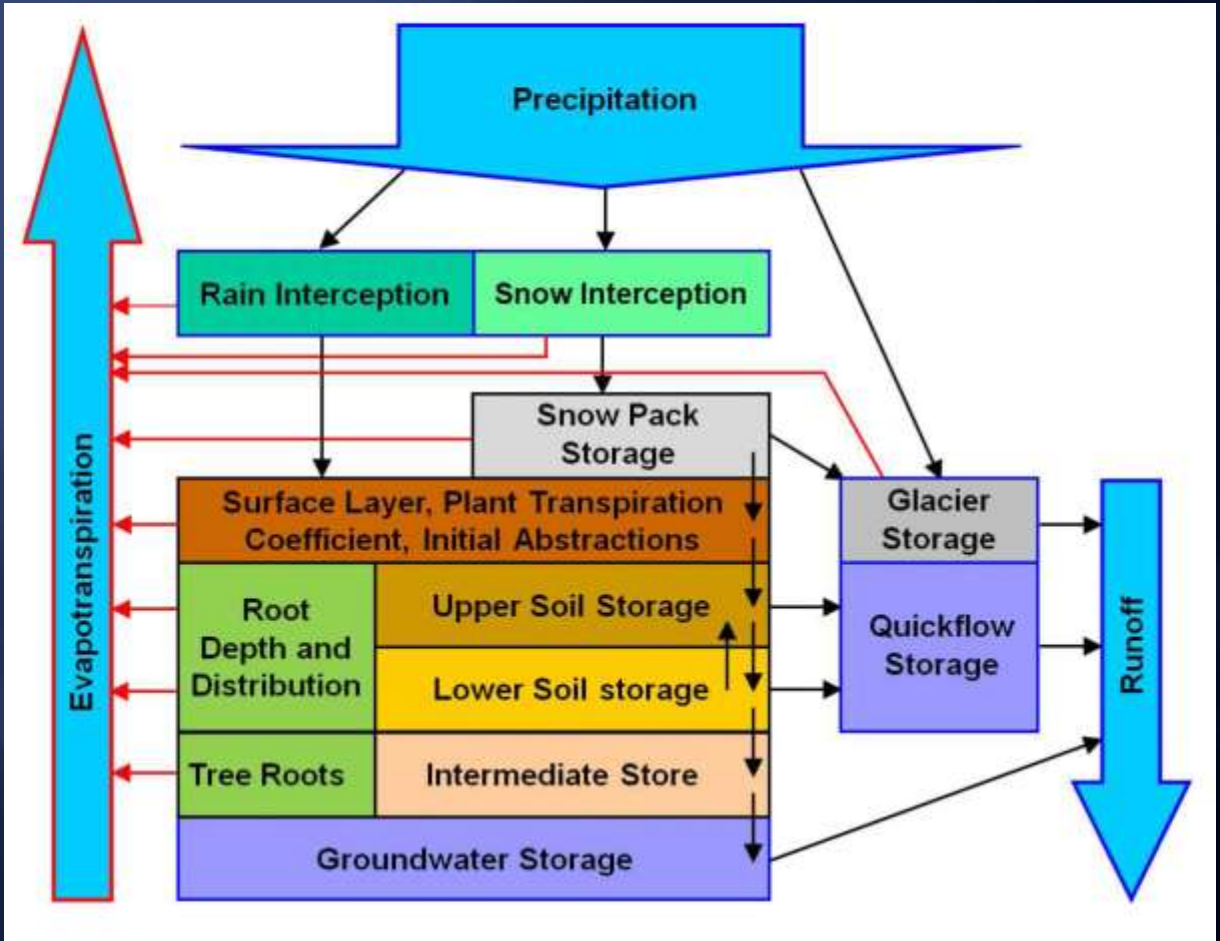
Department of Geography

Watershed Modelling Lab

University of Lethbridge

FIAT LUX

ACRU agro-hydrological modelling system

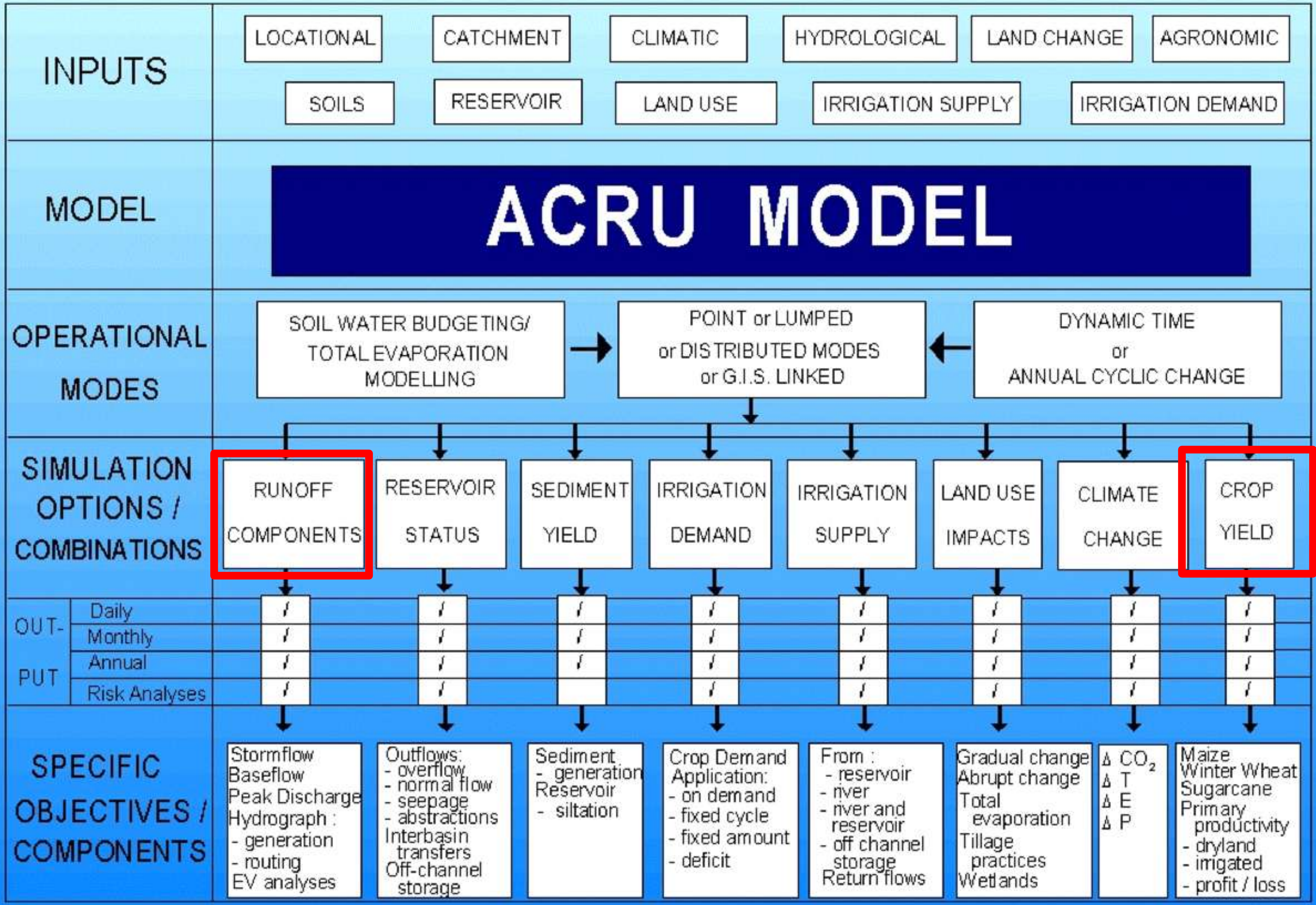


Multi-purpose

Multi-level

Integrated physical model

- Actual evaporation
- Soil water and groundwater storages
- Snow
- (Glaciers)
- Land cover and abstraction impacts on water resources
- Streamflow at a daily time step.



INPUTS
LOCATIONAL
CATCHMENT
CLIMATIC
HYDROLOGICAL
LAND CHANGE
AGRONOMIC
SOILS
RESERVOIR
LAND USE
IRRIGATION SUPPLY
IRRIGATION DEMAND
MODEL
ACRU MODEL
OPERATIONAL MODES
SOIL WATER BUDGETING/ TOTAL EVAPORATION MODELLING
POINT or LUMPED or DISTRIBUTED MODES or G.I.S. LINKED
DYNAMIC TIME or ANNUAL CYCLIC CHANGE
SIMULATION OPTIONS / COMBINATIONS
RUNOFF COMPONENTS
RESERVOIR STATUS
SEDIMENT YIELD
IRRIGATION DEMAND
IRRIGATION SUPPLY
LAND USE IMPACTS
CLIMATE CHANGE
CROP YIELD
OUT-PUT
Daily
Monthly
Annual
Risk Analyses
SPECIFIC OBJECTIVES / COMPONENTS
Stormflow
Baseflow
Peak Discharge
Hydrograph :
- generation
- routing
EV analyses
Outflows:
- overflow
- normal flow
- seepage
- abstractions
Interbasin transfers
Off-channel storage
Sediment
- generation
Reservoir
- siltation
Crop Demand Application:
- on demand
- fixed cycle
- fixed amount
- deficit
From :
- reservoir
- river
- river and reservoir
- off channel storage
Return flows
Gradual change
Abrupt change
Total evaporation
Tillage practices
Wetlands
Δ CO_2
Δ T
Δ E
Δ P
Maize
Winter Wheat
Sugarcane
Primary productivity
- dryland
- irrigated
- profit / loss

ACRU agro-hydrological modelling system

Applications in:

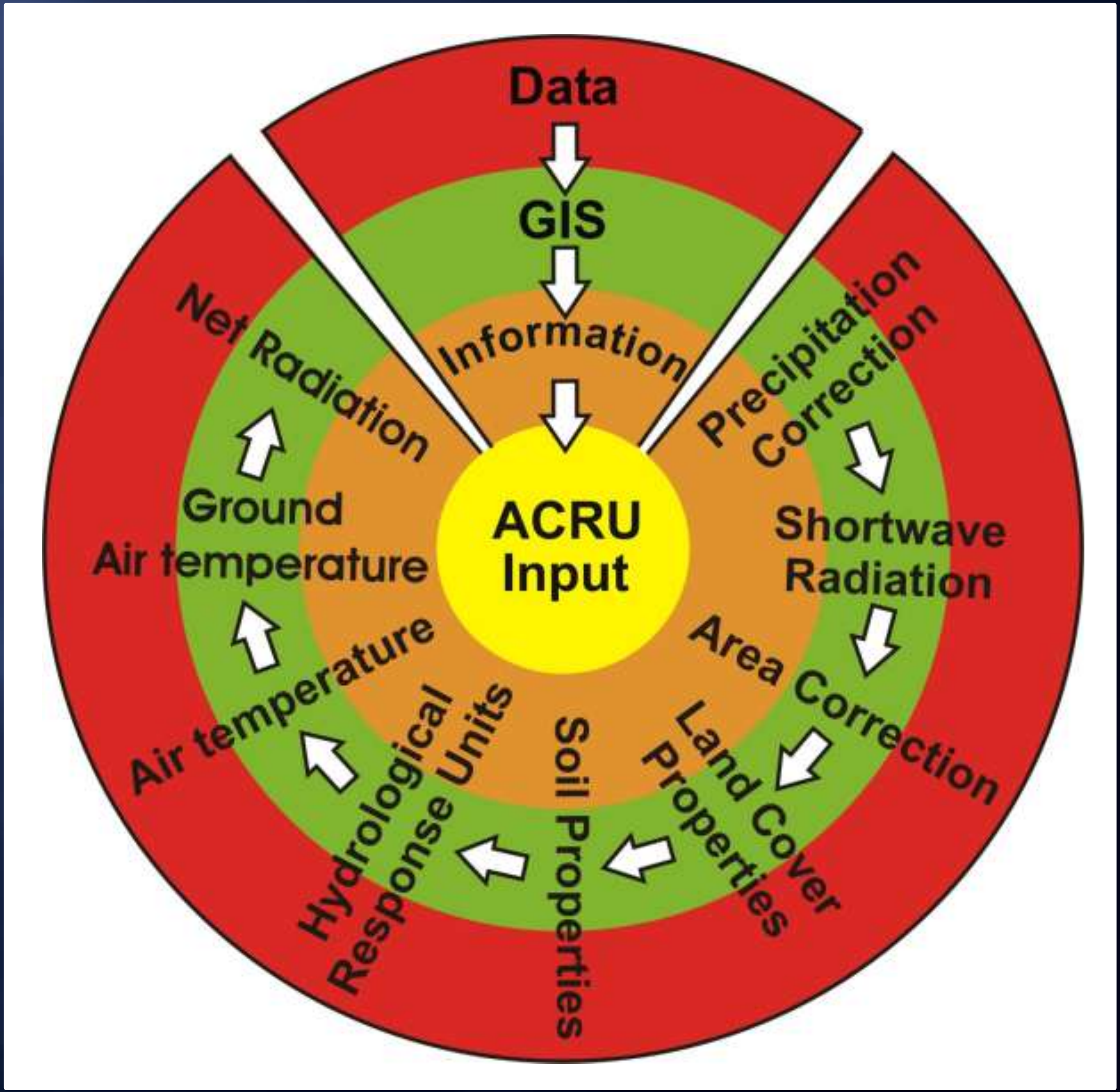
- Water resource assessments
  - (Everson, 2001; Kienzle *et al*, 1997; Schulze *et al.*, 2004)
- Flood estimation
  - (Smithers *et al.*, 1997; 2001; 2012)
- Land use impacts
  - (Kienzle and Schulze, 1991; Tarboton and Schulze, 1993, Kienzle, 2008)
- Climate change impacts
  - (New, 2003; Schulze *et al.*, 2004; Forbes *et al.*, 2011; Nemeth et al., 2012; Kienzle et al., 2012)
- Irrigation supply & demand
  - (Dent, 1988; Kienzle, 2008)

Actual Evapotranspiration

Monthly values for

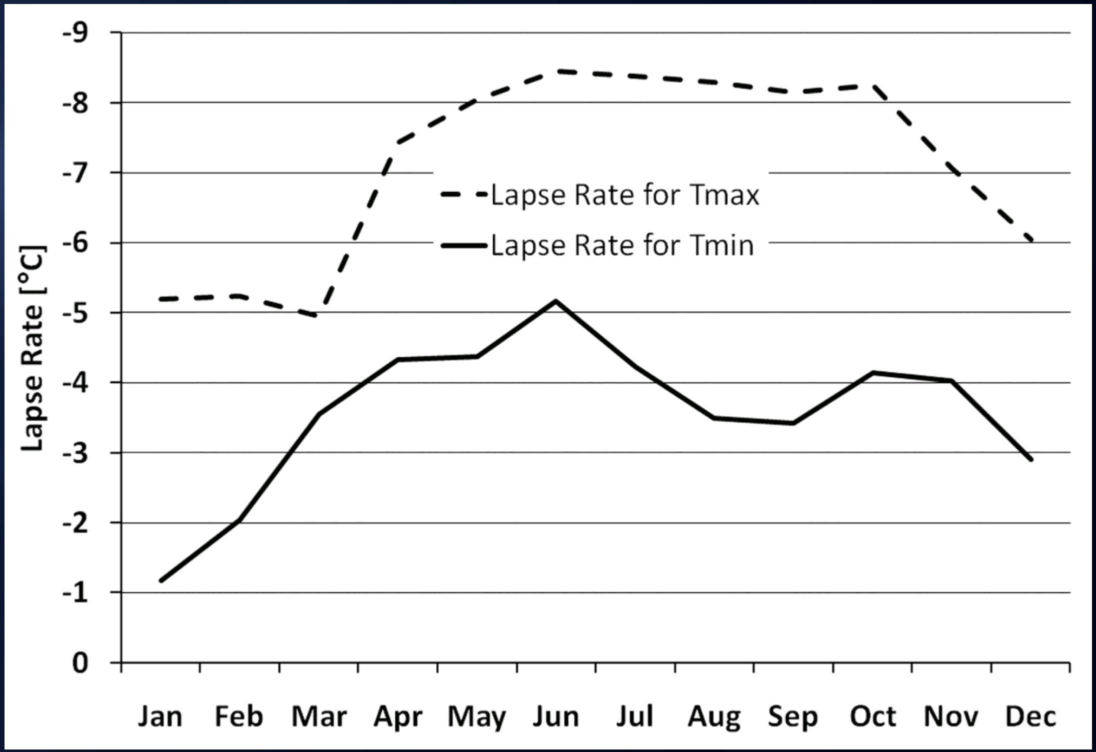
- Plant Transpiration Coefficient
  - = crop coefficient
- Stress threshold
- Interception
- Root distribution
- Initial abstractions

Extensive Data Pre-processing

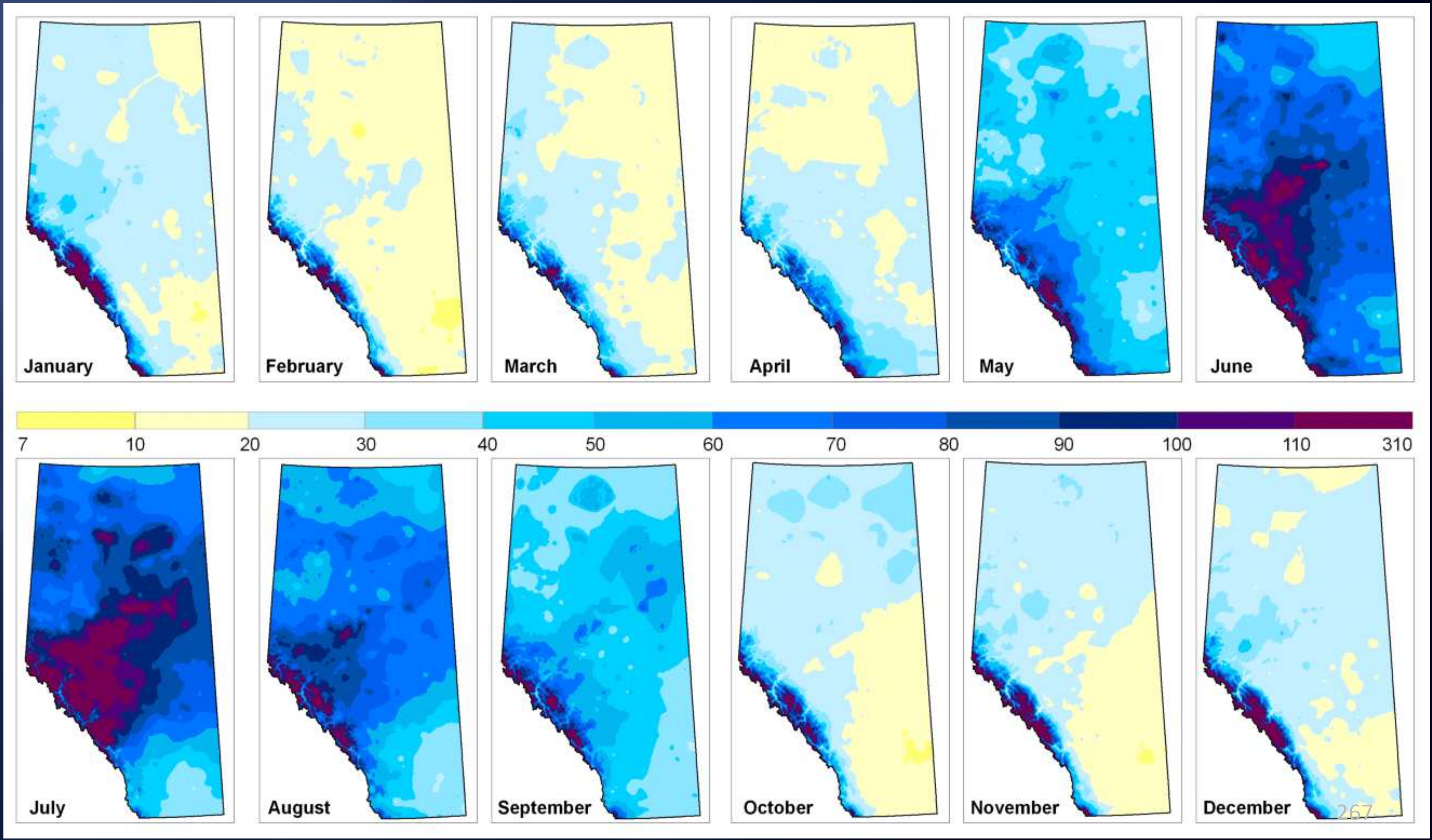


Seasonality of many variables

- Lapse rates
- Wind speed
- Relative humidity
- Albedo
- Radiation
- Sunshine hours

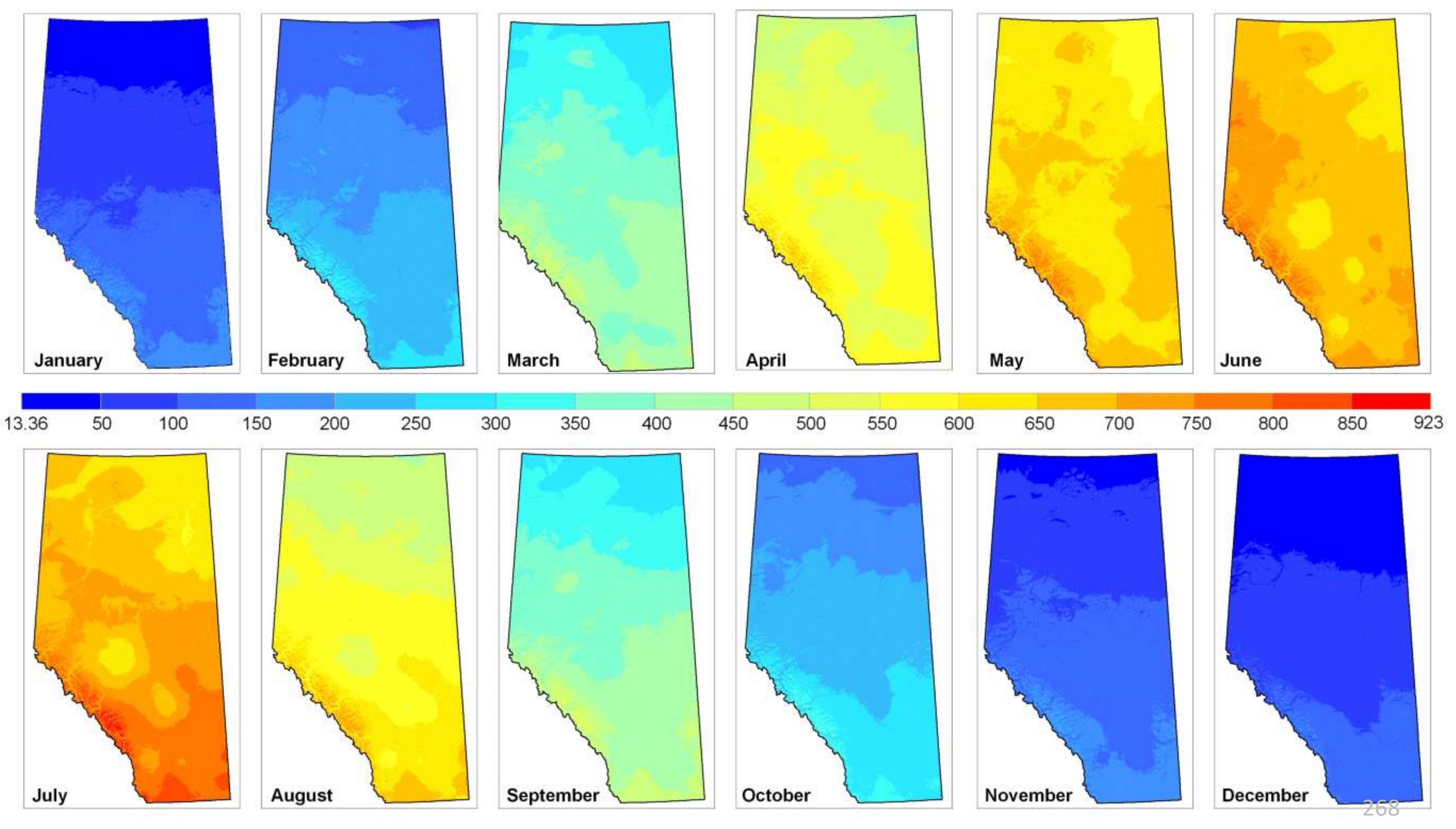


PRISM Mean Monthly Precipitation (1971-2000)
[mm month-1]

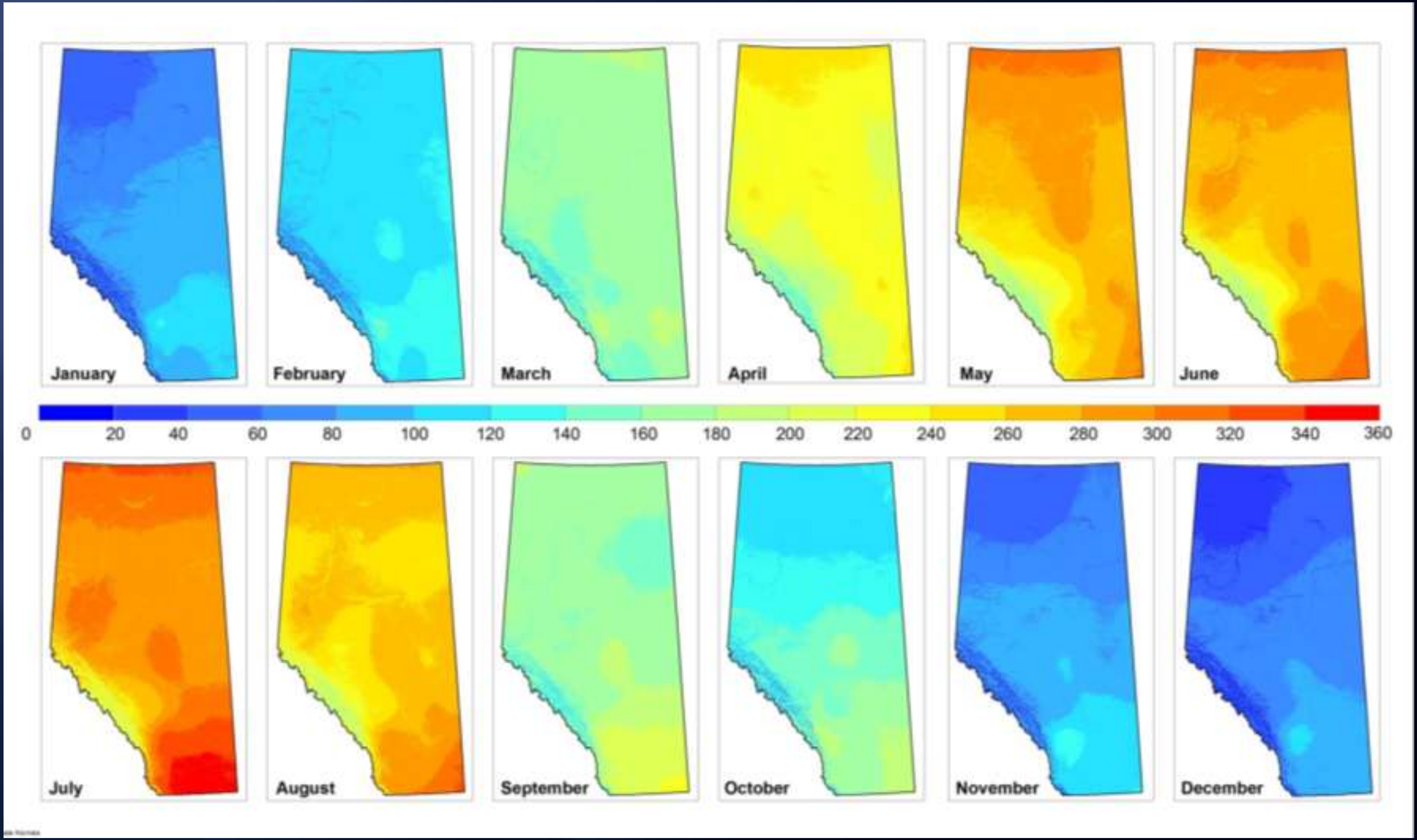


Mean Monthly Incoming Solar Radiation

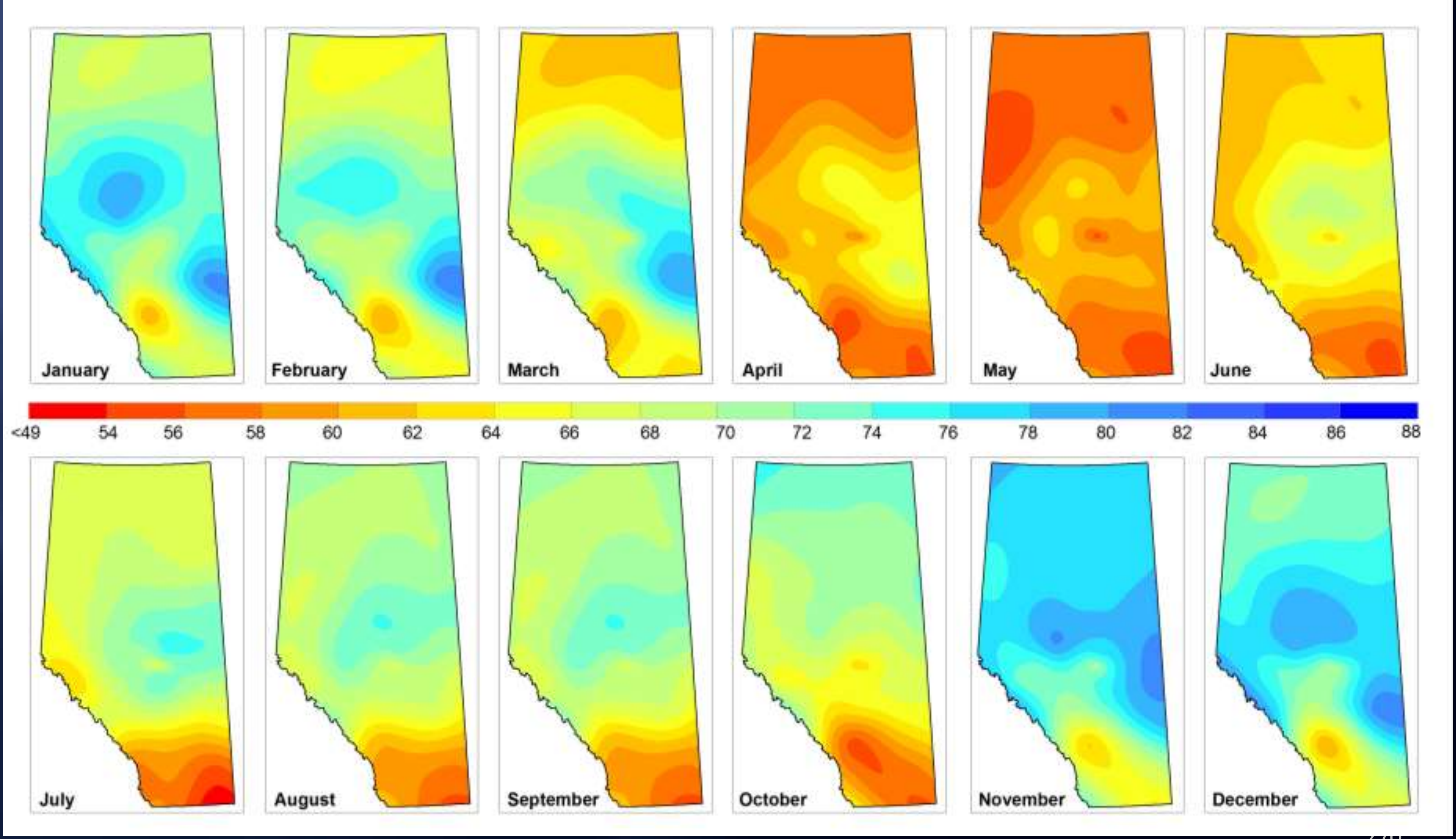
[MJ m-2 month-1]



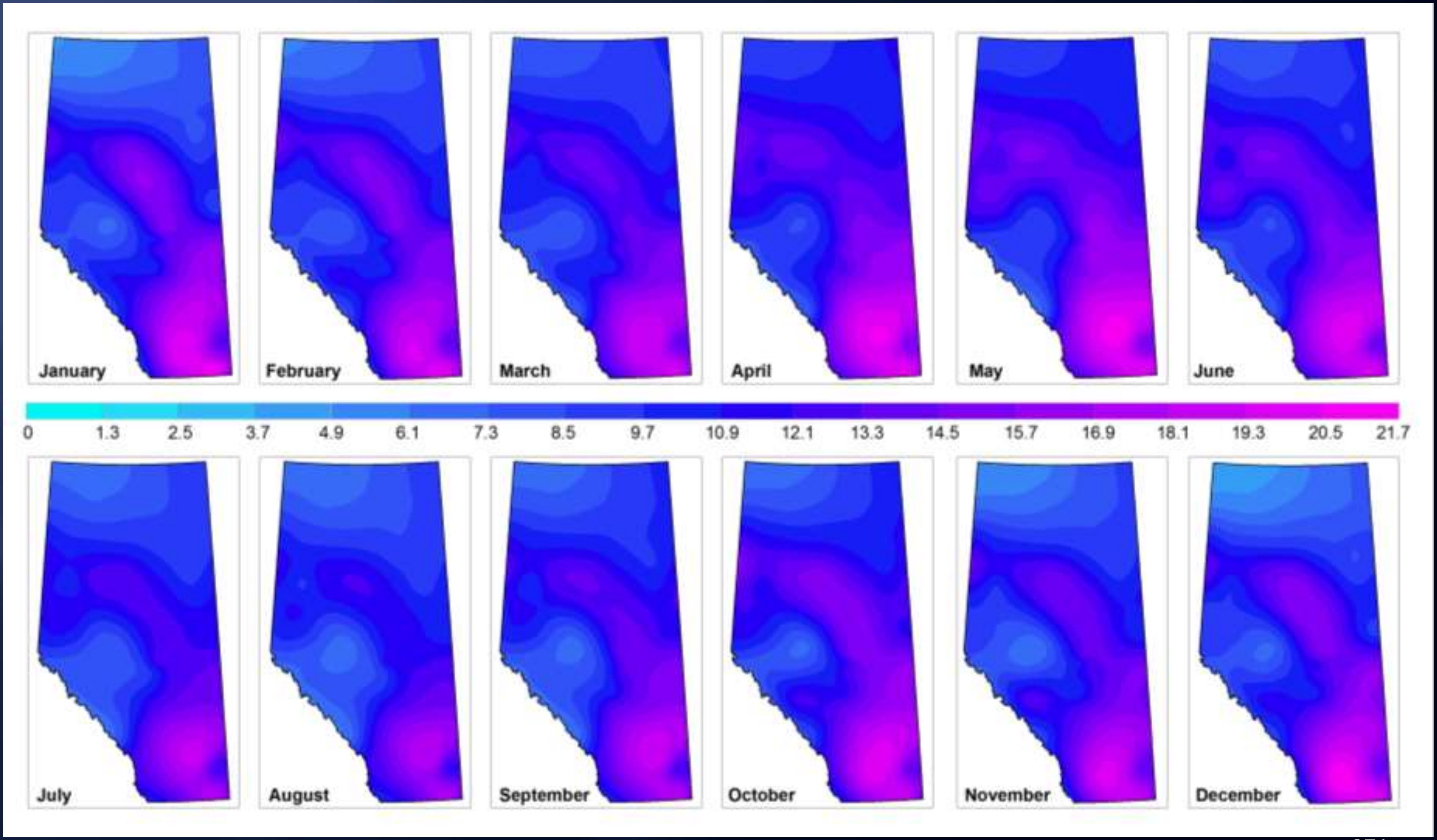
Mean Monthly Sunshine Hours



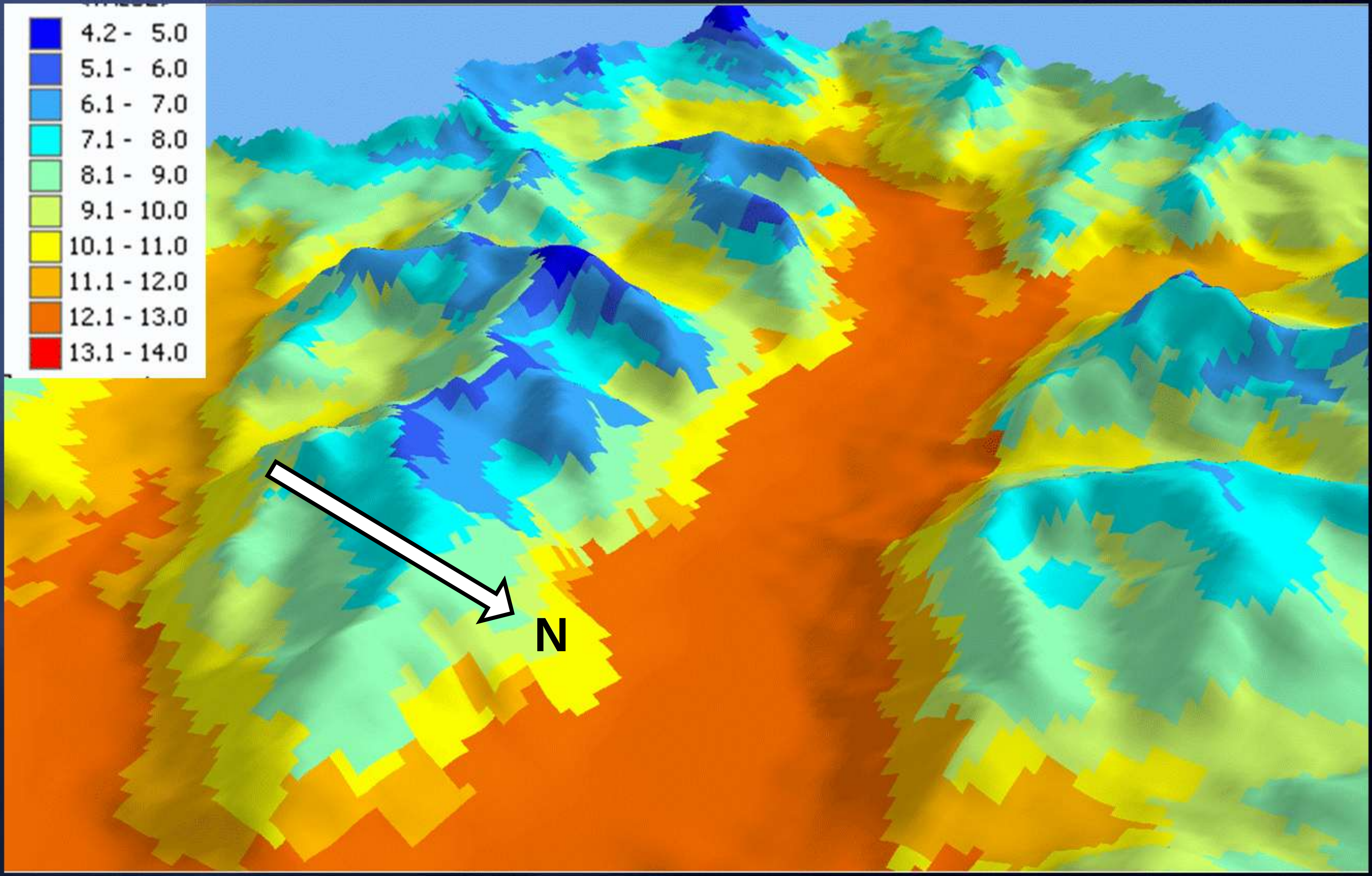
Mean Monthly Relative Humidity [%]



Mean Monthly Wind Speed [km/hr]



MEAN ANNUAL MAX. TEMPERATURE – ADJUSTED



Example Application: Impacts of Climate Change Modelling Approach

1. Setup of all input variables for the physical-based hydrological model

2. Verify baseline (1961-1990) output against observations
   - Air temperature
   - Snow pack (SWE)
   - Streamflow
     - – calibrate within physically meaningful boundaries

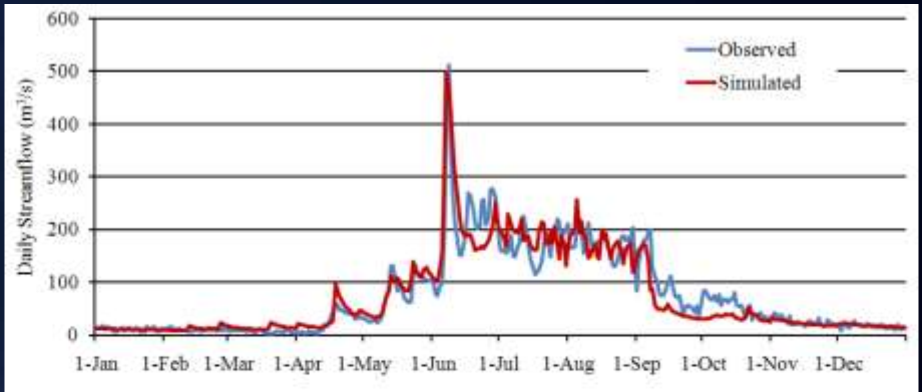
3. Simulate hydrology under environmental change

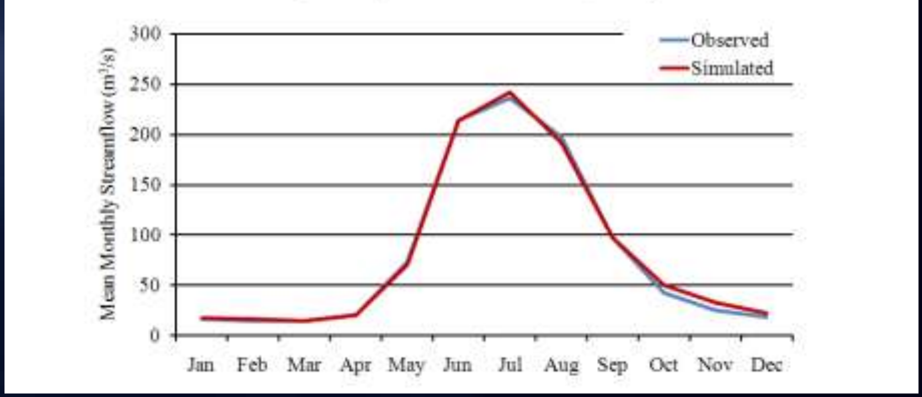
- Risk analysis for operational hydrology

Simulation Objectives: Operational Hydrology

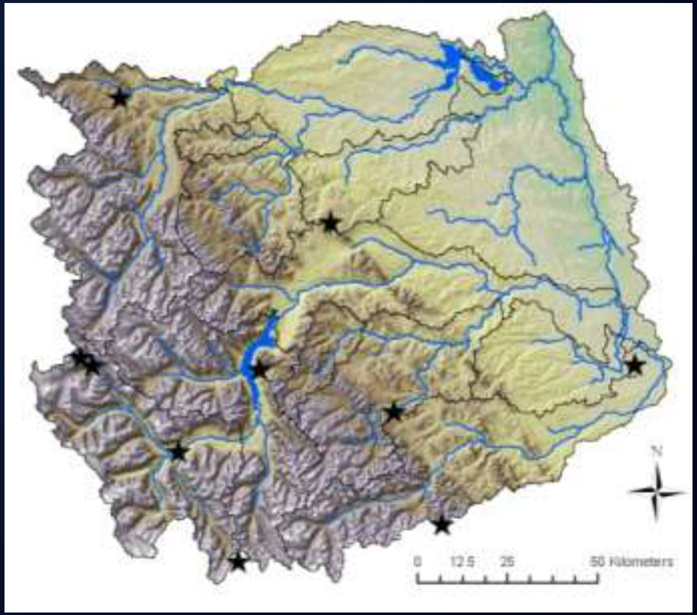
Simulate streamflow for the base period 1961-1990 to replicate these characteristics:

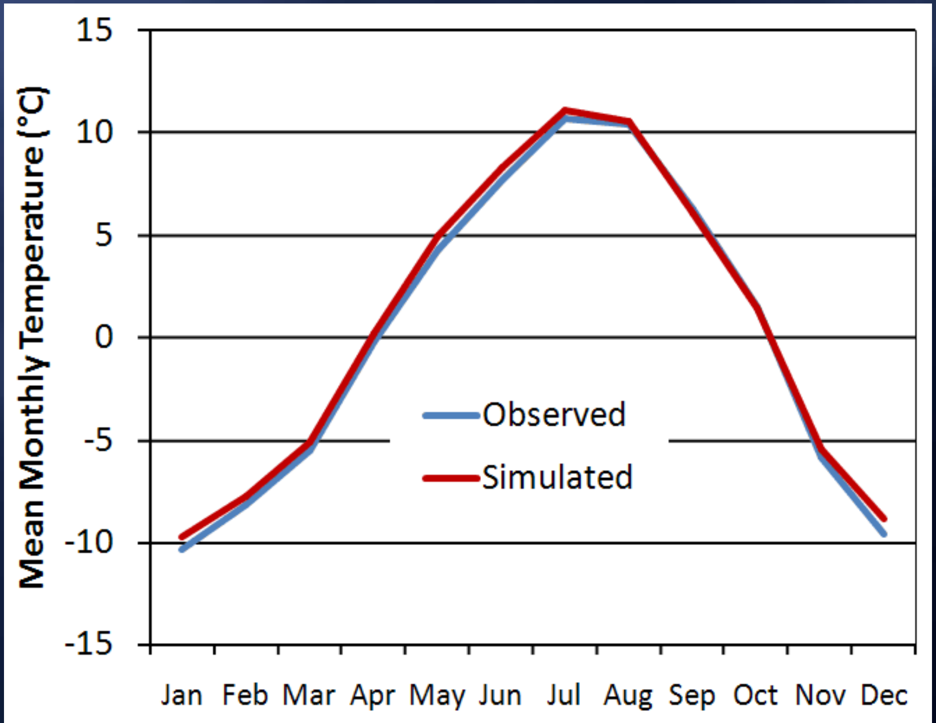
- Annual water yield
- Seasonality
- Shape of hydrographs
- Timing of snowmelt
- Peak flows
- Low flows
- Variance





Temperature Verification

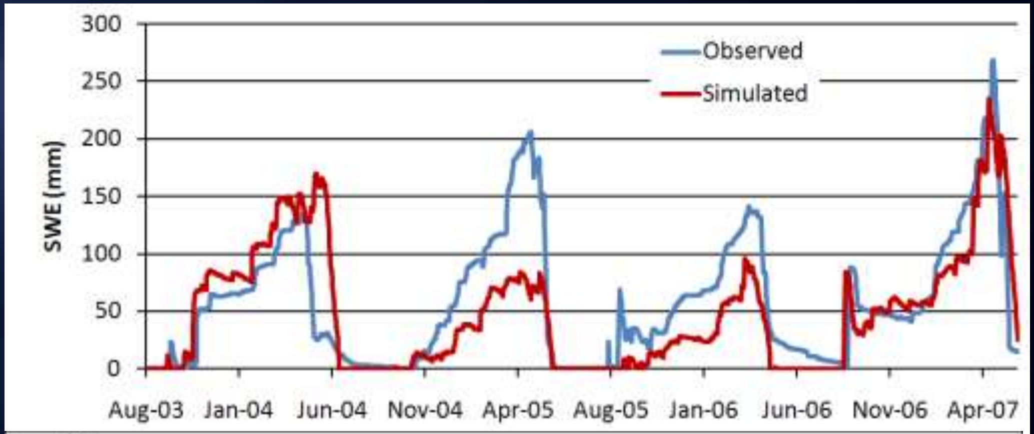


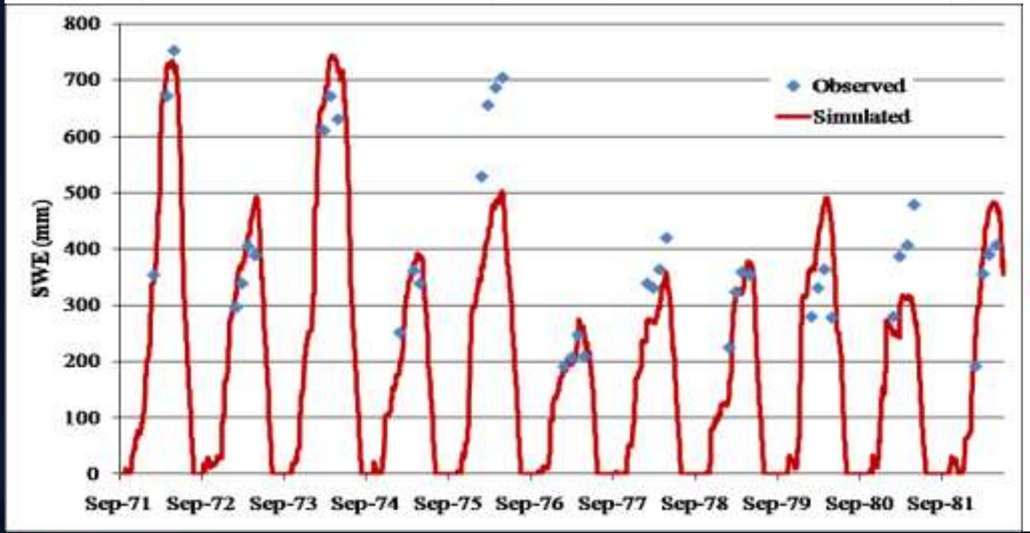


	Daily	Monthly
N	37402	499
Observed Mean (°C)	3.30	0.40
Simulated Mean (°C)	3.67	0.77
P(T<=t) two-tail	0.00	0.46
Observed Variance	78.98	67.04
Simulated Variance	75.48	64.59
% Difference	-4.64	-3.79
Coefficient of Determination (r^2)	0.88	0.98
Regression Coefficient (Slope)	0.92	0.97
Regression Intercept	0.75	0.39

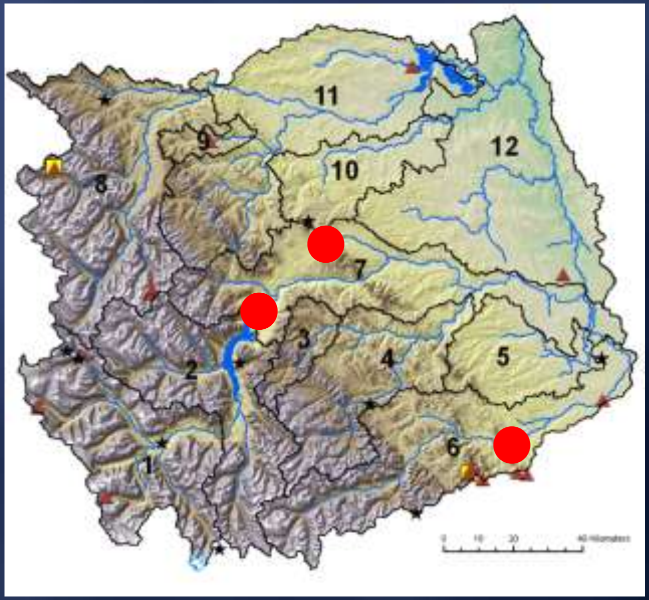
Snow Verification

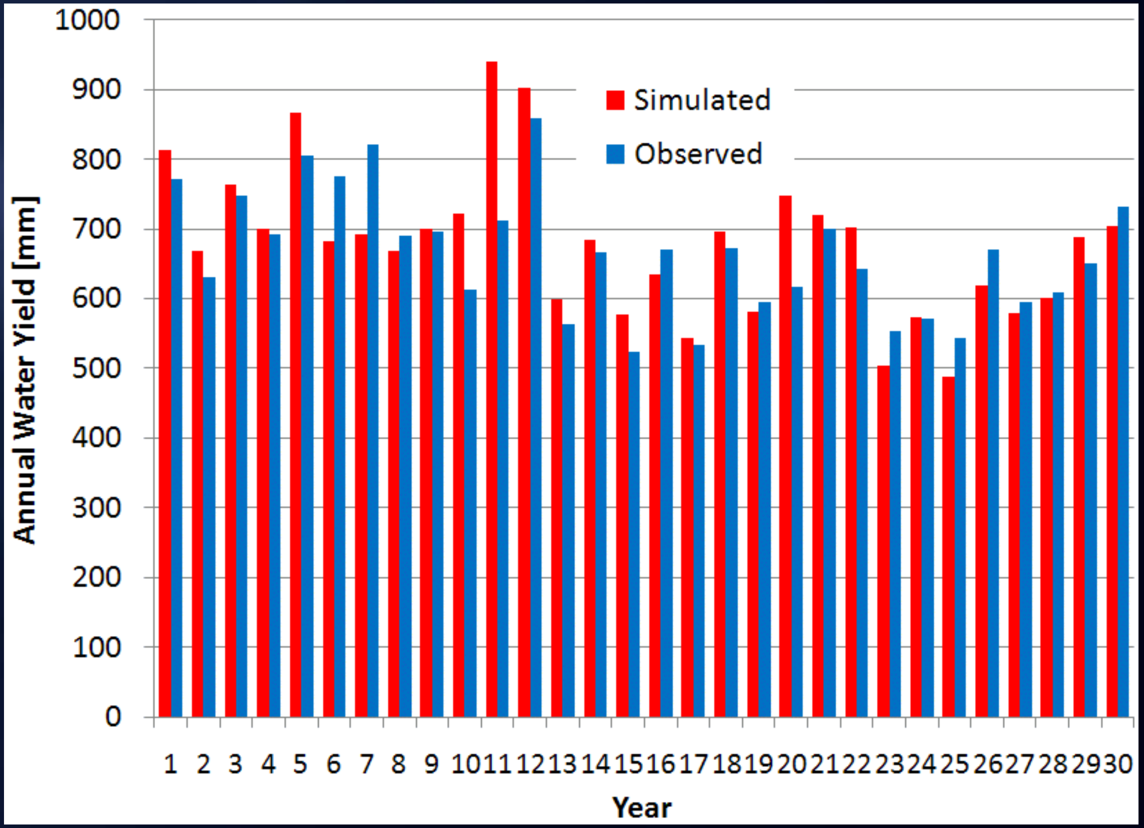
- Average conditions and their variance are simulated successfully.



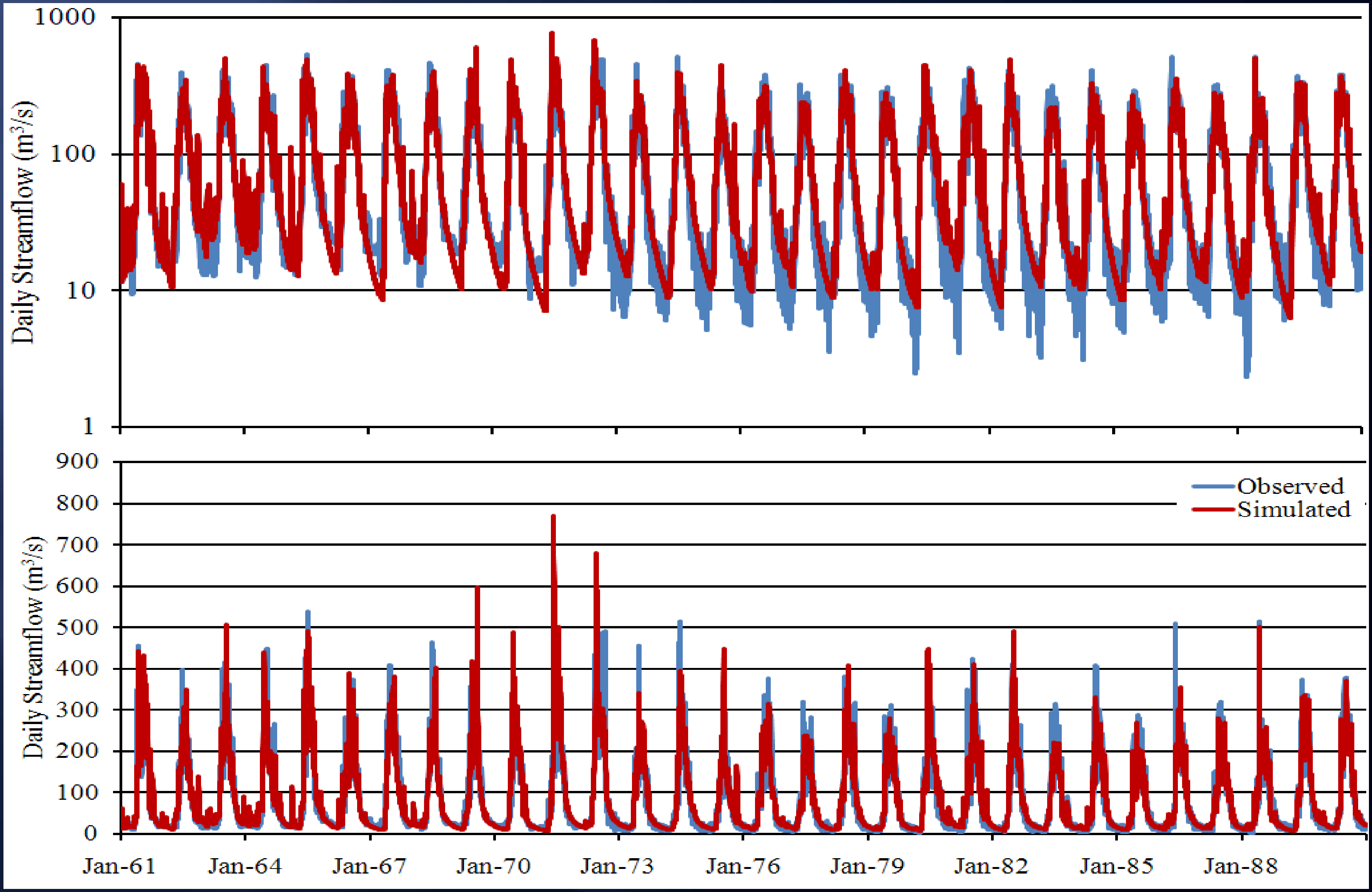


Simulated and Observed Annual Streamflow





Simulated and Observed Daily Streamflow



Cline River: Simulated and observed streamflow

	1961-90	
	Daily	Monthly
Observed Sample Size (Days/Months)	10957	360
Simulated Sample Size (Days/Months)	10957	360
Observed Mean (m^3/s)	81.18	80.77
Simulated Mean (m^3/s)	82.95	82.54
% Difference	2.13	2.14
P(T<=t) two-tail	0.16	0.78
Observed Variance	8756.30	7419.40
Simulated Variance	8445.30	7401.60
% Difference	-3.68	-0.24
Observed Standard Deviation	93.58	86.14
Simulated Standard Deviation	91.90	86.03
% Difference	-1.82	-0.12
Coefficient of Determination (r^2)	0.83	0.92
Regression Coefficient (Slope)	0.89	0.96
Regression Intercept	0.23	0.11

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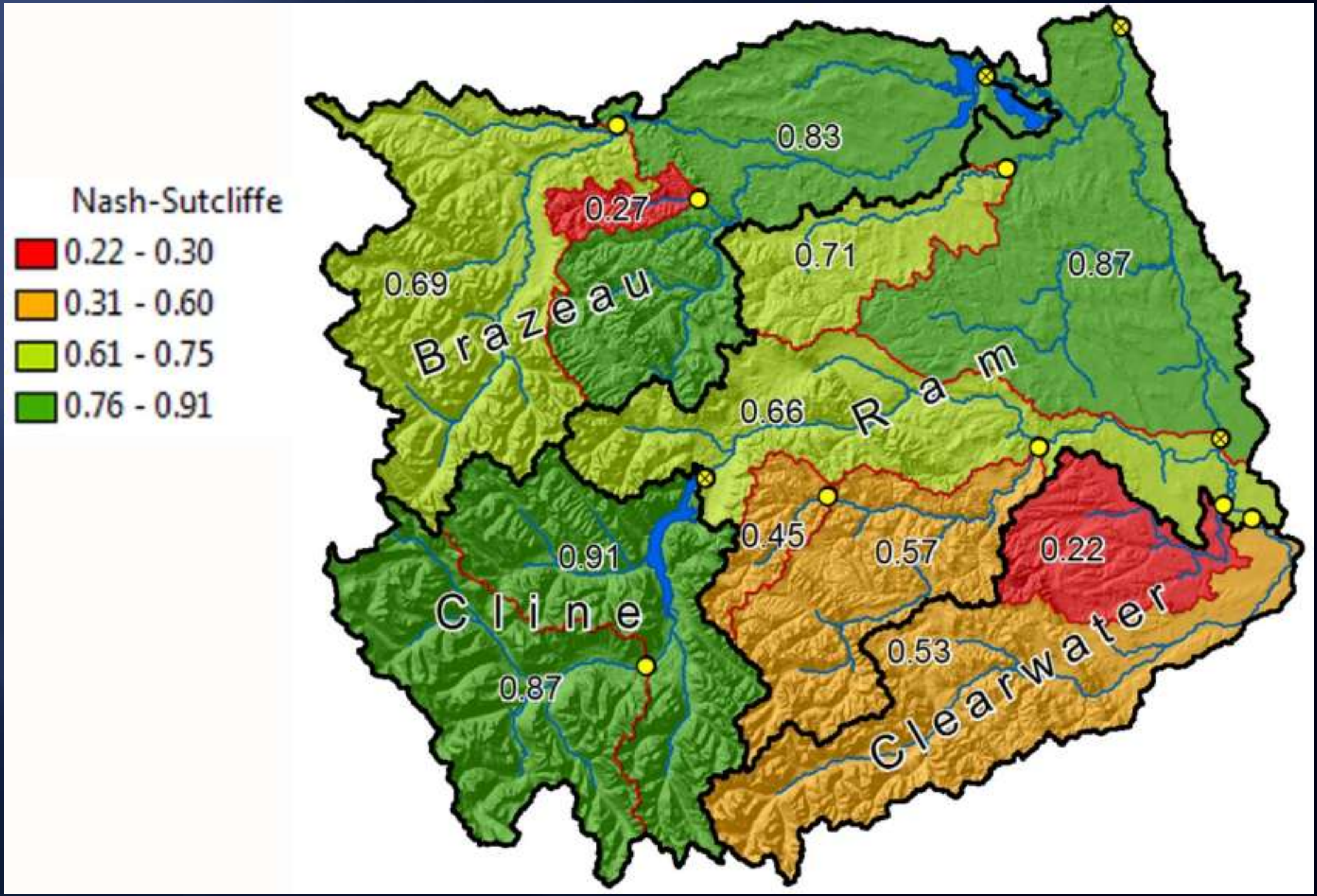
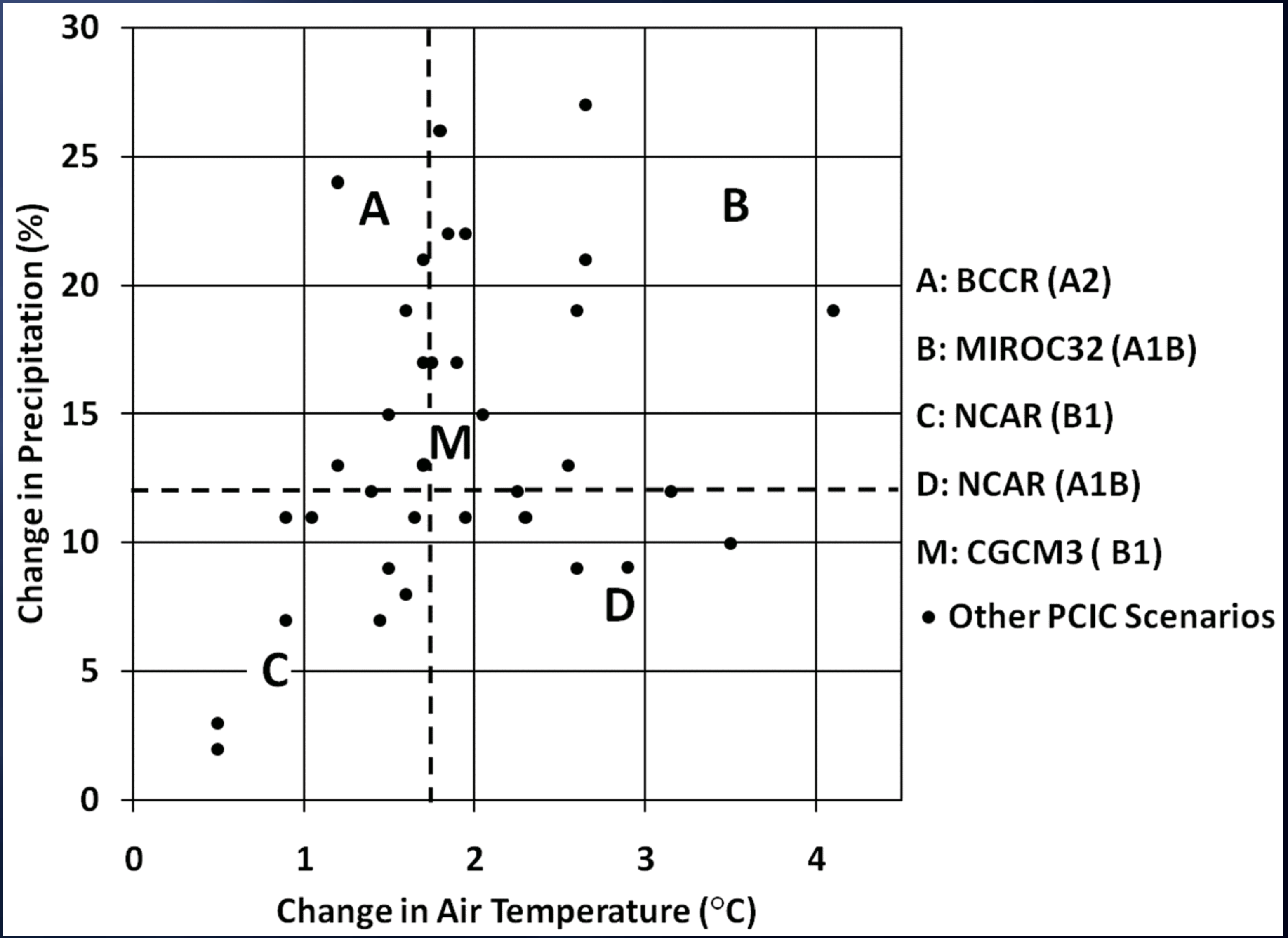
Upper North Saskatchewan River Simulation

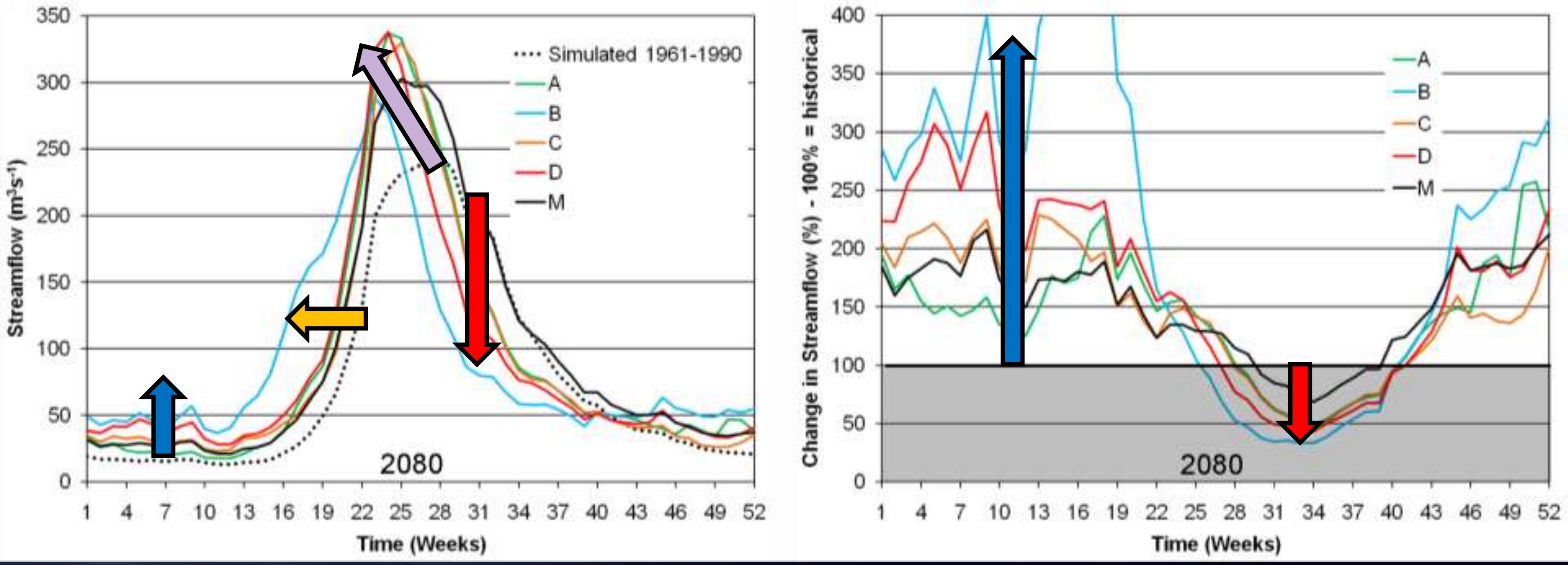
Nash-Sutcliffe Efficiency coefficients for 12 sub-watershds



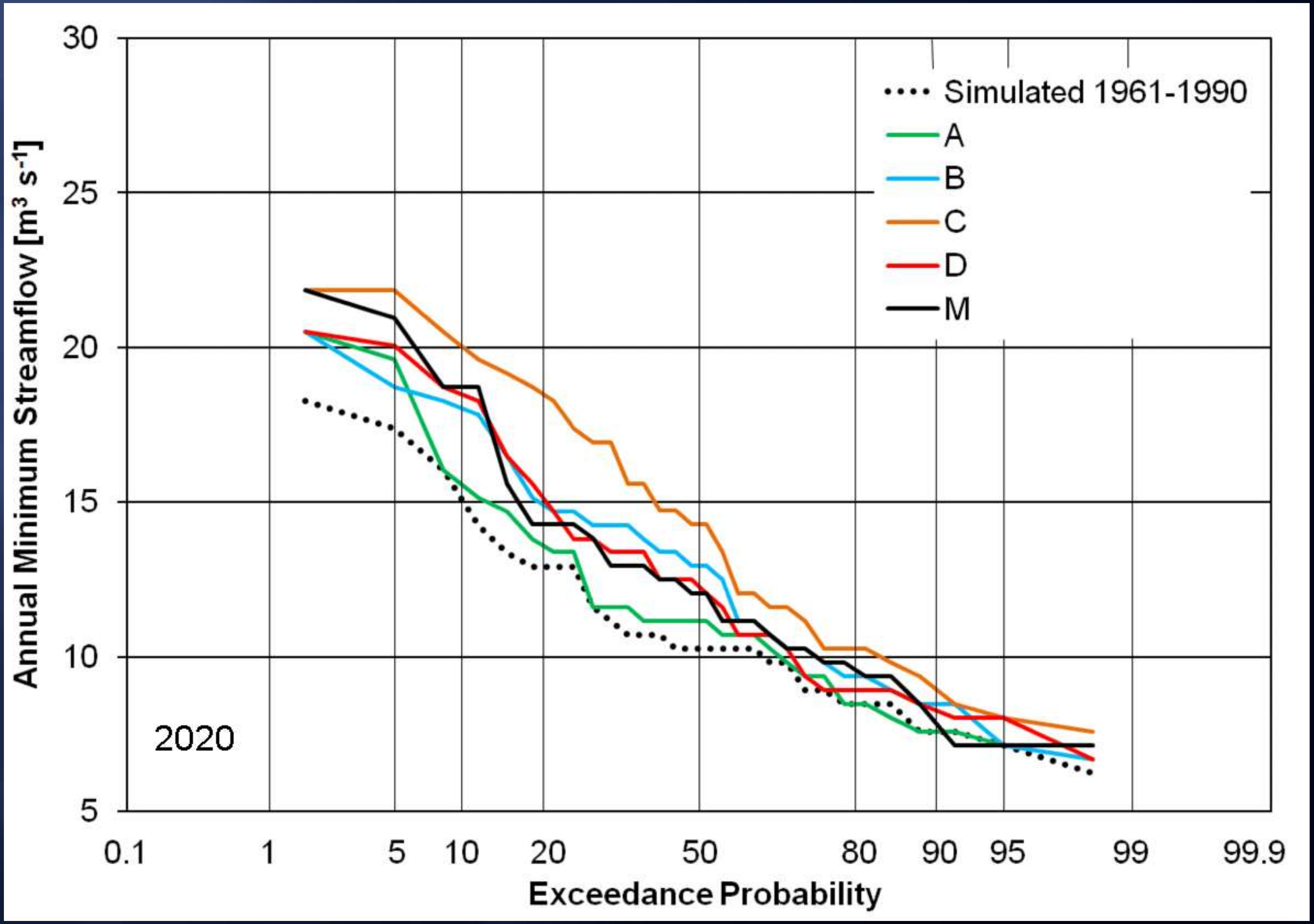
Selection of Climate Scenarios



Cline River: Streamflow Impacts 2040-2069



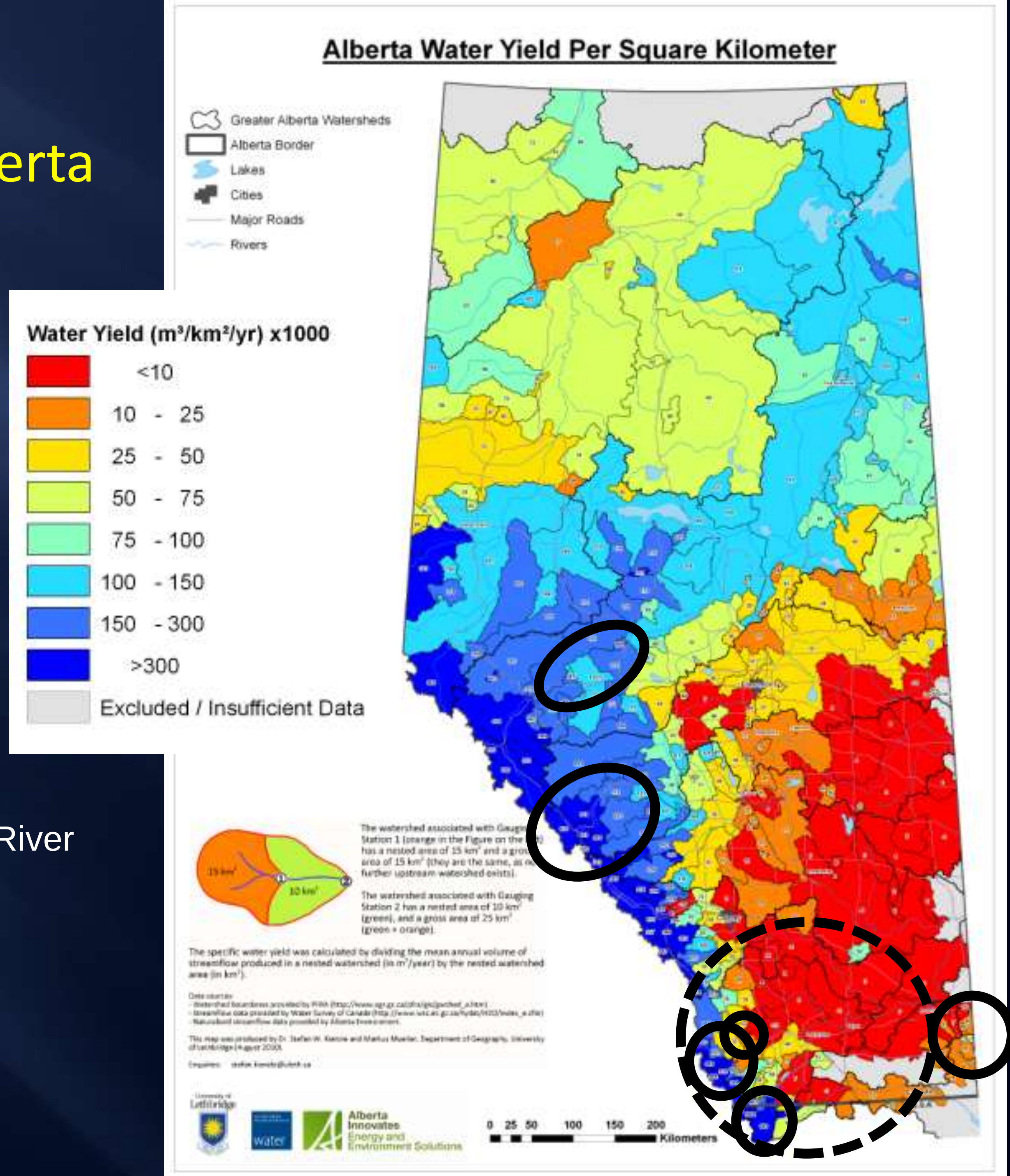
Cline River: Annual Minimum Streamflow Exceedance Probability: 2020



Many hydro-climatological variables

- Daily time series for each HRU:
  - 52 variables
    - Streamflow
    - Groundwater contribution
    - Potential evapotranspiration
    - Actual evapotranspiration
      - Evaporation
      - Transpiration
    - Soil water storage
      - Soil water deficit
      - Groundwater recharge
      - Irrigation demand
    - .....

Water Yield in Alberta



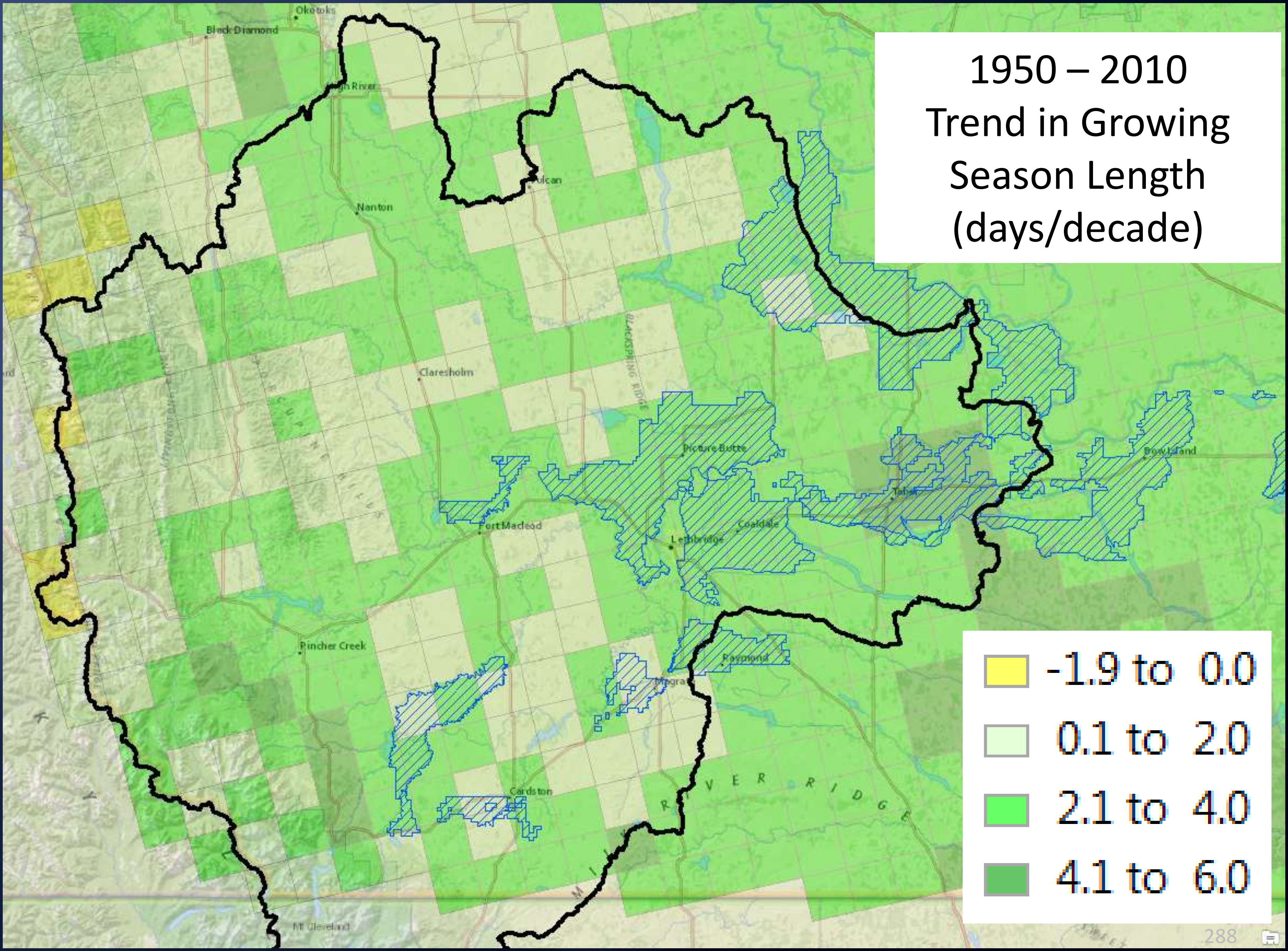
ACRU Simulations in:

- Upper North Saskatchewan River
- Castle River
- St. Mary's River
- Beaver Creek
- Swift Current Creek
- Oldman River
- McLeod River

The ACRU model is used as a translator of climate change and land cover scenarios into hydrological responses.

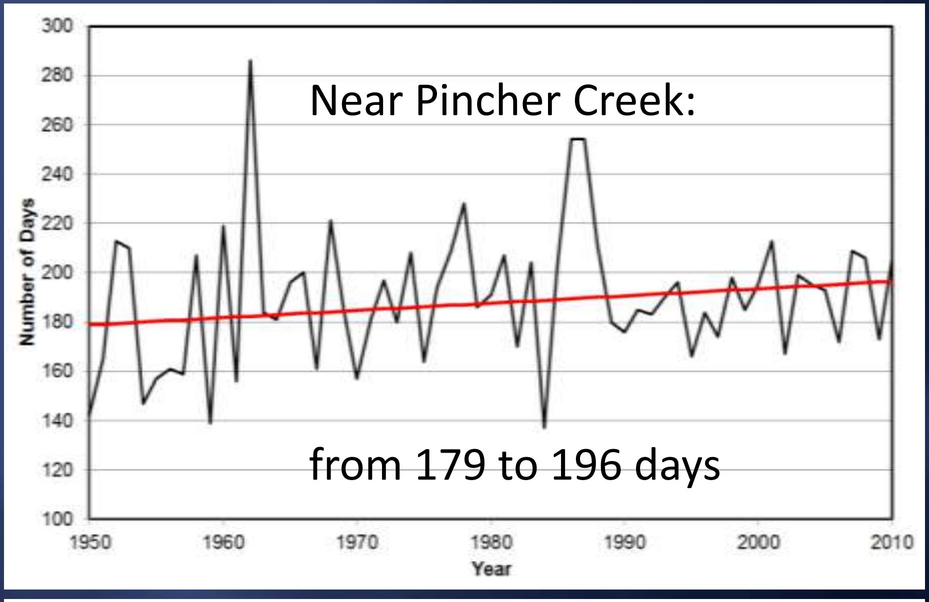
Land Use Impacts on Streamflow
Mgeni Watershed

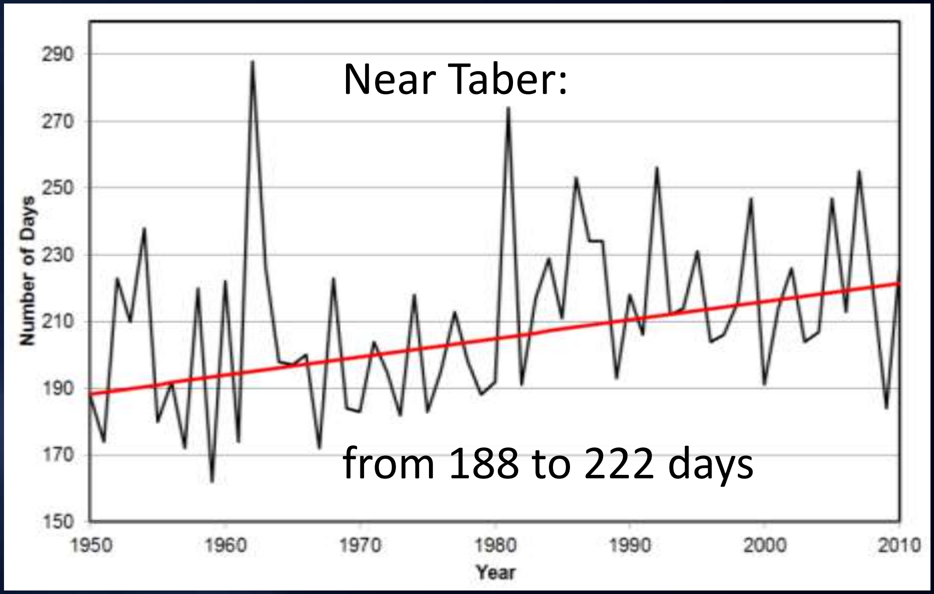
Scenario		Mean annual runoff (mm)			
		Lions MC (MAP = 979 mm)		Karkloof MC (MAP = 1 081 mm)	
A	Baseline land cover	233.4		345.6	
B	Present land use	204.5	(–12.4%)	277.6	(–19.7%)
C	Baseline + irrigation	180.2	(–22.8%)	319.7	(–7.5%)
D	Baseline + afforestation	192.9	(–17.4%)	272.0	(–21.3%)
E	Baseline + 2 × afforestation	178.4	(–23.6%)	241.6	(–30.1%)

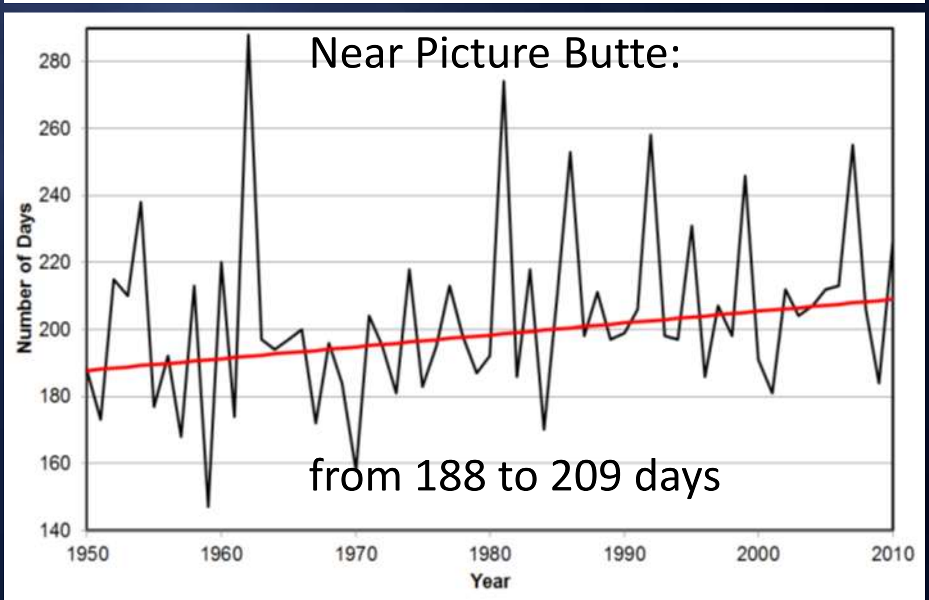


1950 – 2010
Trend in Growing Season Length
(days/decade)
-1.9 to 0.0
0.1 to 2.0
2.1 to 4.0
4.1 to 6.0
Okotoks
Black Diamond
Vulcan
Nanton
Claresholm
Picture Butte
Fort Macleod
Lethbridge
Coaldale
Taber
Bow Island
Pincher Creek
Raymond
Cardston
Mt Cleveland

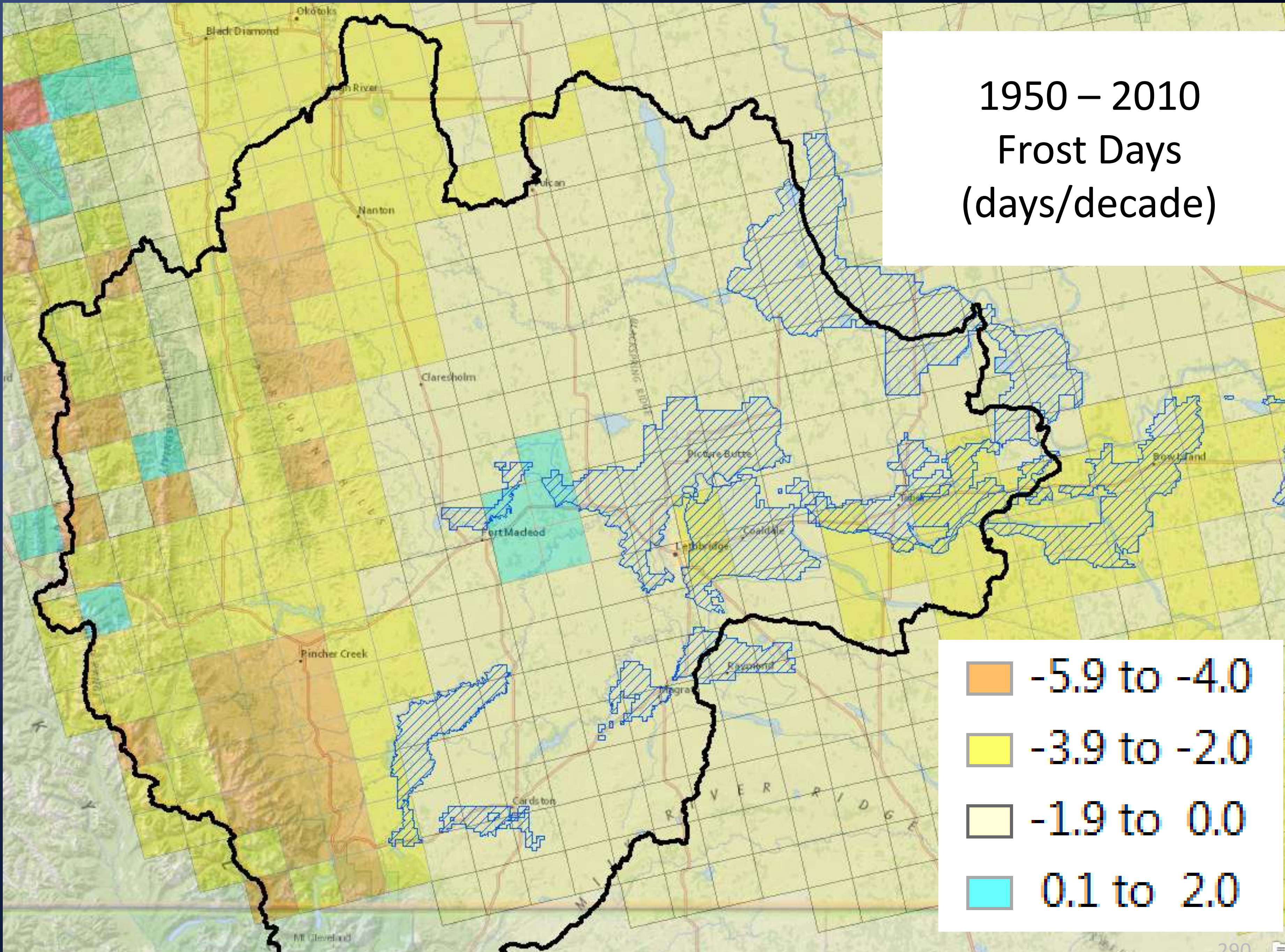
Historical Trend in Growing Season Length



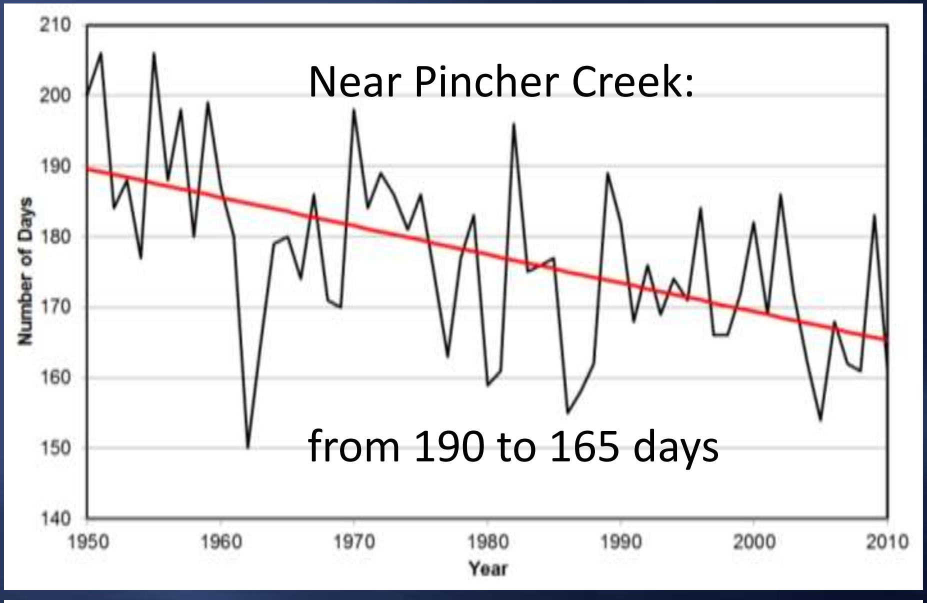


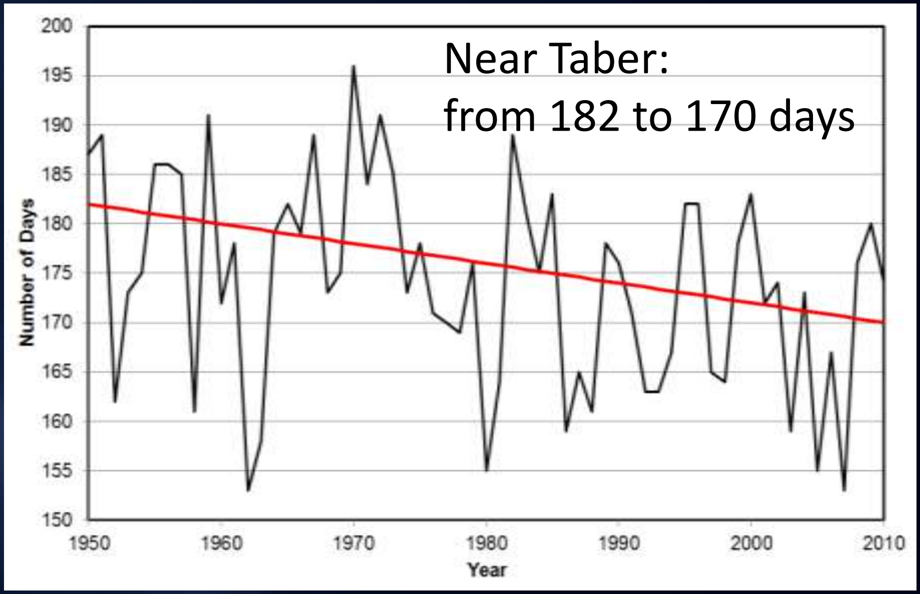


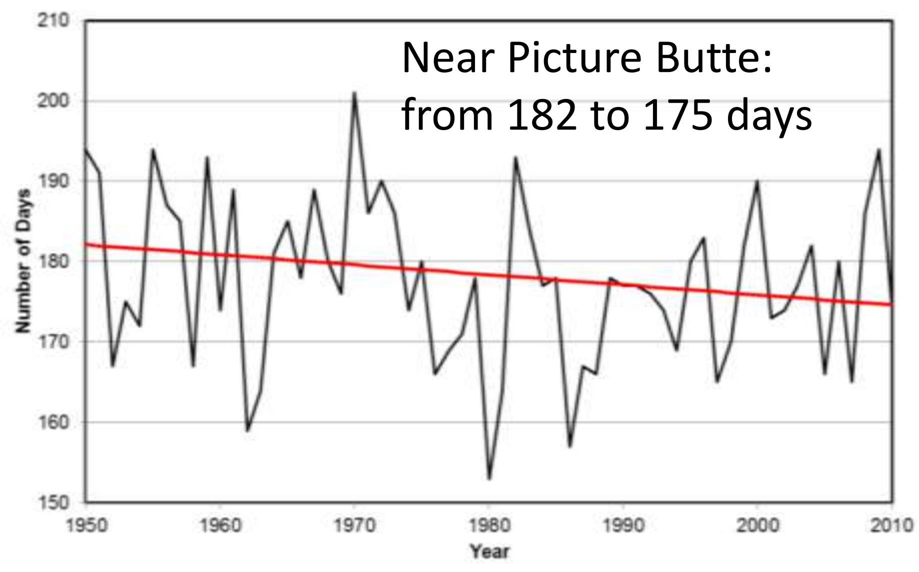
1950 – 2010 Frost Days (days/decade)



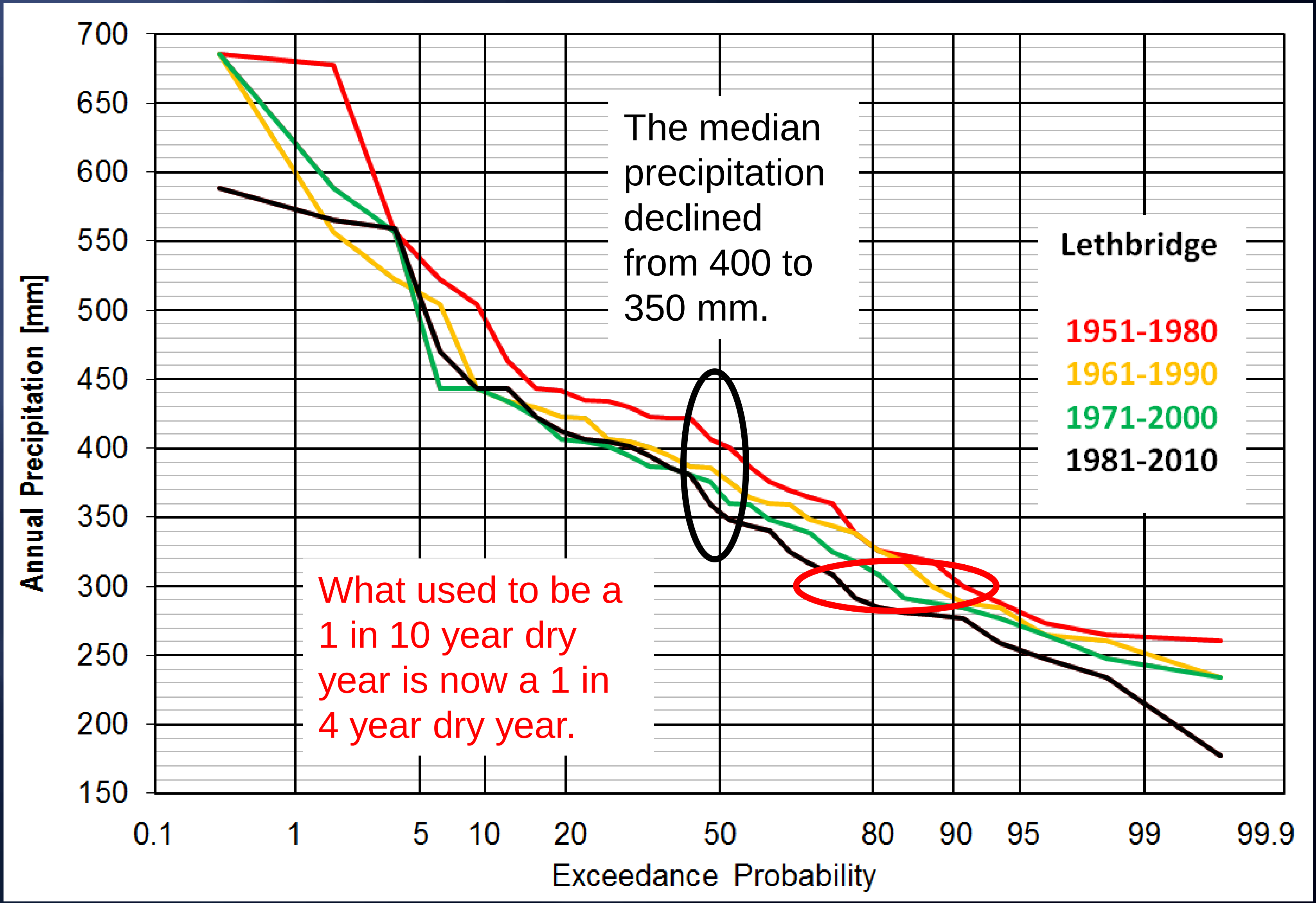
Historical Trend in Number of Frost days







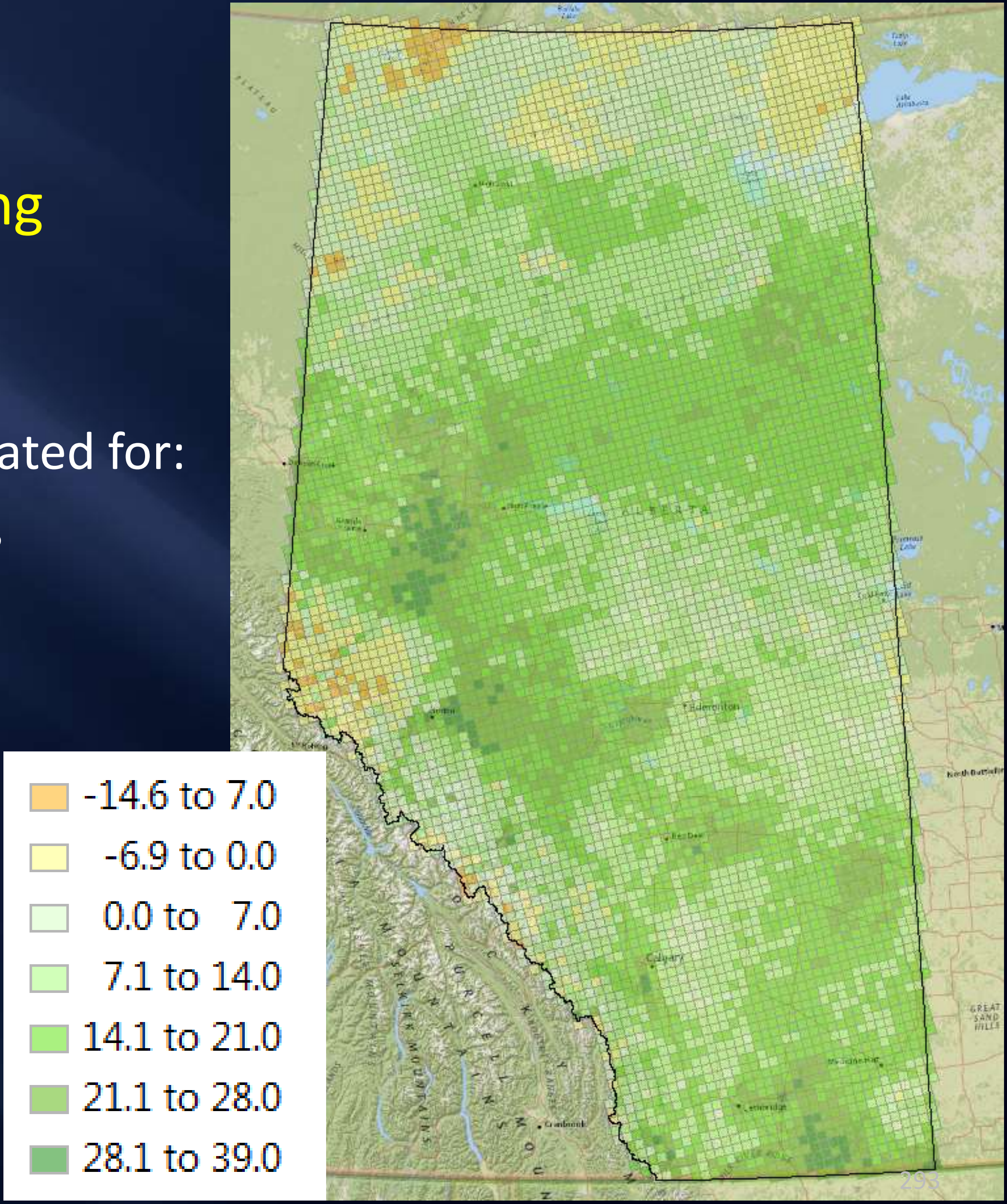
What is the chance of annual precipitation being over a certain value in Lethbridge?



Alberta
1950-2010
Change in growing season length [in days]

Alberta maps will be created for:

- Many climate indices
- PET
- Future climates
- Drought indices
- Crop yields



Day 1 – Session 2

Krish Vijayaraghavan – ENVIRON

BIOGRAPHY

Krish Vijayaraghavan has over 15 years of experience in air quality modelling and analysis, with particular expertise in linkages with watershed models and emissions models.
He has published over 30 peer-reviewed papers in scientific journals and directed modelling studies of photochemical air pollution (ozone, particulate matter), exposure to air toxics such as mercury and arsenic, and atmospheric deposition of sulfur, nitrogen, mercury and other gases to watersheds. These have included studies on diverse topics such as the effect of motor vehicle emissions standards on ambient ozone and PM, the contributions of oil sands emissions in Alberta to acidic deposition and ozone, the long-range transport of atmospheric mercury, and the development of a interface between two advanced air quality and watershed models.

Day 1 – Session 2

Krish Vijayaraghavan – ENVIRON

ABSTRACT

Atmospheric deposition is often a major component of pollutant loading to sensitive watersheds and ecosystems. However, the models used to track the fate of pollutants in the atmosphere and in watersheds have different features and are run at varying spatial and temporal scales with diverse chemical constituents and model inputs. This paper discusses the issues that need to be considered when integrating information from air quality and watershed/ecosystems models to address the impacts of sulfur, nitrogen and mercury deposition on ecosystems.

Linking Air Quality and Watershed Models

Krish Vijayaraghavan and Ralph Morris
ENVIRON International Corporation
Novato, California

AESRD Environmental Modelling Workshop
March 13-14, 2013
Edmonton, Alberta

ENVIRON

Acknowledgements

- Alberta ESRD
- Cumulative Environmental Management Association
- Electric Power Research Institute
- RTI International
- Southern Company
- Stantec
- Systech Water Resources
- Trent University
- U.S. EPA

Integrated Environmental Modelling

ENVIRON

Cumulative Effects Management (CEM)

From the perspective of an air quality modeller

Air Quality Modelling ⟷ **Water, Land and Biodiversity Modelling**

Old Paradigm

Modellers operate in isolated spheres of expertise

New Paradigm

Two-way communication between modellers

Synergize modelling efforts and models where possible

Potential Needs Filled by Air Quality Models in an Integrated Modelling Approach

ENVIRON

- Supplement measurement networks that are sparse in temporal and spatial extent and chemical composition
- Provide dry and wet deposition to aquatic and terrestrial models for critical loads exceedance and other impacts
  - Acid deposition
  - Nutrient deposition
  - Mercury and other air toxics deposition
- Source attribution – Current contributions of sources and effect of changes in air emissions on ecosystems
- Ambient air concentrations for vegetation and human exposure studies
  - Ozone
  - PM
  - Hazardous air pollutants
- Data for socio-economic cost/benefit models
  - PM etc.

Air Quality Models

- **Global 3-D:** GRAHM, GEOS-Chem, MOZART etc.
- **Regional 3-D**: AURAMS, CMAQ, CAMx, RELAD etc.
- **Local puff/plume:** CALPUFF, AERMOD, SCICHEM etc.
- **Local/regional plume-in-grid:** CMAQ-APT, CAMx-PiG

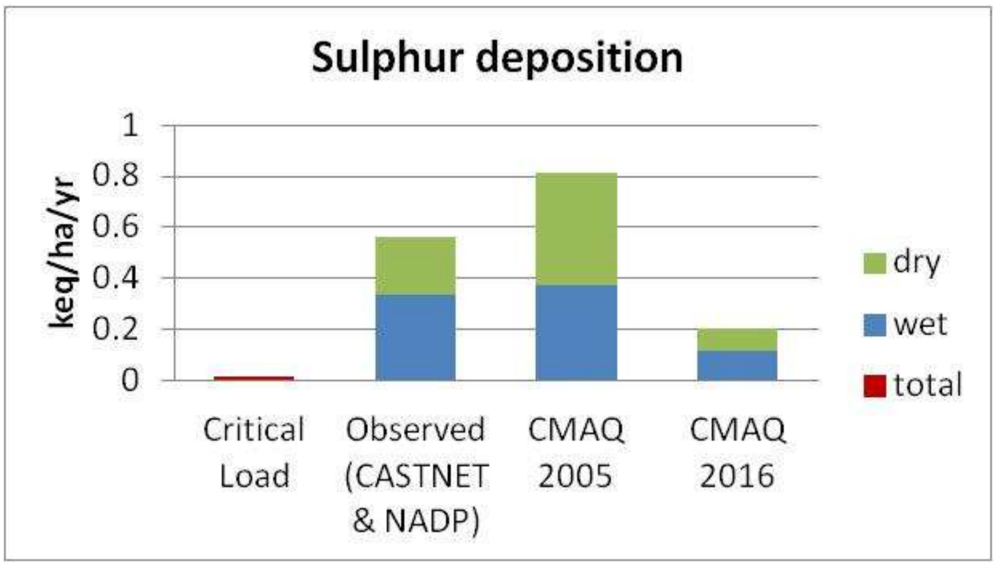
- Focus here on deposition modelled by CMAQ and its potential role in integrated modelling systems

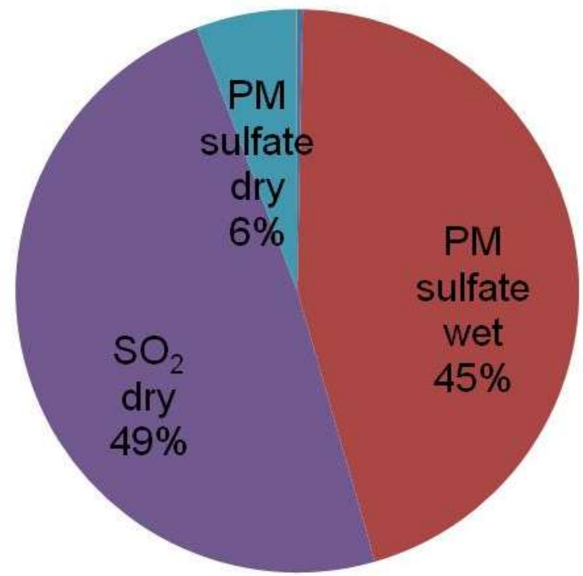
  CMAQ
  - Applied by Alberta ESRD and CEMA
  - Advanced multi-pollutant 3-D photochemical model
  - Developed by U.S. EPA with regular scientific updates from the community
  - Emissions from natural and anthropogenic sources, dispersion, chemical and physical transformations, dry and wet deposition of gases and particulate matter
  - Ozone, PM, acid deposition of N and S compounds, mercury and other air toxics
  - Base cations are modelled but emission inventories are uncertain

Sulphur Deposition in CMAQ

- Sulphur dioxide (SO_2)
- Particulate sulphate ($SO_4^{=}$)
- Sulphuric acid (gaseous H_2SO_4 quickly condenses on to PM sulphate)

Example of application to identify critical load exceedances of surface water acidity: Sulphur deposition at Shenandoah National Park in Virginia





Total = 0.8 keq/ha/yr in 2005
For comparison, levels in Alberta range approximately from 0.01 to >1 keq/ha/yr

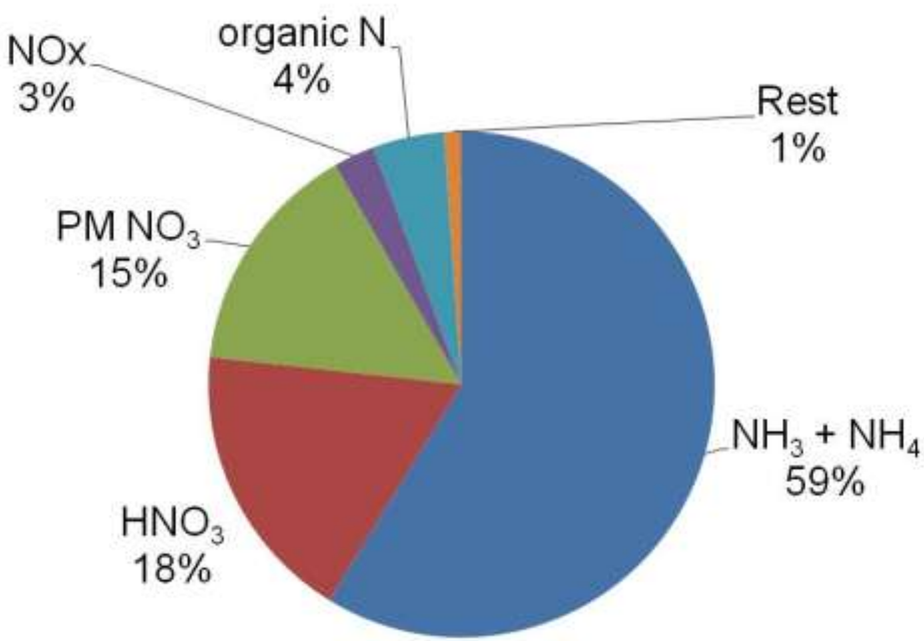
Source: Vijayaraghavan et al., 2012

Acknowledgement: U.S. EPA

Nitrogen Deposition in CMAQ

- NOx (NO, NO_2)
- Inorganic oxidized Nitrogen (HNO_3, N_2O_5, HONO, HNO_4, PM NO_3)
- Reduced Nitrogen (NH_3, PM NH_4^+)
- Organic Nitrogen (PAN, PANX, NTR)

Example: Components of nitrogen deposition at Shenandoah National Park



Total = 1.3 keq/ha/yr in 2005

Large fraction from NH_3 and NH_4

Potential in Alberta too

Source: Vijayaraghavan et al., 2012

Role of Ammonia/Ammonium Deposition

- Deposition of PM sulphate and nitrate associated with ammonium
- Reduced nitrogen itself can be a large fraction of total deposition
  - Gaseous ammonia dry deposition (wet smaller)
  - Particulate ammonium wet and dry deposition
- Eutrophication
- Acidification
  - Simpler air quality models assume constant ammonia concentrations and consider acidification due to only sulphate and nitrate
  - However, ammonia nitrification → acidification
- Alberta has one of the largest ammonia emissions inventories in Canada - large livestock population and fertilizer application
- Potential emissions from tailings, forest fires etc.
- Forest Service has measured high NH_3 (> 1 ug/m3) in remote areas in AB
- Air quality models used in integrated modelling in Alberta need to accurately characterize ammonia air concentrations and deposition

Deposition and Exceedances of Critical Loads (CL) of Surface Water Acidity

- Unlike sulphur, some of the deposited nitrogen is retained in the terrestrial system and does not contribute to acidification.
- Potential acid input = S deposited + N deposited – N retained – BC
- CL of waters already includes BC. Methods for calculating exceedance:
  - EPA: Use measurements in surface streams to estimate net N loading to water

    Exceedance = S deposition + Measured N – Critical Load

    Cannot be applied for source attribution because modelled N is not used

  - Assessments in the oil sands region assume that 25% of the nitrogen compounds are acidifying when the N deposition is < 10 kg N/ha/yr

    Exceedance = Pre-development (loading estimated from measured S and N) + Post-development (modelled S dep + modelled N dep x retention factor) – Critical Load

    Simple approach for post-development but may be applied in emissions scenarios

  - Alternative advanced approach

    Apply mechanistic watershed model to estimate terrestrial retention of deposition from air quality model. Laborious but ideal for source attribution.

    Exceedance = S dep + Modelled N calibrated using measured N – Critical Load

Mercury Deposition

- Potential for dry deposition and wet deposition in rain and snow in Alberta

- Gaseous elemental mercury (HG)
  - negligible wet but undergoes dry deposition (bidirectional like NH_3)

  Gaseous oxidized mercury (HGIIGAS)

  Substantial wet and dry deposition

  Particulate-bound mercury (PHG)
  - Intermediate wet and dry deposition

- Mercury deposition → Risk due to methyl mercury in fish and wildlife ?
  - Advanced Hg watershed/biocycling model, e.g., D-MCM or WARMF
  - Simpler approach - Human health risk assessment model such as HHRAP
  - Simplest approach – assume linearity

ENVIRON

Examples of Air-Watershed Linkages

U.S. EPA's Watershed Deposition Tool

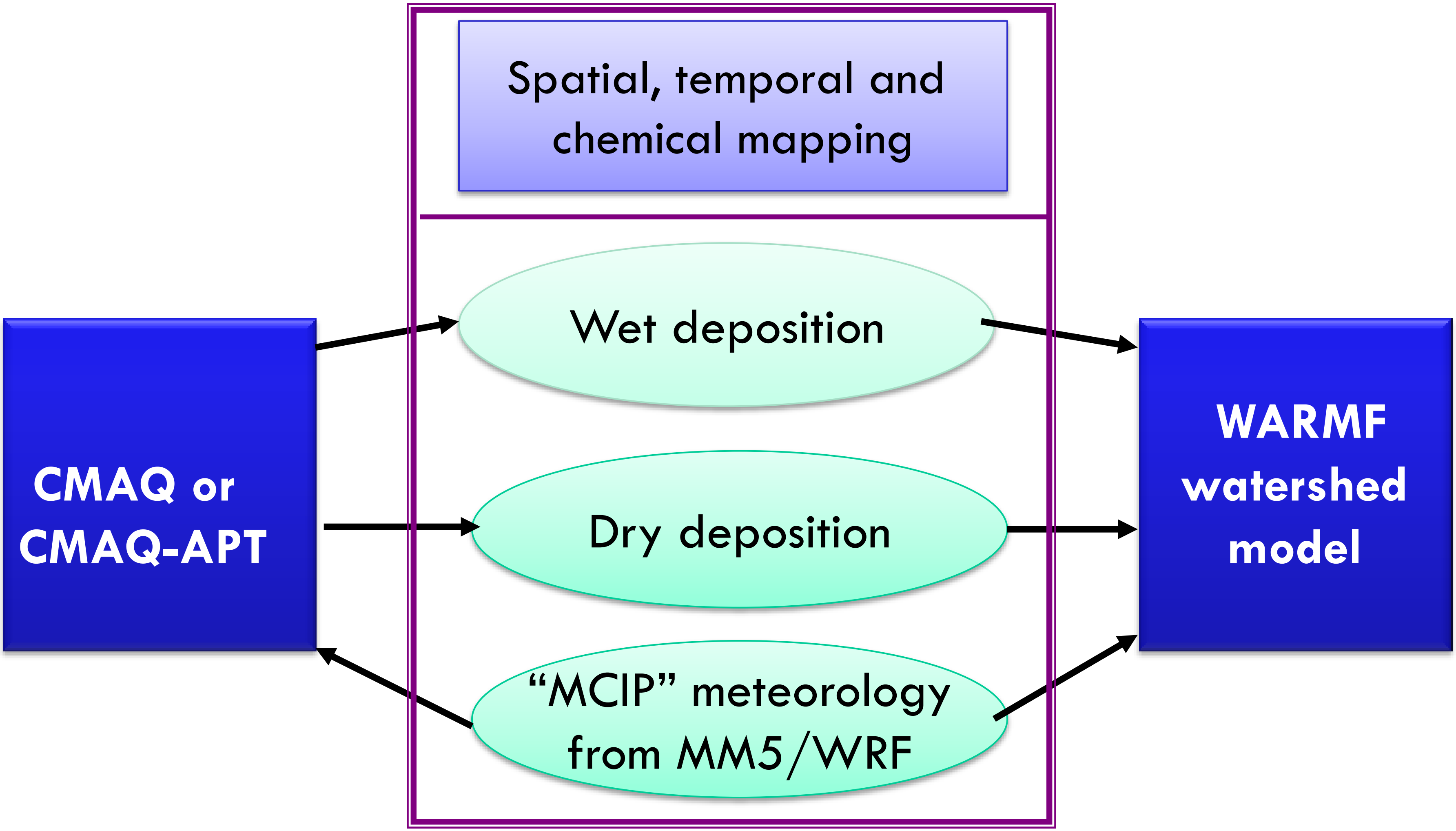
Schwede et al., 2009

- GIS-based tool that maps gridded deposition estimates from CMAQ to 8-digit hydrologic unit codes within a watershed or region.
- Deposition components:
  - Total Nitrogen – Dry and Wet; Oxidized and Reduced
  - Total Sulphur – Dry and Wet
  - Total Mercury – Dry and Wet
- Calculate the weighted average deposition over a HUC and the average change in a HUC between two different emission scenarios
- Advantage: Simple to use
  Disadvantage: Cannot use the deposition values to model within a watershed as values are averaged over watersheds

Examples of Air-Watershed Model Linkages

Linkage between CMAQ & WARMF and CMAQ-APT & WARMF

Herr et al., 2010; Vijayaraghavan et al., 2010



Acknowledgement: Systech Water Resources

CMAQ-WARMF Linkage
Application in Catawba River Basin, USA

Spatial Mapping

CMAQ-APT domain

Southeastern USA

Rectangular grid:

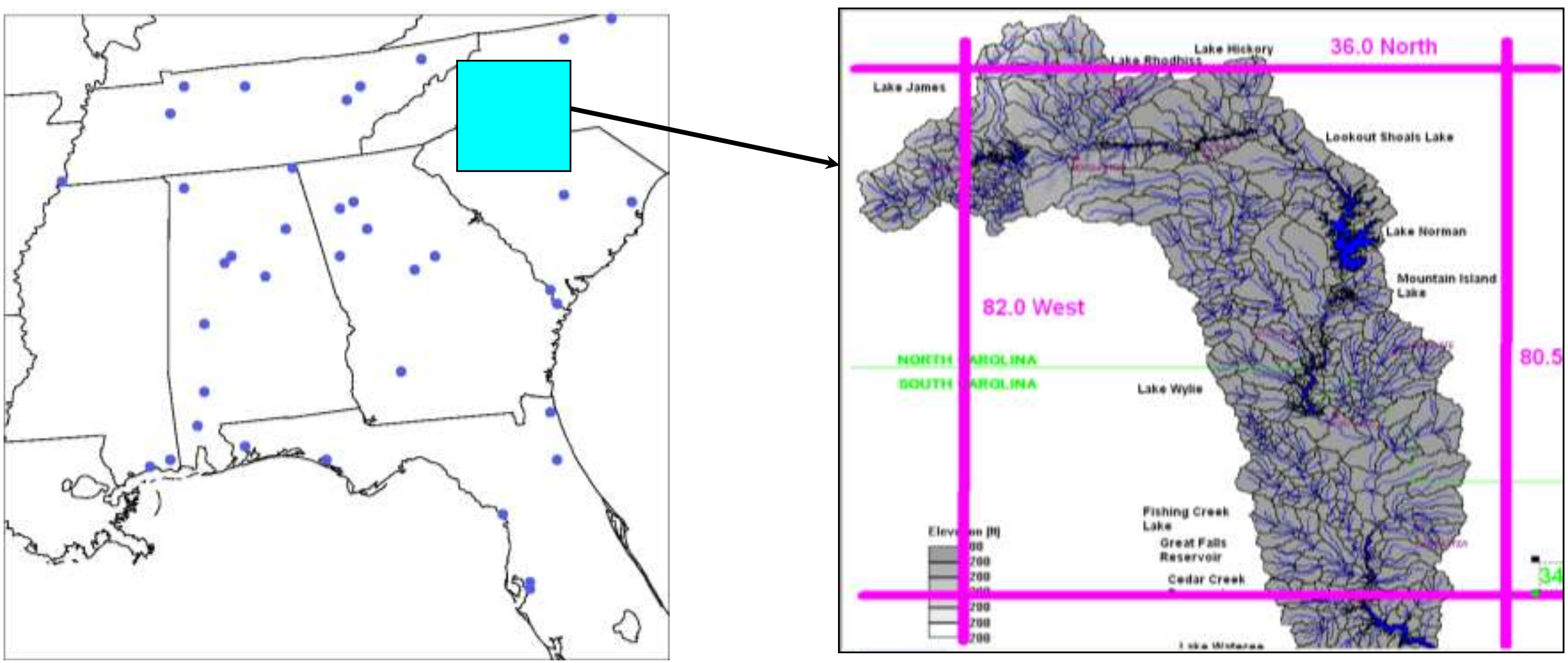
12 or 4 km resolution

WARMF domain

Catawba watershed

Irregular catchments/ reservoirs

~ 1 km^2 and larger



CMAQ-WARMF Linkage
Temporal Resolution and Extent

- Temporal Resolution:

  CMAQ hourly temporal resolution → Daily totals for WARMF

  Match time zones
- Temporal extent:

  CMAQ 1-5 years → 50-100+ years for WARMF

  Important to model multiple years with air quality model to account for inter-annual variability in meteorology (e.g., precipitation)

  Model climatologically normal or “dry, wet and normal” years

  Communication important among modellers on extrapolating the AQ model deposition to the time period of the watershed model
- Important to identify key historical and planned future changes in emissions to get proper time record in the watershed model

CMAQ-WARMF Linkage
Chemical Species Mapping

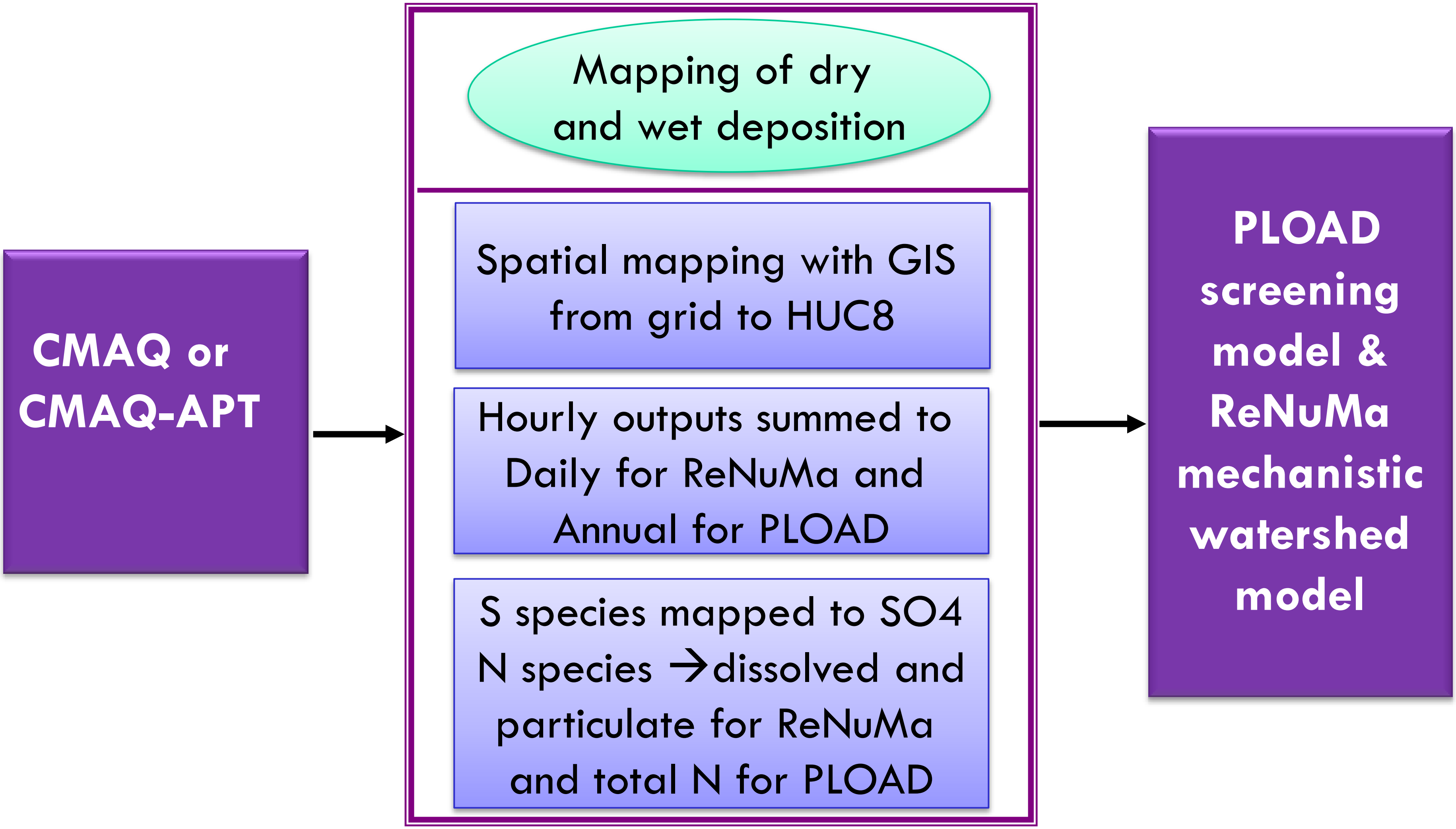
ENVIRON

WARMF species	Mapping from CMAQ species	Notes
SOX	SO2	as S
SO4	PM SO4	as S
NOX	NO + NO2	as NO2
NO3	Total NOz	Oxidized N other than NOx (as N)
NH4	NH3 + PM NH4	as N
CA, MG, K	Ca, Mg, K are not commonly modelled	Interpolate from NADP data
NA, CL	Use PM Na and Cl (however concentrations uncertain)	Interpolate from NADP data
HG0, HG2	HG, HGIIGAS	
HGP	PM Hg	

Examples of Air-Watershed Model Linkages

Linkage between CMAQ & PLOAD and CMAQ & ReNuMa

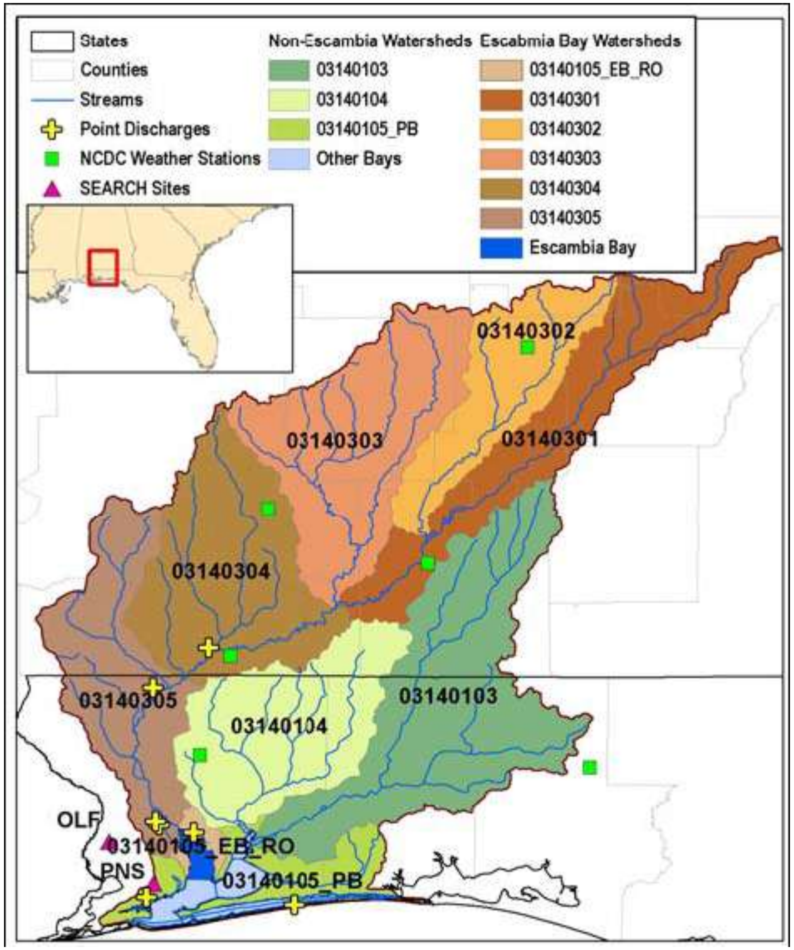
Brandmeyer et al., 2007; Vijayaraghavan et al., 2010b



Acknowledgement: RTI International

Linkage between CMAQ & PLOAD and CMAQ & ReNuMa

Escambia Bay and Watershed in Alabama/Florida



1. Increase in NH_3 dry deposition after SO_2 and NOx reductions at local power plant and regionally → Dis-benefit

Change in NOy deposition (tons/yr N)	Change in NHx deposition (tons/yr N)	Change in Total N deposition (tons/yr N)
-2571	838	-1733

2. Calculated that approximately 10-18% of N deposition to the watershed reaches the Bay after terrestrial retention

Source: Brandmeyer et al., 2007; Vijayaraghavan et al., 2010b

Example of Air-Water Model Linkage

Proposed Work

- Link CMAQ deposition outputs to MAGIC model

- MAGIC: dynamic hydrogeochemical model of water acidification

- MAGIC Inputs:
  Precipitation
  Wet and Dry deposition of SO4, Cl, NO3, NH4, Ca, Mg, Na, K
  MAGIC conventionally uses measured wet deposition and scales those to estimate dry deposition

- Use CMAQ to supplement measurements by providing wet and dry deposition at selected receptor locations: average deposition over each of the catchments modelled in MAGIC

- Important to select appropriate CMAQ emissions scenarios, i.e., identify when and where deposition changes due to changes in emissions (e.g., mines coming online) to specify historical and future break-points in MAGIC

Inconsistencies in Inputs of Different Model Components of an Integrated Modelling System

- **Precipitation**

  Problem

  Hydrology in water model driven by measurements

  Wet deposition in air model driven by modelled precipitation or modelled + measured precipitation

  Partial solution

  Scale wet deposition from air model by measured precipitation before handover to water model

- **Land use**

  Problem: Land use used to simulate dry and wet deposition in the air model often different from the land use in the land/water model

  Partial solution: Keep track of deposition in air model by land use type within a grid cell and handover to land/water model

Summary

- Frequent interactions between modellers in different disciplines are important for efficient integrated modelling efforts
- Advanced air quality models such as CMAQ can serve multiple needs for cumulative effects management
- Nitrogen species have different deposition characteristics and need to be modelled separately. In particular, important to model the impact of reduced nitrogen in Alberta
- Several approaches have been reported for linking air and watershed models
- Integrated models should resolve spatial, temporal and chemical differences in model configuration and inconsistencies in model inputs

Day 1 – Session 2

Kent Berg– AESRD

BIOGRAPHY

Kent Berg has a Bachelor of Science degree in Civil Engineering from the University of Calgary and is a professional engineer with AESRD. He has over thirty years experience with the department in water management and planning. Over the last twelve years, he has worked with the Water Resources Management Model that has been used by the department to support major water planning activities in southern Alberta since 1980.

Day 1 – Session 2

Tom Tang & Kent Berg– AESRD

ABSTRACT

Model developments and applications in the S. Region have been and are continuing to be driven by population growth and demand for safe and secure water supply. The emphasis of the modelling team in the Southern Region is primarily with water modelling. We work with specific water quality models and a water allocation model. The team supports regional delivery functions related to Water Act approvals, Water Management Operations and Watershed planning.

Our presentation describes the model development plan we are implementing to support two major initiatives in Southern Region:

· SSRB (South Saskatchewan River Basin Plan) implementation

· SSRP (South Saskatchewan Regional Plan)

The SSRB plan is an approved water management plan under the Water Act. The effect of the plan is closure of the Bow, South Saskatchewan, Oldman and related southern tributaries to new water allocation applications and introduction of the ability to transfer licences. Our water allocation model (WRMM) has and continues to be part of the plan development and implementation. We are in the process of updating the model to continue supporting the plan.

The SSRP is part of the provincial Land Use Framework initiative wherein a number of major overarching plans are being developed across the province. It is the second plan to be produced under the framework. Our team is working to build the capacity to develop new water quality models as well as land use modelling to support SSRP development and future implementation.

Southern Region Modelling Initiatives

Regional Science and Planning Environmental Modelling Team

Southern Region

Drivers of Model development in the Southern Region

- Population Growth
- Water Scarcity
- Large water consumers

- Need for safe, secure water supply

Southern Region Modelling Team

Primarily Water Modelling

- Allocation
- Quality

Support to

- Approvals
- WMO
- Planning
- Apportionment negotiations

Development Plans

Supporting

- SSRB (South Saskatchewan River Basin) Plan
  - Approved water management plan
  - Basin closure to new applications (except Red Deer basin)
  - Updating of WRMM to support implementation
- SSRP (South Saskatchewan Regional Plan)
  - Land use framework planning
  - Building capacity for Water Quality and Land Use modelling

WRMM
Water Resources Management Model

The Water Allocation Problem

The Water Allocation Problem (in words)

How do you allocate a scarce resource (water) among competing demands in the most efficient way?

More than simple accounting

Constraints add complexity:

- Priorities.
- Instream objectives.
- Sharing agreements.
- Storage
- Variable flow from week to week , month to month, year to year

Origin of WRMM

Water scarcity in southern Alberta led to SSRB planning program

- WRMM was built for Alberta Environment.

To meet our ongoing needs

- WRMM models have grown in number and complexity over time.

Uses of WRMM

Major projects and studies

- SSRB planning program (1980's, 2000's)
- Meridian Dam analysis
- Highwood / Little Bow diversion plan
- Special Areas Water Supply Study
- Acadia Irrigation Proposal
- Negotiations with Siksika on Bassano dam claim
- Expansion of the Carseland Headworks
- Alberta/Montana sharing of flow in the St. Mary and Milk

Model Versions

WRMM (the original)

- Owned by Alberta ESRD
- Designed specifically for Alberta
  - Water Act
  - Instream objectives
  - Reservoir operating policy
- Runs quickly
- Proven itself in Southern Region Projects and GOA Studies
  - 30+ years history

Model Versions

Wrm-Dss (Wrmm version 2)

- New method of formulating solution
  - More optimal solution than WRMM
- No limitation on size of schematic
  - Commercial solver replaces built-in OKA solver
- No longer needs text files (uses databases)
  - Backwards compatible with existing model documents (can still use text files)

Model Versions

Wrm-Dss (cont'd)

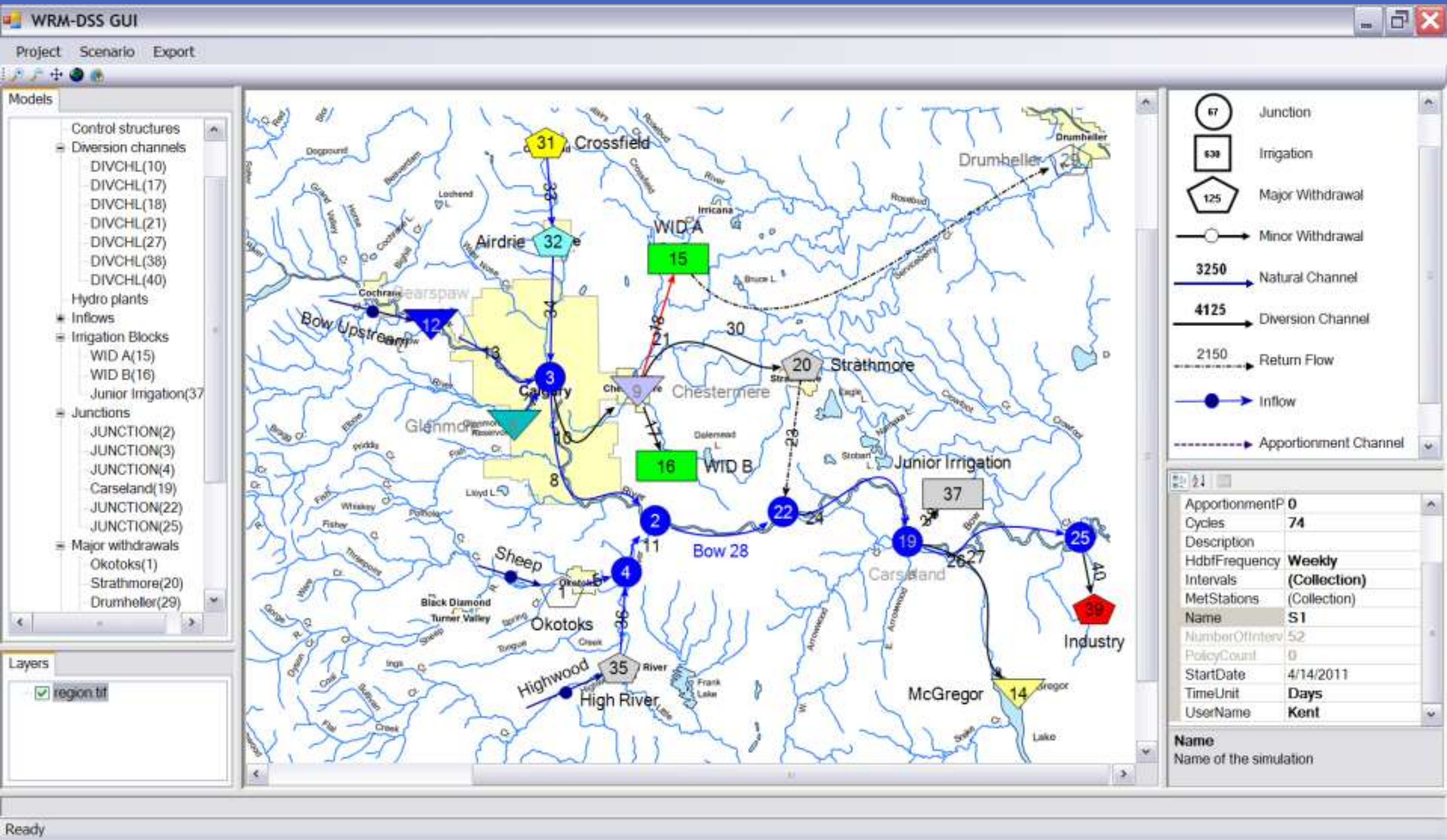
- Includes Channel Routing features
  - For daily operational decision support

- State of the art programming for adaptation to other computing platforms

Wrm-Dss Utility

Graphical User Interface

- Makes model design visual
- Can use maps or images created in GIS applications as backgrounds
- State of the art industry standard programming
  - Potential to migrate to the Web
- Can be developed independently and in parallel to Wrm-Dss application
- No licencing / maintenance fees for dep't


WRM-DSS GUI
Project
Scenario
Export
Models
Control structures
Diversion channels
DIVCHL(10)
DIVCHL(17)
DIVCHL(18)
DIVCHL(21)
DIVCHL(27)
DIVCHL(38)
DIVCHL(40)
Hydro plants
Inflows
Irrigation Blocks
WID A(15)
WID B(16)
Junior Irrigation(37
Junctions
JUNCTION(2)
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JUNCTION(4)
Carseland(19)
JUNCTION(22)
JUNCTION(25)
Major withdrawals
Okotoks(1)
Strathmore(20)
Drumheller(29)
Layers
region.tif
Crossfield
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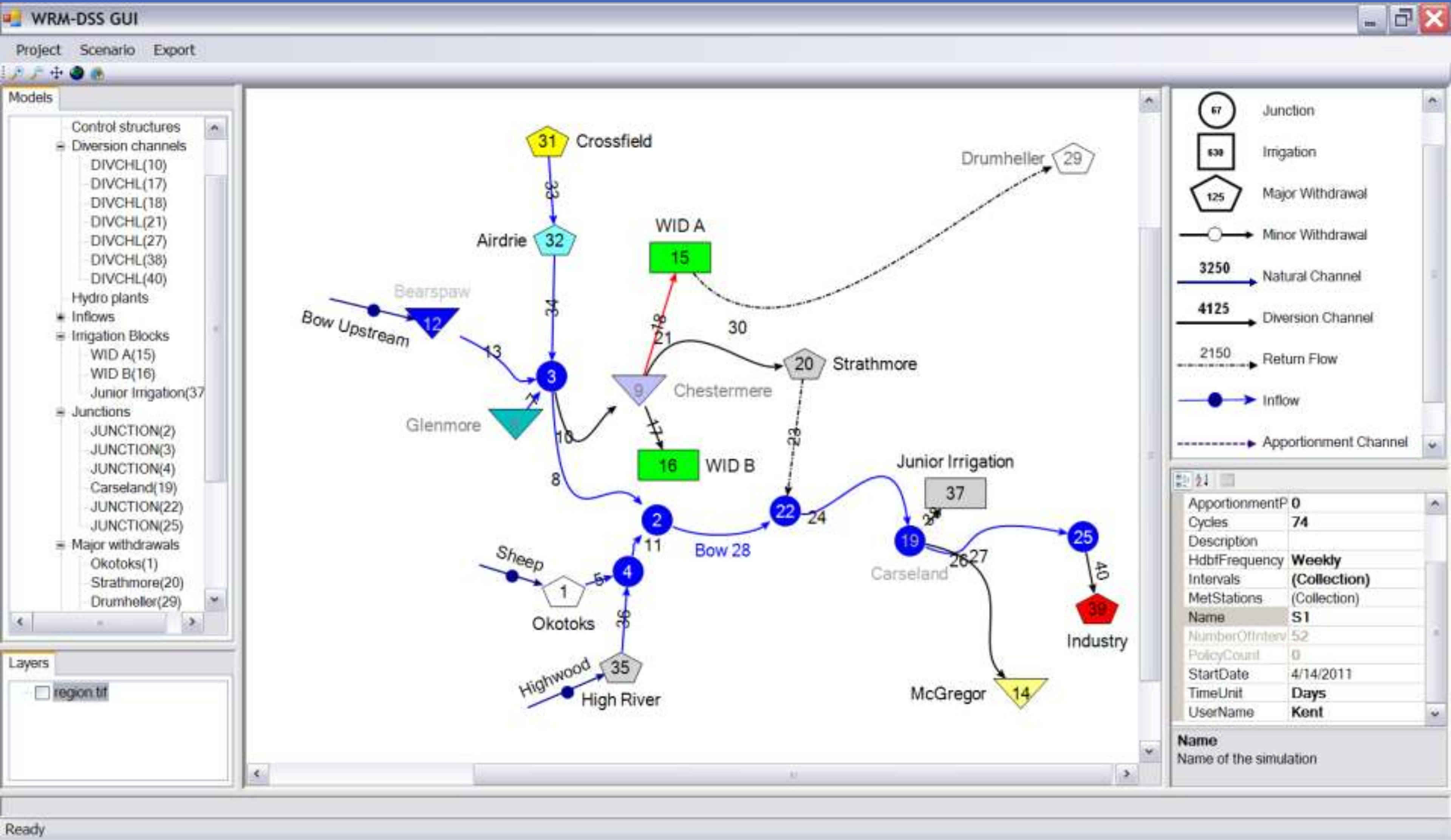
Airdrie
WID A
Bearspaw
Bow Upstream
Calgary
Chestermere
Strathmore
Glenmore
WID B
Junior Irrigation
Bow 28
Sheep
Carseland
Okotoks
Industry
Highwood
High River
McGregor
Junction
Irrigation
Major Withdrawal
Minor Withdrawal
3250
Natural Channel
4125
Diversion Channel
2150
Return Flow
Inflow
Apportionment Channel
ApportionmentP 0
Cycles 74
Description
HdbfFrequency Weekly
Intervals (Collection)
MetStations (Collection)
Name S1
NumberOfInterv 52
PolicyCount 0
StartDate 4/14/2011
TimeUnit Days
UserName Kent
Name
Name of the simulation
Ready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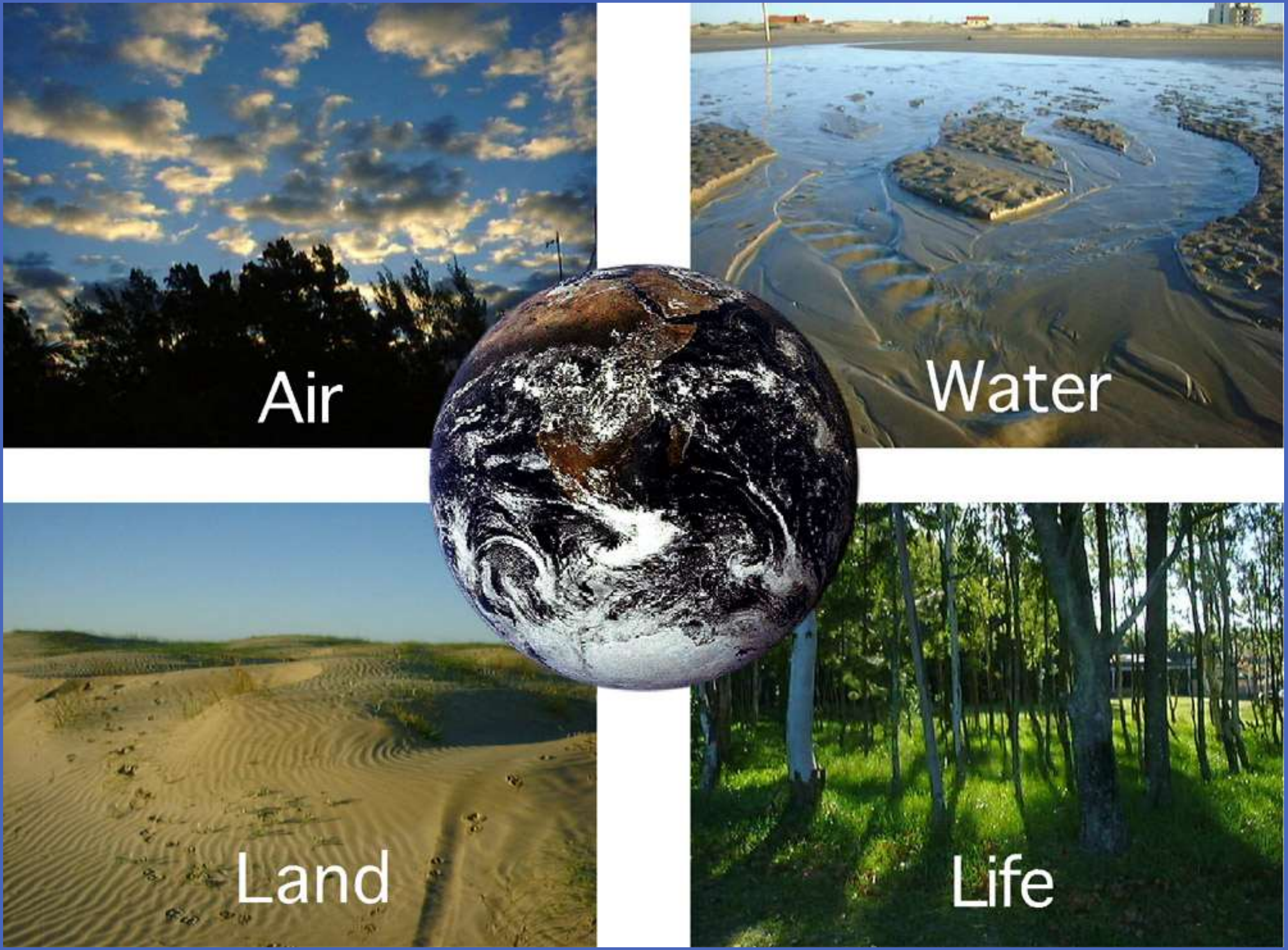
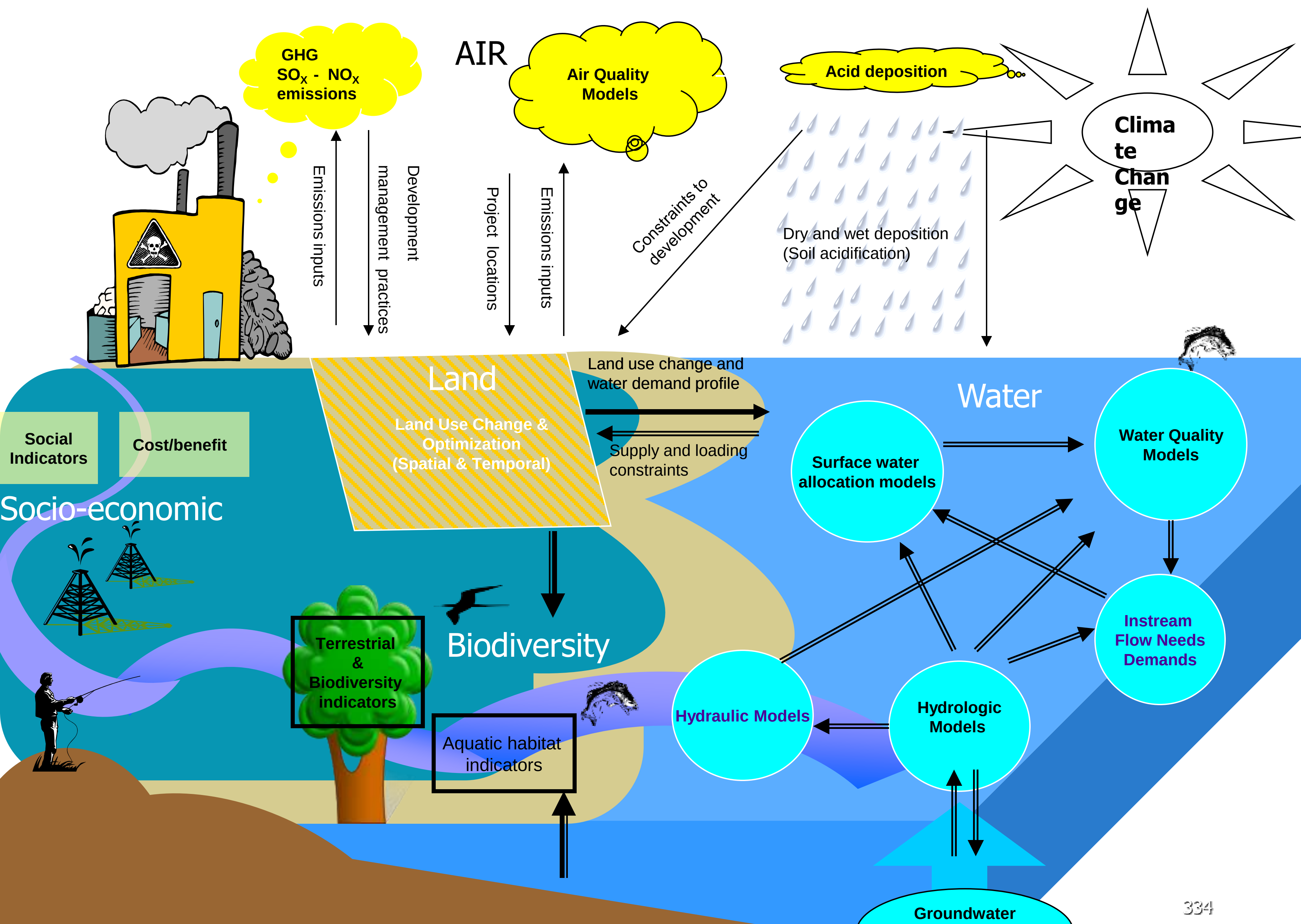
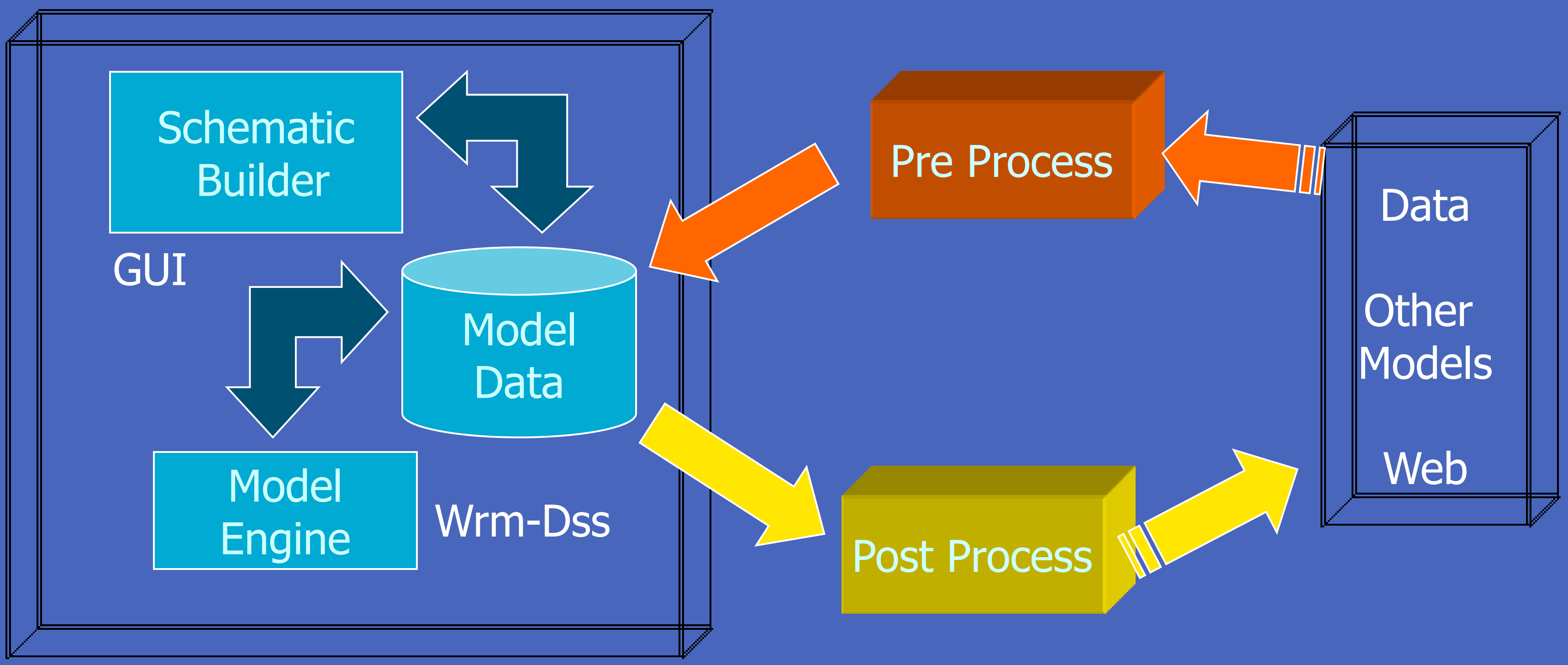

Air
Water
Land
Life



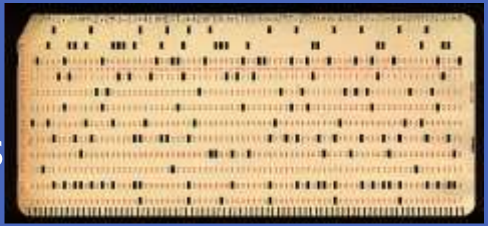
Integrated System of Modelling Tools

WRMM Linkages



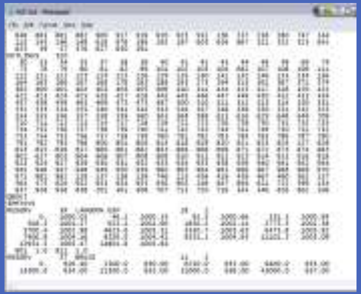
WRMM
Evolving with technology

1970's to 90's



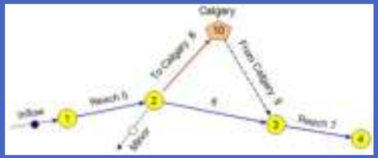
1990's to 2010

Text files




Current to Future

Database




Day 1 – Session 2

Tom Tang – AESRD

BIOGRAPHY

Tom Tang has a Master of Science degree in Civil Engineering from the University of New Brunswick. He is a professional engineer with AESRD currently leading the Environmental Modelling Team for the Southern Region. The team consists of water quality and water allocation modelling specialists supporting government projects ranging in scale from local to provincial and international. He possesses more than 30 years of experience in water resource management and modelling, including flood and water supply forecasting, water resources planning and operation. He has a strong expertise with hydrological and water allocation models.

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Water Quality Model Development and Application

Government of Alberta

Modelling Plan and Priorities

Southern Region – South Saskatchewan and Milk River Basins

South Saskatchewan River Basin

- Bow River sub-basin including Highwood River
- Oldman River sub-basin
- South Saskatchewan River sub-basin
- Red Deer River sub-basin (TBD)

Milk River Basin

Modelling Focus

Model Development

Phase 1 - Data Scoping Study

Phase 2 –Data Collection

(Climate, Water Quality, Hydrometric, Bathymetric/Hydraulic, Sediment and Vegetation)

Phase 3 - Water Quality Models

- Non-point Source Watershed Model: characterize non-point sources
- In-stream Flow and Water Quality Model: characterize the fates of point and non-point sources in main water body

Model Applications

Data Scoping Study

Identify, collect, and assemble existing data and knowledge

Assess current water resources and water quality

SSRP Water Quality Data Scoping

Identify data/knowledge gaps for model development

Provide guidance for determining the approach and selecting appropriate models

Oldman/S. Sask., Milk, Highwood/L. Bow, Red Deer (Central Region)

SSRP Land Use Land Cover (LULC) Data and Model Scoping

- Potential Impact of Climate Change on Water Availability and LULC (Novus Environmental)
- LULC Mapping for SSRP (U. of Calgary)

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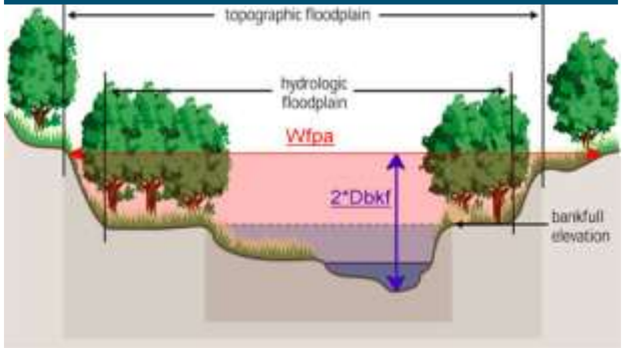
Address Data & Knowledge Gaps

Bathymetry



Lack of data at rural reaches for the 600 Km long of River

Sediment

Nutrients and organic matters;
DO demands;
Erosition/deposition

Ice

Ice development and its impact on water quality, sediment transport…

Macrophyte

Lack scientific knowledge:
kinetic rates, stoichiometry, community composition…

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Address Data & Knowledge Gaps (cont'd)

Bow River Biosonic Vegetation/Sediment Study (4 phases)

- Joint Project (ESRD, City of Calgary and Golder Associates)
- Selected river reaches within the City of Calgary

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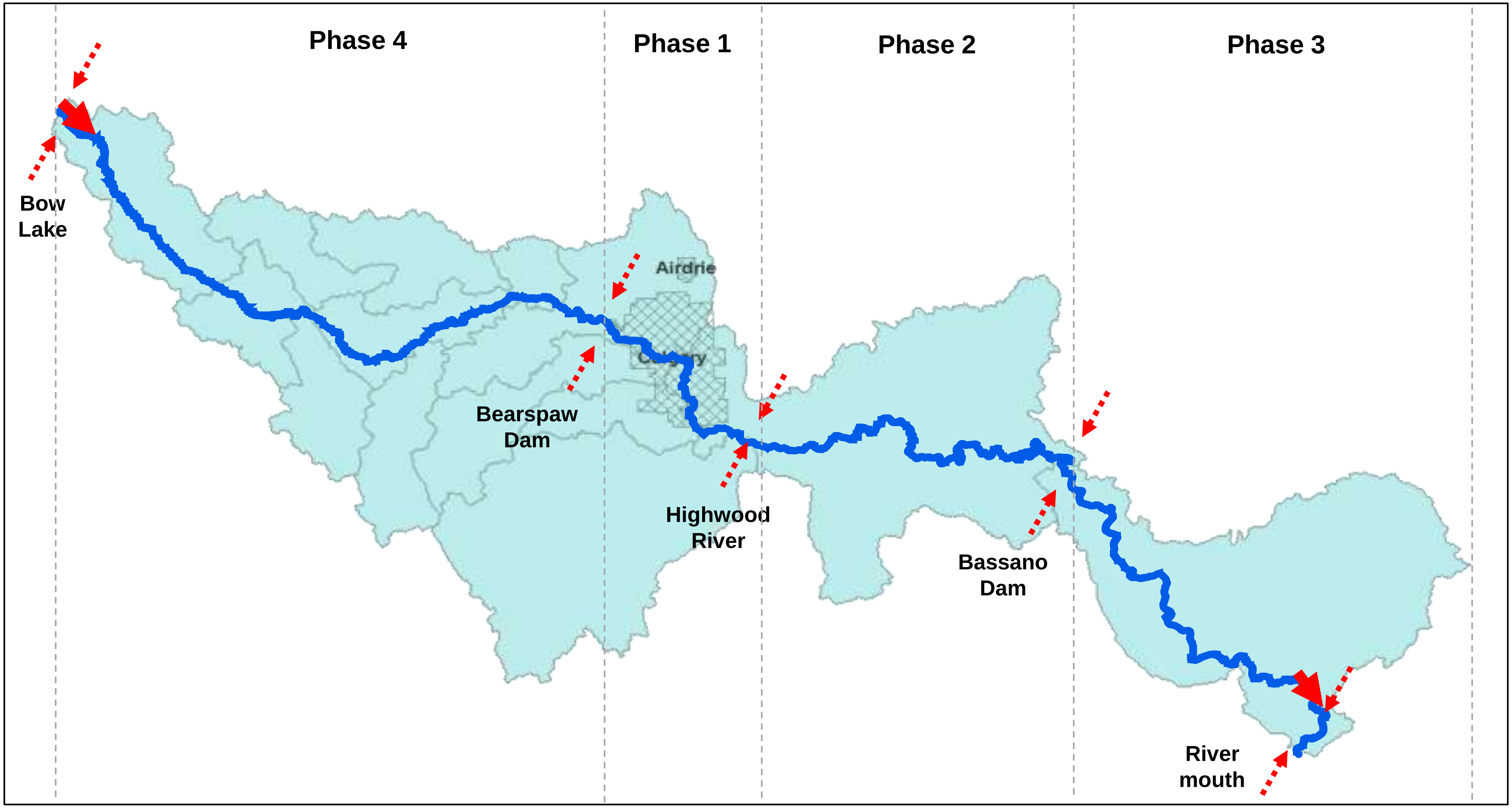
Bow River Sub-Basin



Bow River Water Quality Model (BRWQM)

In-stream Flow and Water Quality Model
(WASP/HECRAS)

Phase 1: Bearspaw Dam (U/S Calgary) to U/S Highwood Confluence
- owned by the City and enhanced by ESRD

Phase 2: Highwood Confluence to Bassano Dam

Phase 3: Bassano Dam – Mouth (Bow/Oldman Confluence)
– under development

Phase 4: Upper Bow River Water Quality Model (U/S Calgary)
-Develop prototype - incorporate Ice Dynamic Mechanism of RIVER1D into CE-QUAL W2

Stormwater Model
(EPA SWMM under development**)**

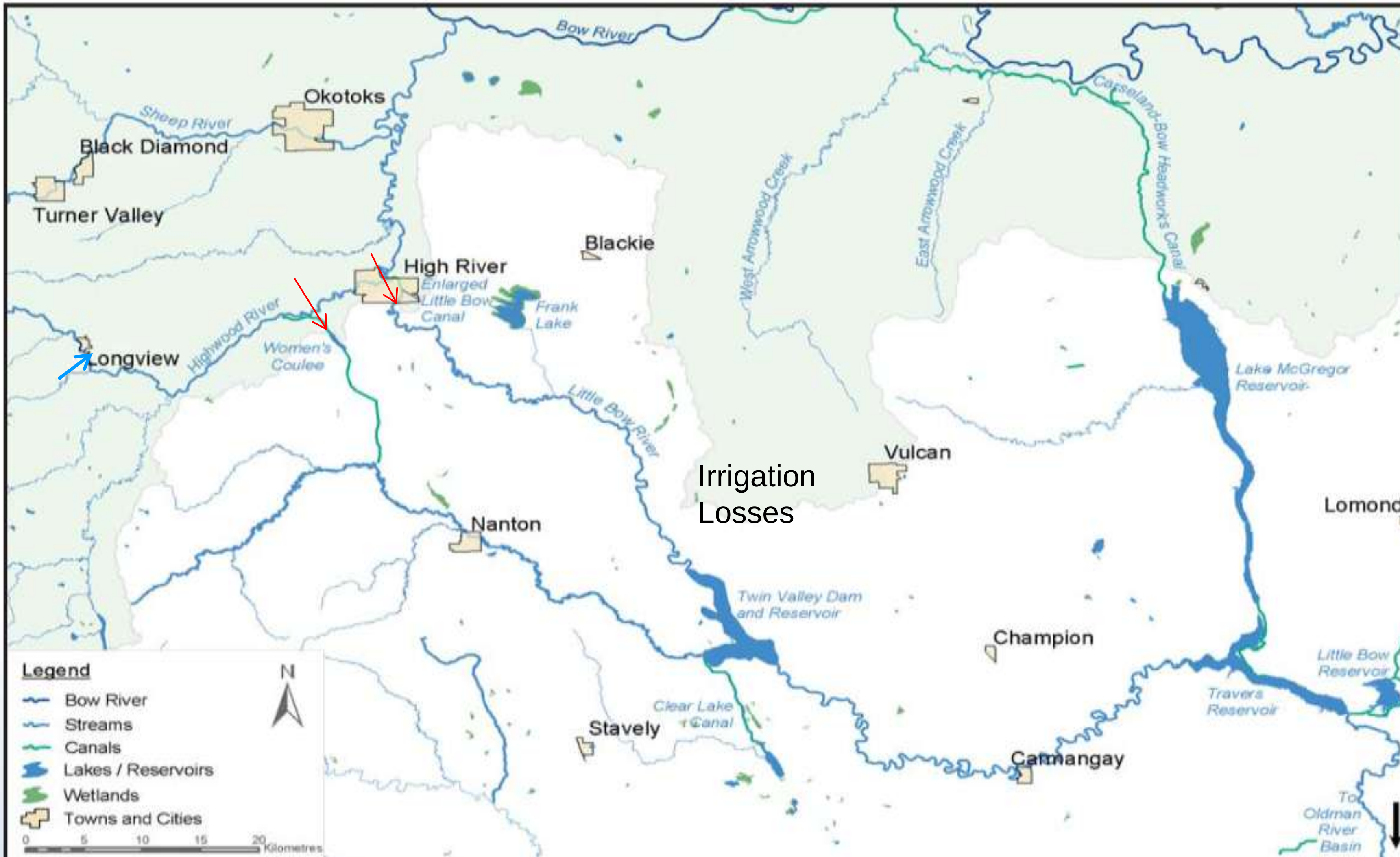
Phase 1: City of Calgary stormwater runoff (QHM)
-owned by the City

Non-point Source Watershed Model
(SWAT)

Phase 2: Crowfoot Creek (WID Major Return Flow)

Phase 3: SWAT

Highwood/Little Bow System



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Water Quality Models (cont'd)

Highwood/Little Bow System (2013 and beyond)

- Major Tributary and Non-point Source contribution to the Bow River

In-stream Flow and Water Quality Model

Phase 1
- *Highwood River*
- *Sheep River*
- *Frank Lake*

Phase 2
- Little Bow River
- Mosquito Creek
- Twin Valley Reservoir
- Other tributaries

Non-point Source Watershed Model

- Agricultural areas

Model Applications

BRWQM Application (Bearspaw Dam to Bassano)

LUF/Region Planning: SSRP – coupled WRMM with BRWQM

Regional Approval (Carseland effluent to the Bow River) - Wheatland County application (in progress)

Water Management Operations - Bow-Carseland Headworks (Travers Reservoir Enlargement EIA; and Bow-Carseland Canal Enlargement DFO approval)

Bow River Phosphorous Management Plan (P Plan) – model data update/extension to 2011, and model re-calibration (in progress)

Other Initiatives and Information

WRMM-CA Model Interface (Geomatic Journal) – in conjunction with U. of Calgary

SSRP Scenario Modelling Report – Modelling Team

Climate Change Impact Analysis (Research) – U. of Alberta; U. of Saskatchewan;

Bow River Biosonic Study on Sediment and Vegetation (CWRA National Conference) – in conjunction with Golder Associates and City of Calgary

Other Jurisdictions – Saskatchewan Water Security Agency etc

Day 1 – Session 2

David Hill – University of Lethbridge

BIOGRAPHY

In September 2012 David Hill was appointed as the inaugural Director of Centres and Institutes and Research Advocacy for the University of Lethbridge. In his role within the office of Research and Innovation Services, David assists university research institutes and centres to be successful in meeting their goals and objectives, in finding new opportunities for trans-disciplinary collaboration between centres and institutes and between the University of Lethbridge and other national and international research universities and organizations. He also seeks opportunities to mobilize knowledge and expertise so as to increase the impact of research outcomes to the community, businesses and the province. Prior to joining the university, David was the Executive Director for Water Resources with Alberta Innovates-Energy and Environment Solutions (AI-EES). He has almost 40 years of experience in water and natural resource management in Alberta, crossing the broadest spectrum of water issues and water companies. David has taken a lead role in the development of tools, policies and processes to promote increased water use efficiency in the agricultural sector, and has been a founding member of a number of regionally based water stakeholder organizations. He has led public-private sector research initiatives and has collaborated on international water research and policy.

David was a member of the Alberta Water Council from its inception in 2003 until joining the University of Lethbridge, representing the first irrigated agriculture and has been representing the science and research community since the fall of 2007. David is the Water Policy Co-Chair for the Pacific Northwest Economic Region, is a member of the Canadian Water Network's Canadian Municipal Water Consortium, a member of the Board of Directors of Inside Education, a member of the Board of Directors of the TEC Fund Limited Partnership (Edmonton) and has been a participant of the Rosenberg International Forum on Water Policy (University of California, Berkeley) since 2004. He is the Past-President of the Canadian Committee on Irrigation and Drainage and is a former member of national Board of Directors of the Canadian Water Resources Association. David has also served on Alberta's Endangered Species Conservation Committee, the Alberta Environmentally Sustainable Agriculture Council and was an advisory member of the Board of Directors for the Northwest Irrigation Operators Inc. in Boise, Idaho for 5 years. David is committed to finding proactive evidence-based solutions to priority issues in Alberta, with a focus on rapid step changes to allow Alberta to secure a world-leading position in the research, science and policy domains.

Day 1 – Session 2

David Hill – University of Lethbridge

Abstract

The status quo in integrated natural resource management no longer addresses Alberta's current needs and is ill suited to actively bring together the best of science, policy and practice in discovering new and adaptable solutions that can be readily implemented to meet Alberta's social, environmental and economic needs. Relationships and interdependencies between the management of air, land, water and bio-diversity are complex. It has often been difficult to resolve issues about perspective, data, information and knowledge and to visualize the opportunities that might exist to achieve improved and sustainable outcomes from these finite and ever-changing resources. This presentation will highlight some of the research and other activities that are ongoing at the University of Lethbridge. Emerging opportunities that exist to train students at the undergraduate and graduate levels alongside leading practitioners will be explored. The focus of these efforts is to develop and sustain the processes that Alberta needs to ensure that resource management decisions are well informed and that Alberta has the capacity for ongoing adaptive management.

Discovering the Possible:
Tools for Collaborative Learning and Improved Outcomes

Environmental Modelling Workshop 2013
Edmonton, Alberta

David F Hill, Director
david.hill@uleth.ca
Centres and Institutes and Research Advocacy
University of Lethbridge

Background ...

- Complexity of issues and decision-making ... status quo is insufficient to deal with relationships between air, land, water and biodiversity
- Interests vs. Positions
- Engaging experience and real-world actors is key to success
- Tackling reality in a virtual world, not a theoretical world

Approach ...

- Bring together the 'best' of science, practice and policy to discover and implement adaptable solutions to meet Alberta's social, environmental and economic needs in response to ongoing change/uncertainty
- Develop a long-term view of the requirements for research, training, and the development/refinement of analytical tools to support informed decision-making

University Contributions …

- Emerging increased focus on capitalizing on research findings to meet provincial priorities and to support economic development,
- Campus Alberta has a significant depth of expertise in teaching, research and working with communities, government and industry
- There is little appetite for duplication of activities, but heightened appetite for increased collaboration and added value

U of L Strengths …

- WISE, Water Institute for Sustainable Ecosystems
- ATIC, Alberta Terrestrial Imaging Centre
- Prentice Institute for Global Population and Economy
- ARRTI, Alberta RNA Research and Training Institute
- CSRM, Centre for Socially Responsible Marketing

5 of 9 existing U of L research organizations have water, land, biodiversity and community as research focus areas.

Capacity ...

- WISE ... Full range of water expertise, advanced and modern laboratory facilities designed to answer complex questions, complimented by physical geographers, economists, agrologists and policy expertise
- Long history in use of analytical tools (models) and visualization (GIS)
- Leading development of new modelling and monitoring approaches ... Functional environmental flows ... Riparian systems ...

Capacity …

- ATIC … Single largest aggregation of hyper-spectral imaging scientists in western Canada, global experience in advanced remote sensing, on campus earth satellite receiving station, focussed on the development of tools and applications to support decision-making, excellent connections and collaboration with industry
- Developing expertise and tools for large landscape monitoring and reporting

Capacity ...

- Prentice Institute ... Trans-disciplinary global experience in addressing issues of population growth and economy with a focus on policy relevant outcomes
- ARRTI ... Leading advances in synthetic biology to address human health & industrial issues, undergraduate team developed petrochemical-eating bacteria, only Canadian team in 2011 at MIT iGEM competition, top 4 globally

Capacity ...

- Centre for Socially Responsible Marketing ... Focussed on supporting/training NGOs, community organizations, business in leading behaviour change for specific outcomes
- Other campus expertise focussed on aspects of the air, land, water & biodiversity space – chemistry, media arts, management, computing science, environmental education, etc
- Strong partnerships in the area of open, transparent access to data and commercial tool development

Experience/Opportunity ...

- Long history of collaboration with community, government and private sector in responsible natural resource management
- Specific interest in development of tools, models as key components of research and teaching/training
- Experience in use of ACRU, OASIS, SWAT, G-EPIC, I/O economic models and in development/piloting of new approaches

Experience/Opportunity ...

- Well developed collaborative relationships within Campus Alberta, Canadian Water Network, national and international organizations
- Going forward ... Development/deployment of trans-disciplinary, multi-institution undergrad and graduate student training focussed on integrated natural resource management with an emphasis on environmental modelling

Experience/Opportunity ...

- Going forward ... Initiation of specific on-line and on campus training resources for professional and executive training – extending research findings & opportunities into the workplace
- Going forward ... Fostering new approaches to research and knowledge mobilization, secondments, internships, fellowships

Closing Observations ...

- U of L is well positioned to contribute to the development and refinement of evidence-based analytical tools across much or the air, land, water & biodiversity spectrum
- Collaborative processes that involve shared learning and making use of (capturing) experience will enhance research, training and realization of improved outcomes

Questions ...

Research Info$ource Names University of Lethbridge, University of the Year 2012 (Undergraduate)
Accolades from Maclean's and Globe and Mail

Day 1 – Session 2

Hugh Norris – AESRD

BIOGRAPHY

Hugh Norris was born and raised in Alberta. Norris holds a BSc from U of C and a MSc from U of A. He has worked for Alberta Fish and Wildlife Division in the field (SW), HQ, field (Head of Fisheries Mgmt - NE Region), HQ (Head of Fisheries Allocation and Use), then 3 years as the F&W representative on Sustainable Resource Developments Land-use Framework Integration Team, and the last year continuing that work but through F & W. In the last four years his work included participating in the regional land-use planning processes, and developing the Biodiversity Management System and Biodiversity Management Frameworks.

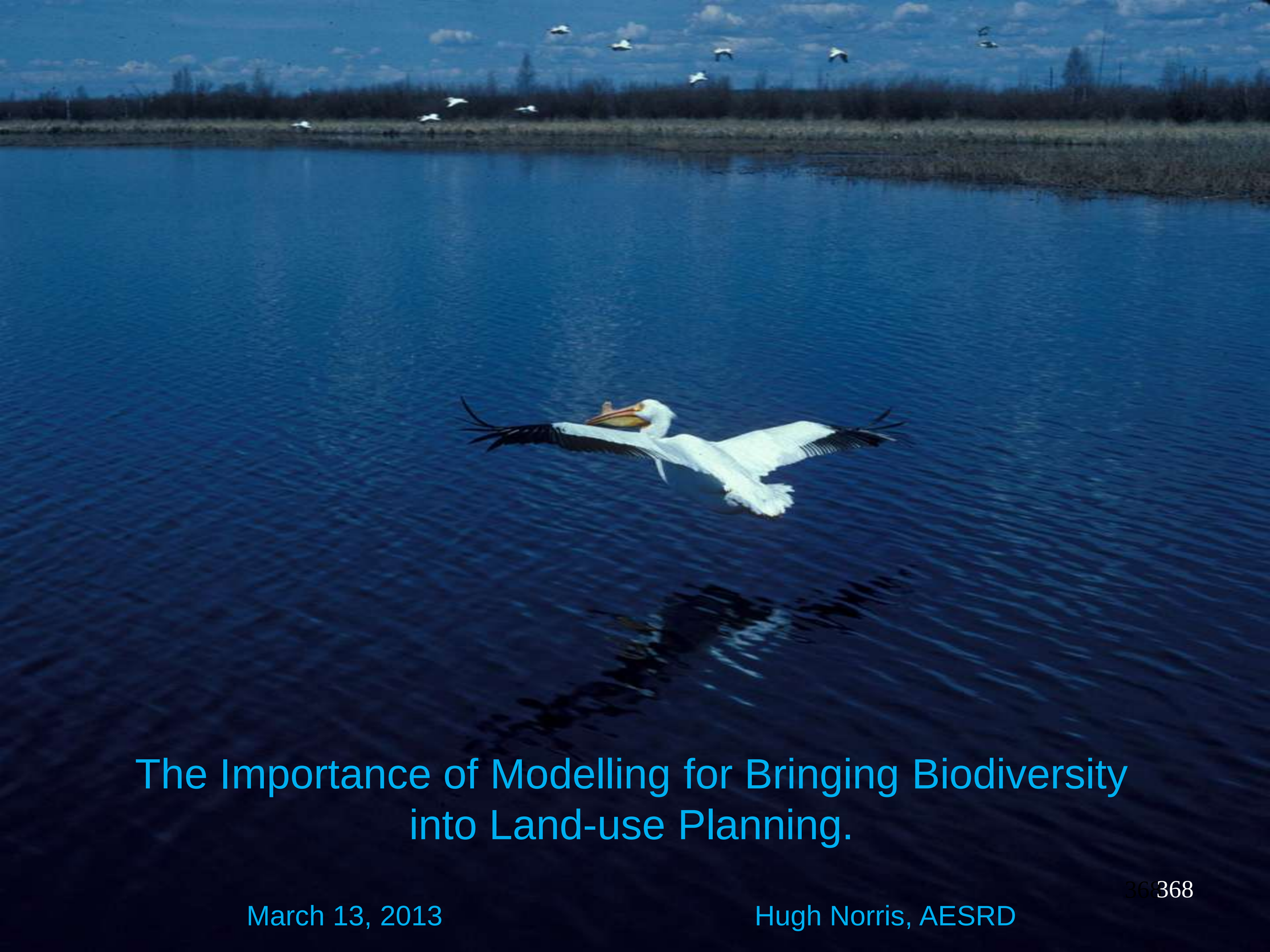
With very recent reorganization, Norris is now the Biodiversity Section Head, Policy Integration Branch, Policy Division, Environment and Sustainable Resource Development.

Day 1 – Session 2

Hugh Norris – AESRD

ABSTRACT

Alberta's Land-use Framework (2008) defined a change to cumulative effects (CE) based management to deal with the competition that population increase and development activities were having for natural landscapes. The presentation is based on Alberta's Biodiversity Management System (BMS) which defines the steps necessary for bringing biodiversity into any cumulative effects based land-use planning to balance social, economic and environmental (SEE) values. Within this process, modelling is needed to approximate biodiversity indicator reference points; project CE based trajectories of biodiversity indicator outcomes into the future; test the tools that could be used to control effects of development; and likely in the future to help assess monitoring results.



The Importance of Modelling for Bringing Biodiversity into Land-use Planning.

March 13, 2013

Hugh Norris, AESRD

Alberta Land-use Framework, 2008

- 7 regional plans with GoA approved future outcomes.

- Complete a biodiversity strategy.

- Balance social, economic and environmental values.

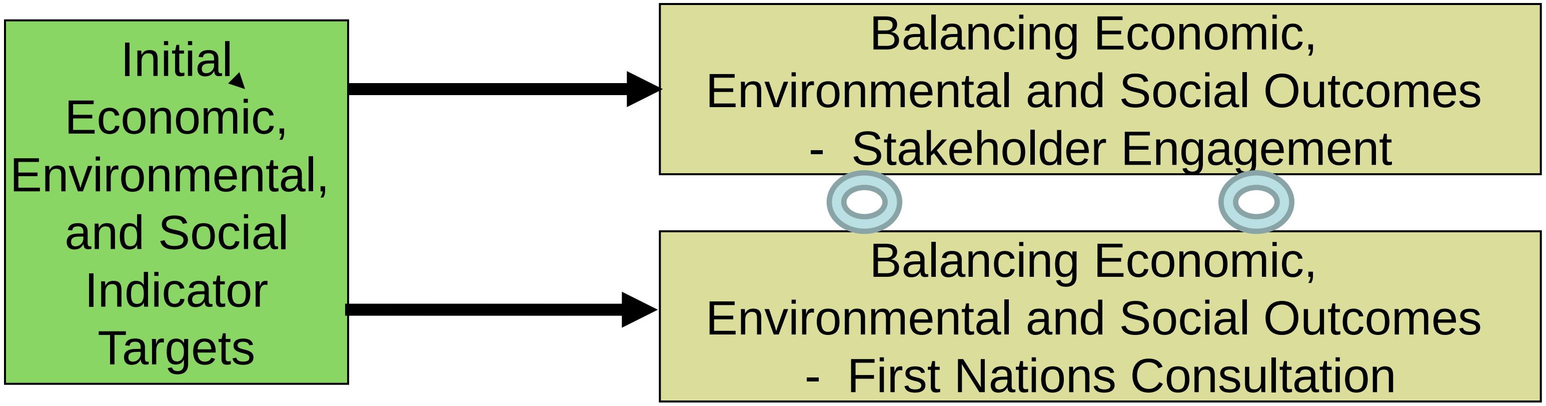
- New cumulative effects approach.

- GoA expectation to include Albertans in planning.

- LARP - build a Biodiversity Management Framework.

Planning - Building Plans and Management Frameworks

Cumulative effects – all values for one area considered at the same time.



GoA dept representatives will meet with a small but diverse group of stakeholders and with First Nations to try to optimize what everyone wants from the particular piece of land.

A Structured Recommendation Making process will be used to help the groups.

Recommendations go to the GoA who will finalize plans and Mgmt Frameworks.

Terrestrial Biodiversity Indicators

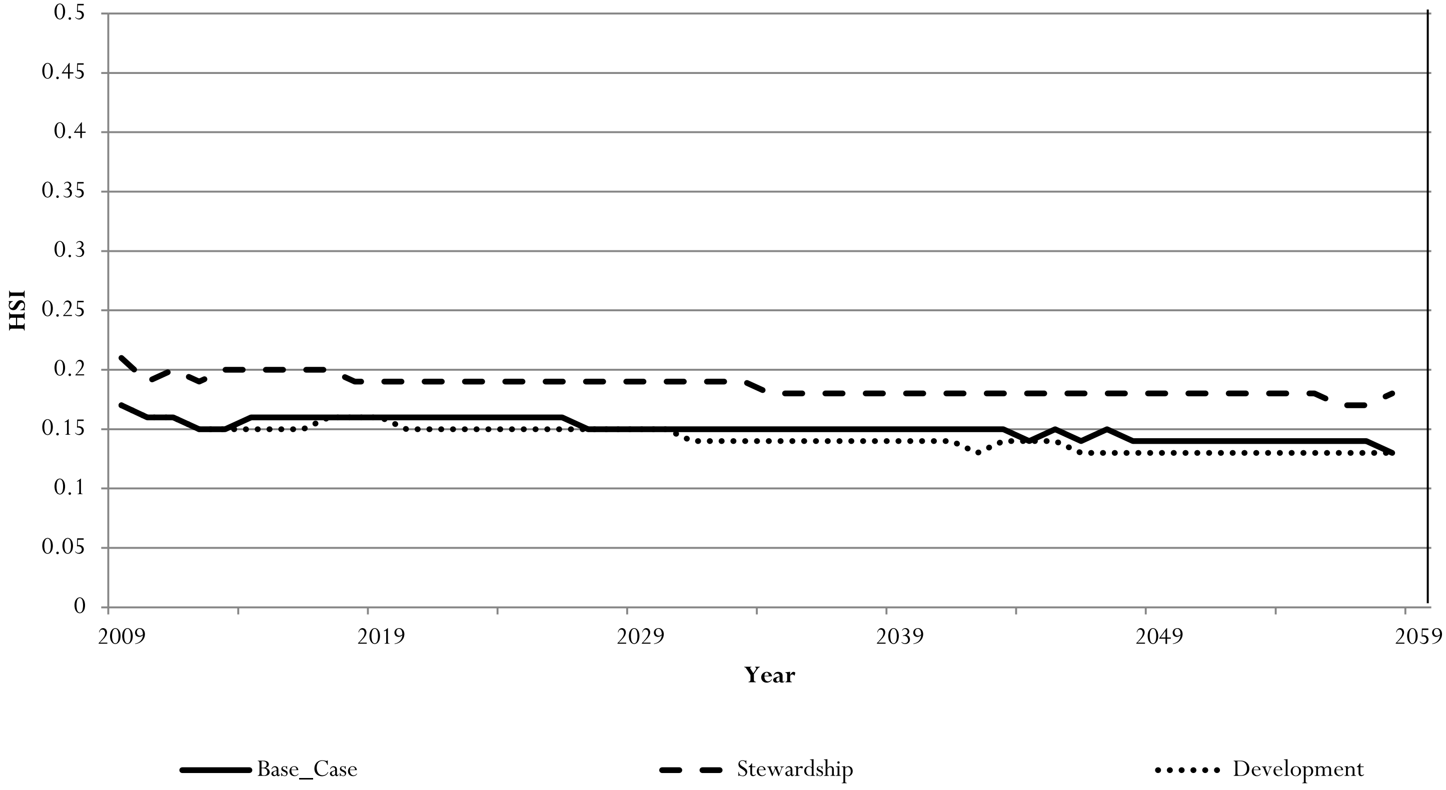
- Must represent breadth of biodiversity with:
  - coarse filters:
    - land-covers – 33, e.g., deciduous, white spruce, shrubland, fescue grassland, marsh,
    - habitat features – 11, e.g., amount of, seral stage, fragmentation, snags,
  - fine filters (often specific habitats):
    - guilds – 6, e.g., old forest birds, human associated birds, weedy vascular plants,
    - species – 16+, e.g., caribou*, moose, marten, barred owls, Canadian toad.

Aquatic Biodiversity Indicators

- coarse filters:
  - area of wetlands, standing water, flowing water,
  - habitat features – fishkill risk, stream continuity, riparian health,
- fine filters:
  - guilds – e.g., Index of Native Fish Integrity, wetland / riparian vertebrates,
  - species – Fish Sustainability Index.

- Must use models to project indicator status into the future.

Cumulative effects modelling provides indicator probable status trajectories under various land-use scenarios.



Results don’t mean much to most people – need context.

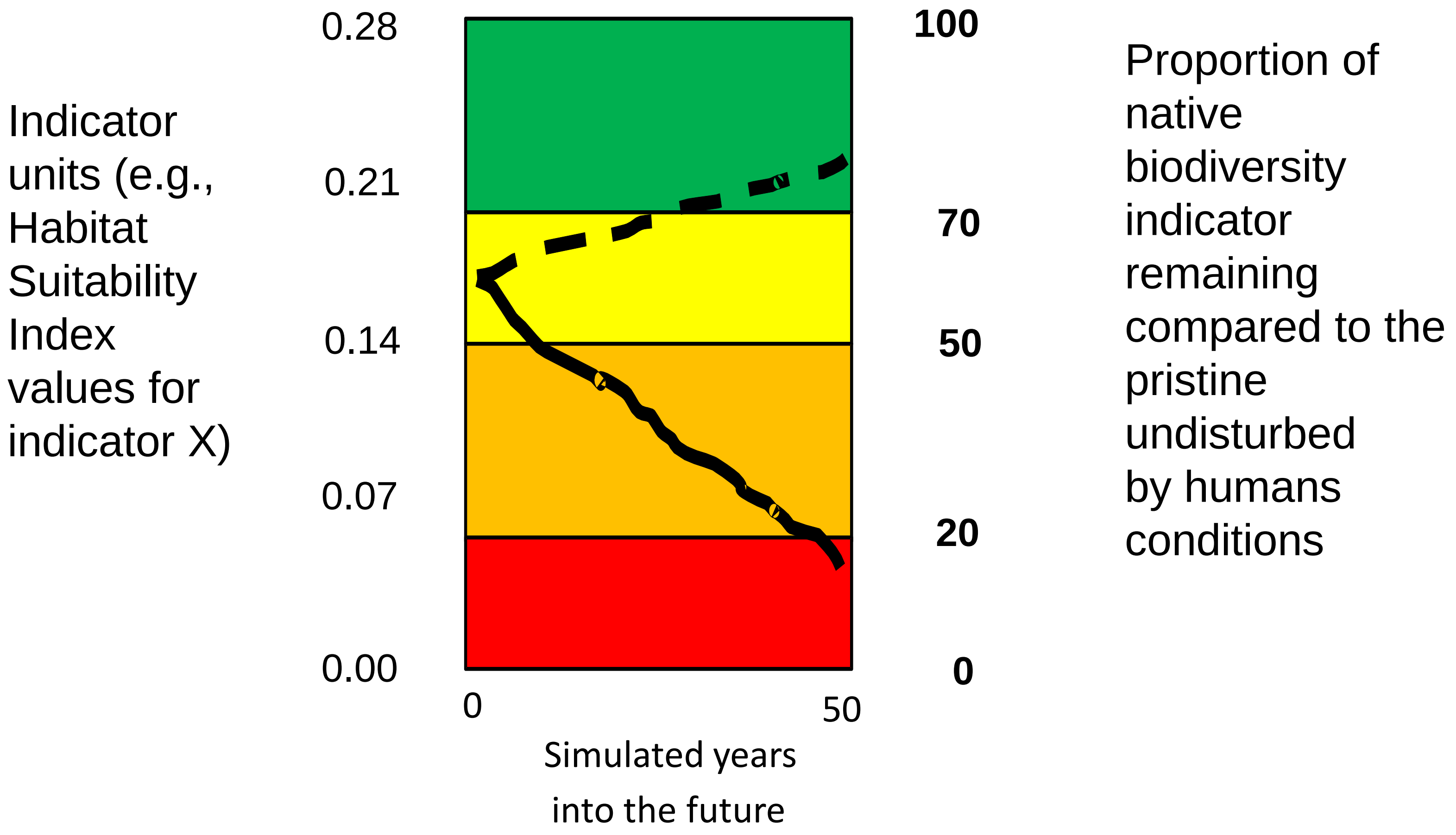
Cumulative Effects

- Land-use Framework definition - combined effects of past, present and reasonably foreseeable future effects of land-use on the environment over time.
- Usually don't have data on changes in quantity and quality of habitats and populations from the "past".

Range of Natural Variability

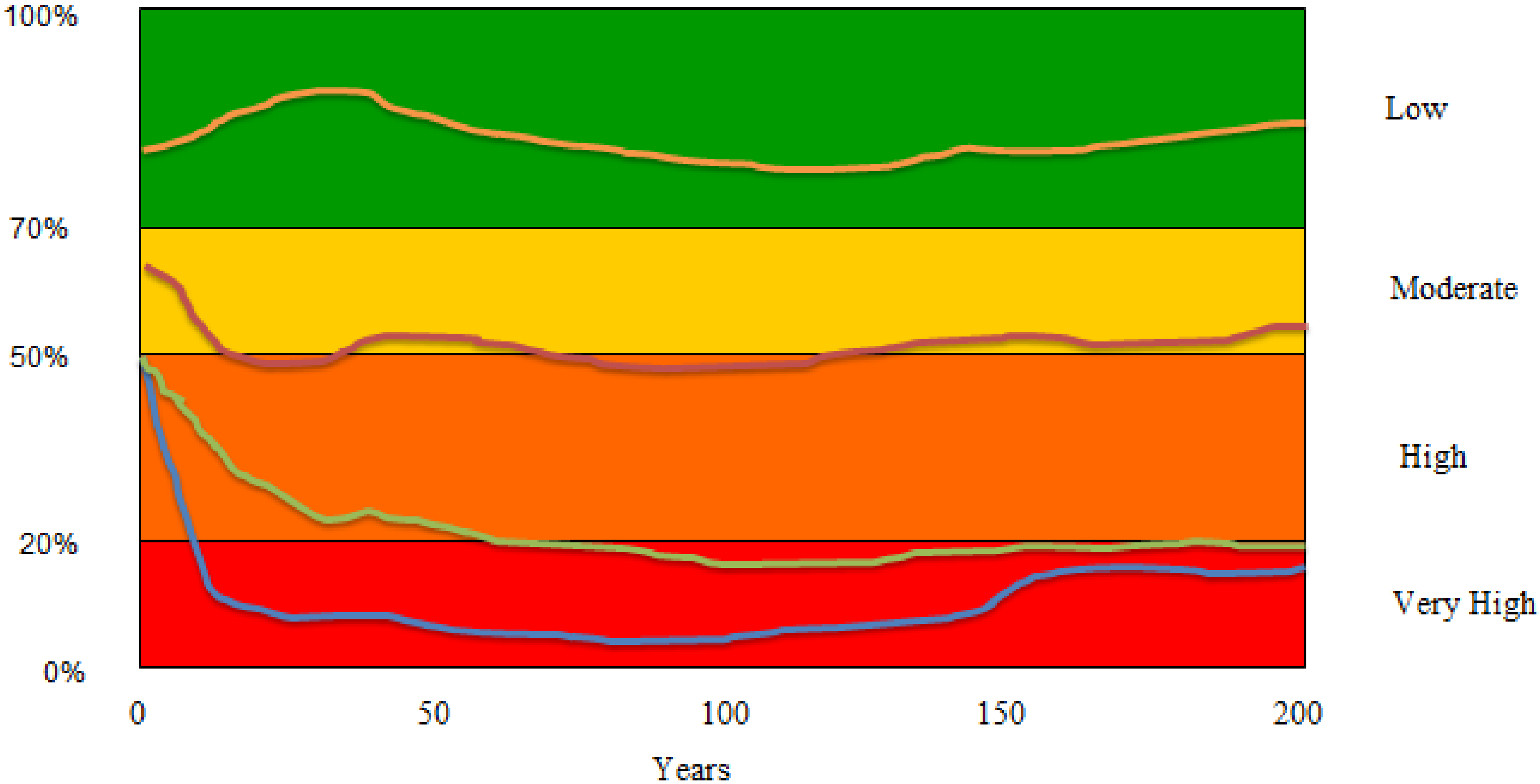
- Use modelling to project RNV of landscapes and indicators to pristine undisturbed by humans conditions, assuming no human footprint or introduced species, and assuming that natural disturbances occur as they did in the past.
- Repeating the modelling runs 50 or more times gives values to generate average, lower and upper limits of RNV.

Reference point = the average of RNV = 100%.
Risk assessment bands based on IUCN break-points.



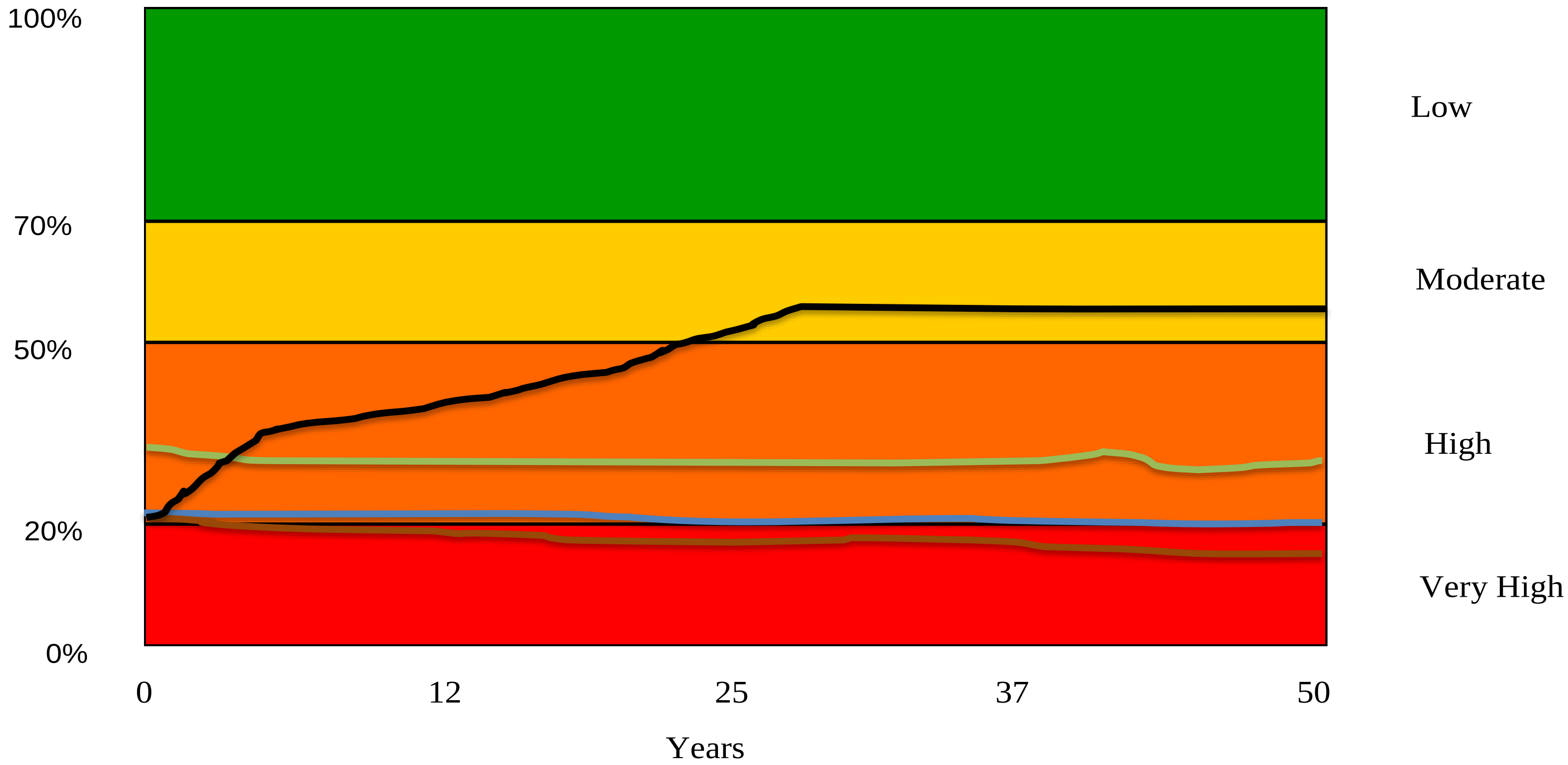
Within RNV is the preferred status from a biodiversity perspective.
Secondary preferred status outside RNV is in the green or high in the yellow risk levels. Ultimately GoA will decide acceptable level of risk.

Modelling facilitates comparisons of different land-use scenarios.



Proportion of a biodiversity indicator remaining compared to undisturbed (by humans) conditions and risk assessment bands. Example 1. Indicator model results: ---- **Base Case**; ---- **Best Practices**; ---- **Moderate Best Practices + Access Management**; ---- **High Best Practices + Access Management**

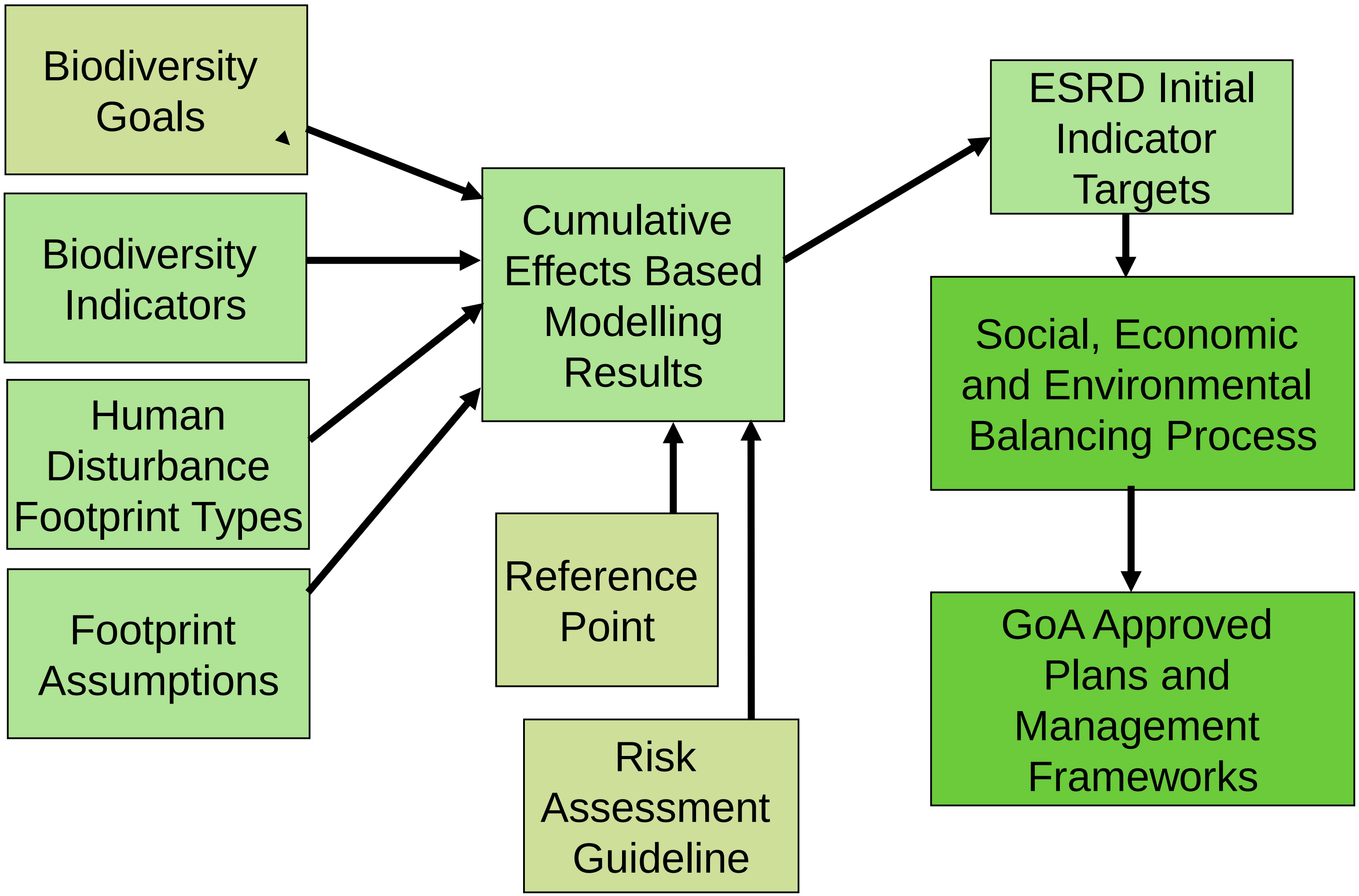
Reverse engineering of the model can be used to determine what land conservation and/or land-use controls would be needed to achieve specific targets.



Proportion of a biodiversity indicator remaining compared to undisturbed (by humans) conditions and risk assessment bands.

Example 4. Indicator model results: ---- Base Case; ---- Development; ---- Best Practices; ---- Approved Trajectory and Target.

Approach Needed for Bringing Biodiversity into Cumulative Effects Based Land-use Planning



Biodiversity Management Framework

- The GoA statement of integrated intent for managing biodiversity within a specific region or subregion.
- Determined by the GoA through the cumulative effects based land-use planning process to balance the economic, environmental and social values (3 pillars).
- Includes the GoA approved biodiversity indicator trajectories and targets to be achieved over a specified time-frame.
- Defines the means of achieving the targets through:
  - establishment of conservation areas,
  - controlling human disturbance footprints,
  - setting footprint reclamation rates and end-points, and
  - controlling public motorized use of the footprints.

Management Frameworks for CE

All MFs for a plan area should be built at the same time and through the same process so they are all fully integrated.

Water Quality and Quantity needs for people, industry and aquatic biodiversity will be different but the MFs should reflect the most sensitive need unless a trade-off has been made.

Air Quality also needs to reflect the needs of people as well as aquatic and terrestrial biodiversity.

A Contaminant MF could list the appropriate compounds known or likely to cause problems in the area and the concentrations of concern to humans and biodiversity.

Day 1 – Session 2

Nesa Ilich – Optimal Solutions Inc.

BIOGRAPHY

Dr. Nesa Ilich is a water resources engineer with over 20 years of consulting practice for various clients in the water resources sector, including Alberta Environment, TransAlta, Environment Canada and a number of international clients. He holds a Ph.D. from the University of Manitoba and M.Sc. from the University of Alberta. Dr. Ilich has significantly improved Alberta Environment's Water Resource Management Model (WRMM) through a series of contracts which started in 1988 and exported its use overseas. This model has been used in numerous multi-disciplinary basin management studies.
He has also recently developed and tested a unique method for multiple-site generation of stochastic hydrologic time series that was used successfully on several projects. Dr. Ilich has published numerous papers on computer modelling topics in river basin management and hydrology.

Day 1 – Session 2

Nesa Ilich – Optimal Solutions Inc.

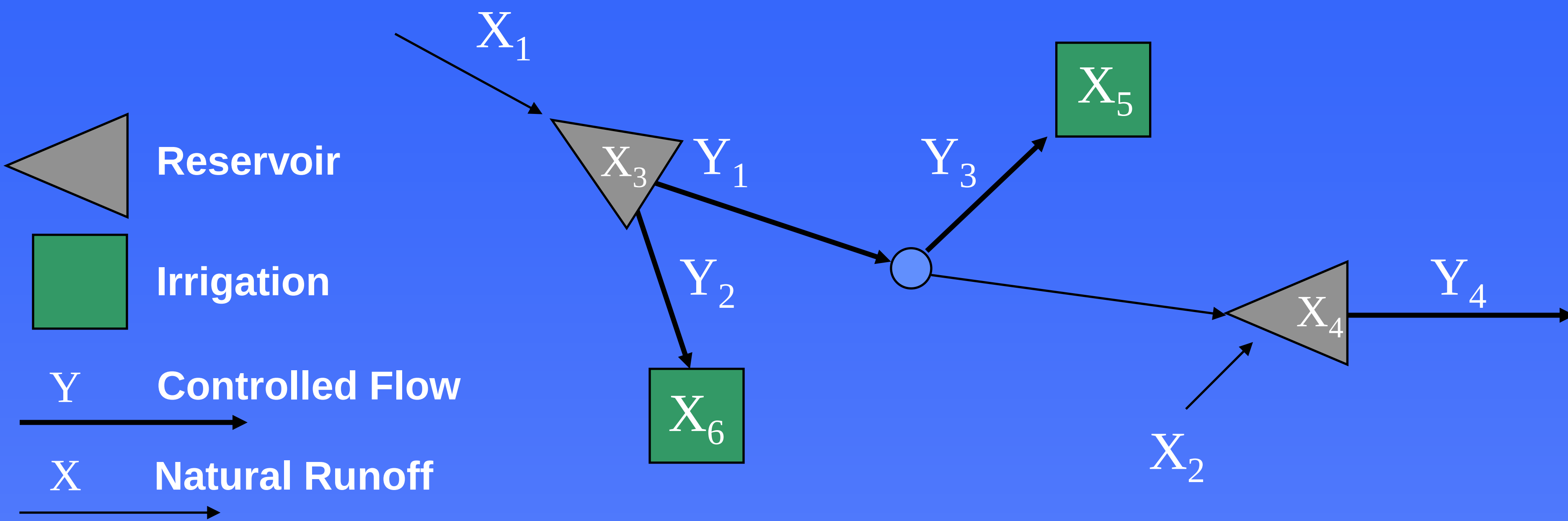
ABSTRACT

River basin management models differ substantially from simulation models, since they typically use some type of mathematical optimization to help address numerous options that decision makers face regarding basin-wide water allocation. New paradigms have emerged that provide substantial improvements to previous modelling. They include a combination of multiple time step optimization (MTO), which optimizes basin allocation at all nodes and for all relevant time steps, in conjunction with the new equal deficit sharing constraint, which de facto optimizes the amount of hedging applied to water demand in dry years, thus enabling firm supply at reduced rates as a function of the reduced hydrologic input and the priority of allocation. The new approach is flexible. When combined with stochastic hydrologic input, it can provide excellent basis for statistical inference of the model solutions, which is a valuable basis for building short term operating rules.

Conjunctive Optimization of Supply and Demand in River Basin Modeling

1. Introduction to Basin Management Models
2. Some Important Modeling Issues:
   - Current Modeling Practices
   - Simultaneous Optimization of Supply and Demand
   - Time Step Length
   - Need for agreement on minimum technical specifications and benchmarks
3. Conclusions and Recommendations

Introduction to Basin Management Models (BMM)



1. BMM simulate decision making process
2. BMM are either:
   - Rule Based (rely on the use of “if-else” rules);
   - Optimization Based, e.g. Maximize $\sum \sum Y_{i,t} P_i$

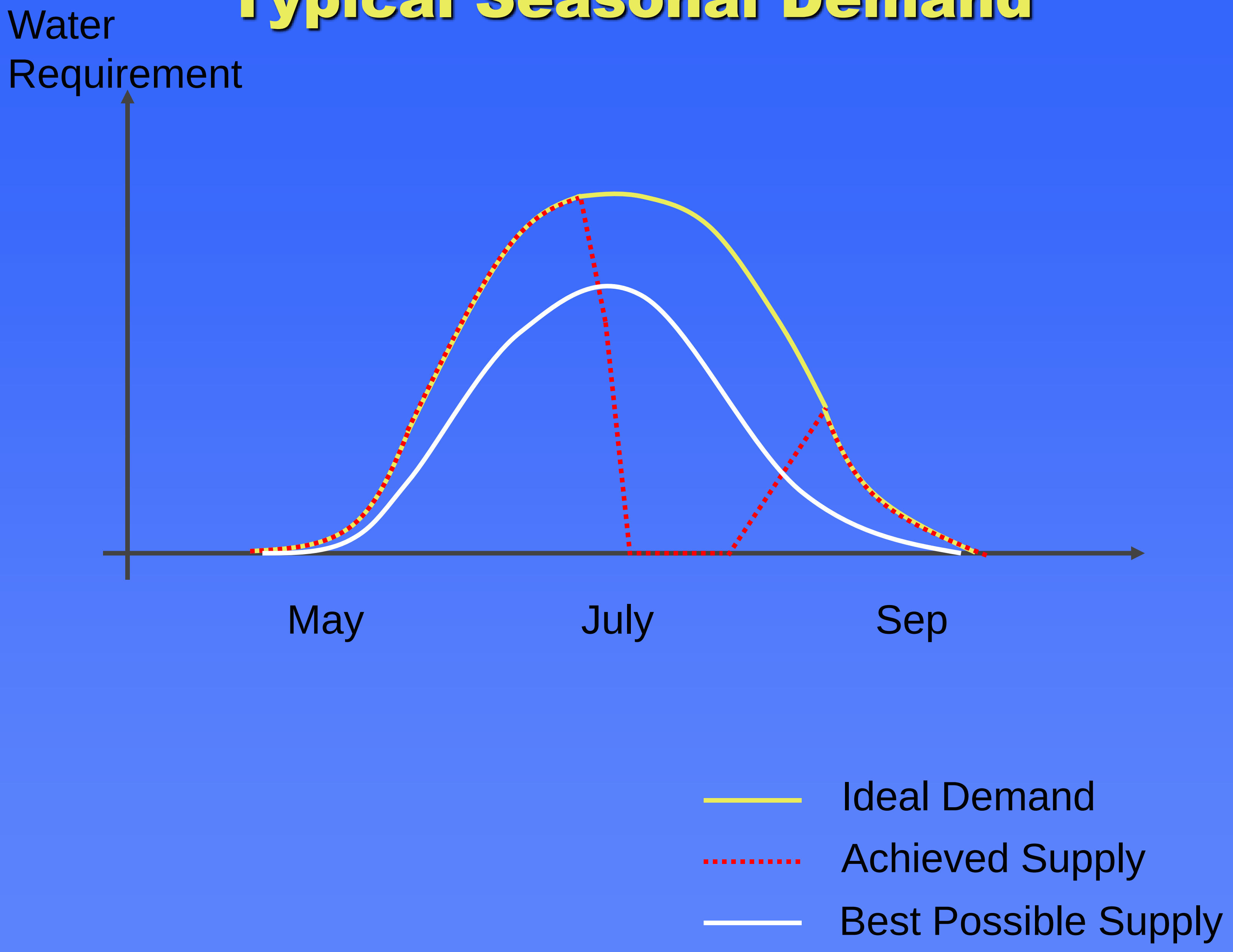
The Purpose and Typical Use of BMMs

The purpose of a BMM is to help us find the best operating regimes for various input scenarios

The use of BMM makes sense only if the obtained solution is better than the solution we would get using the rule of thumb (analogy with computer chess games)

The onus is on modelers to provide evidence that their model solutions are better than the rule of thumb

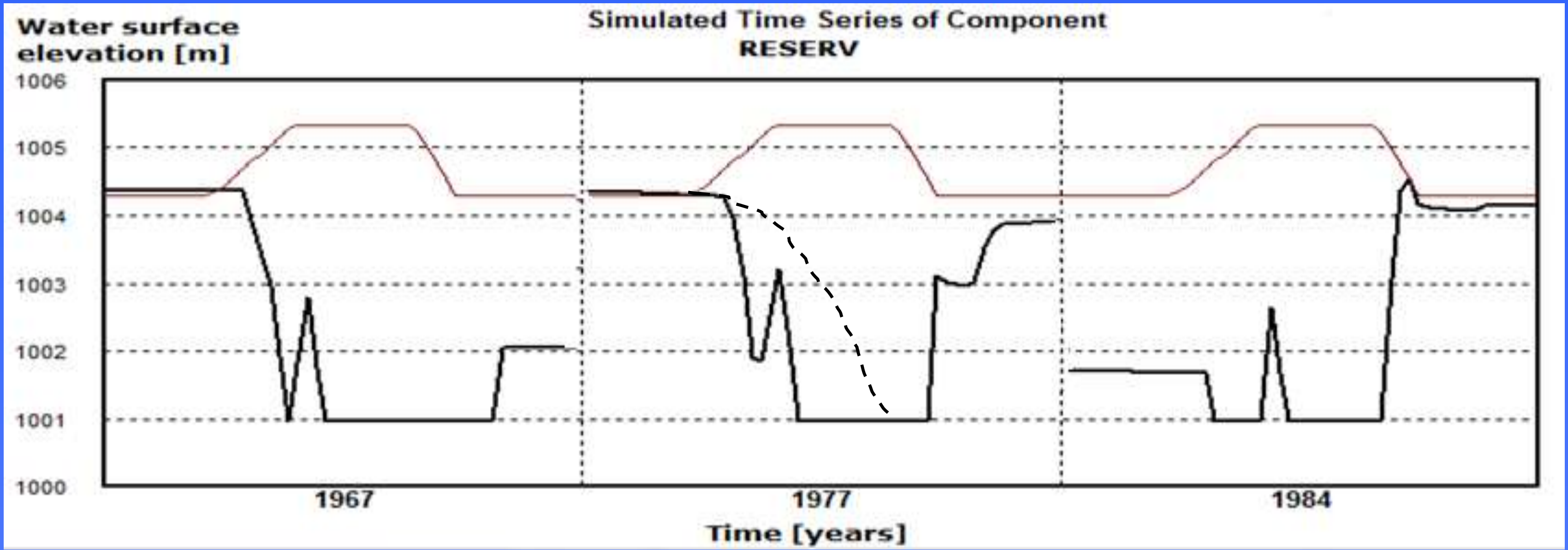
Typical Seasonal Demand

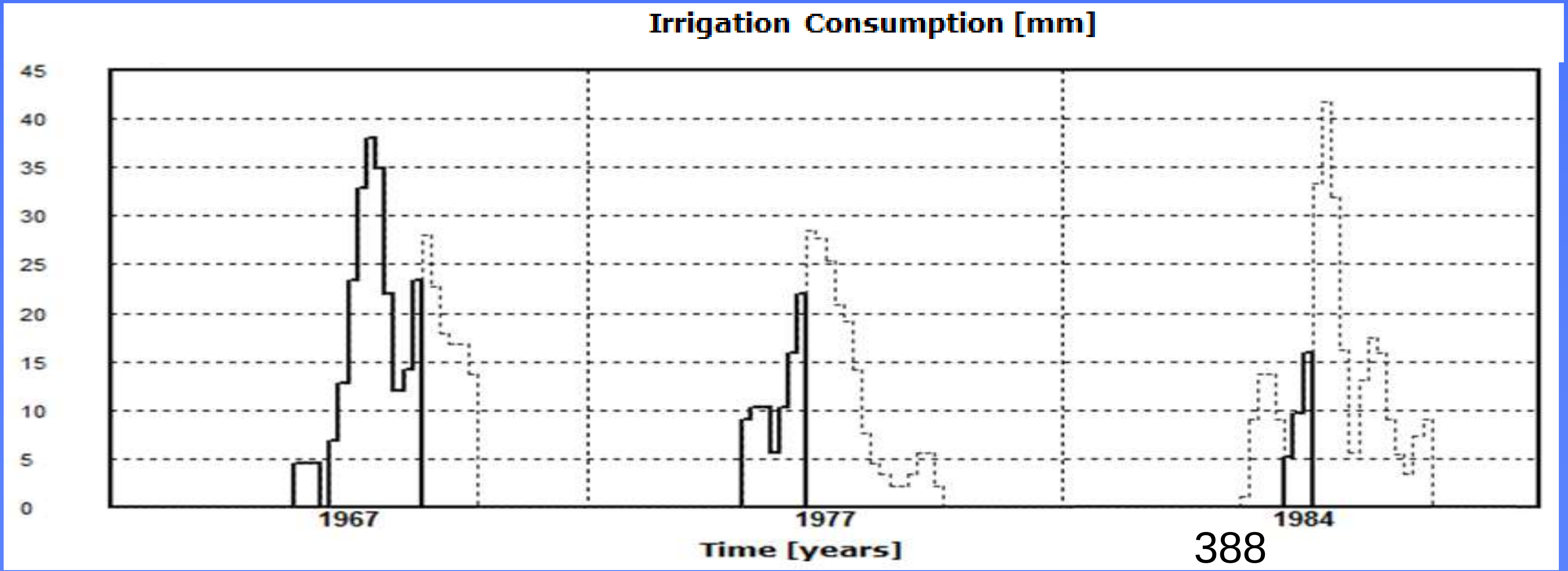


Current Modeling Practices

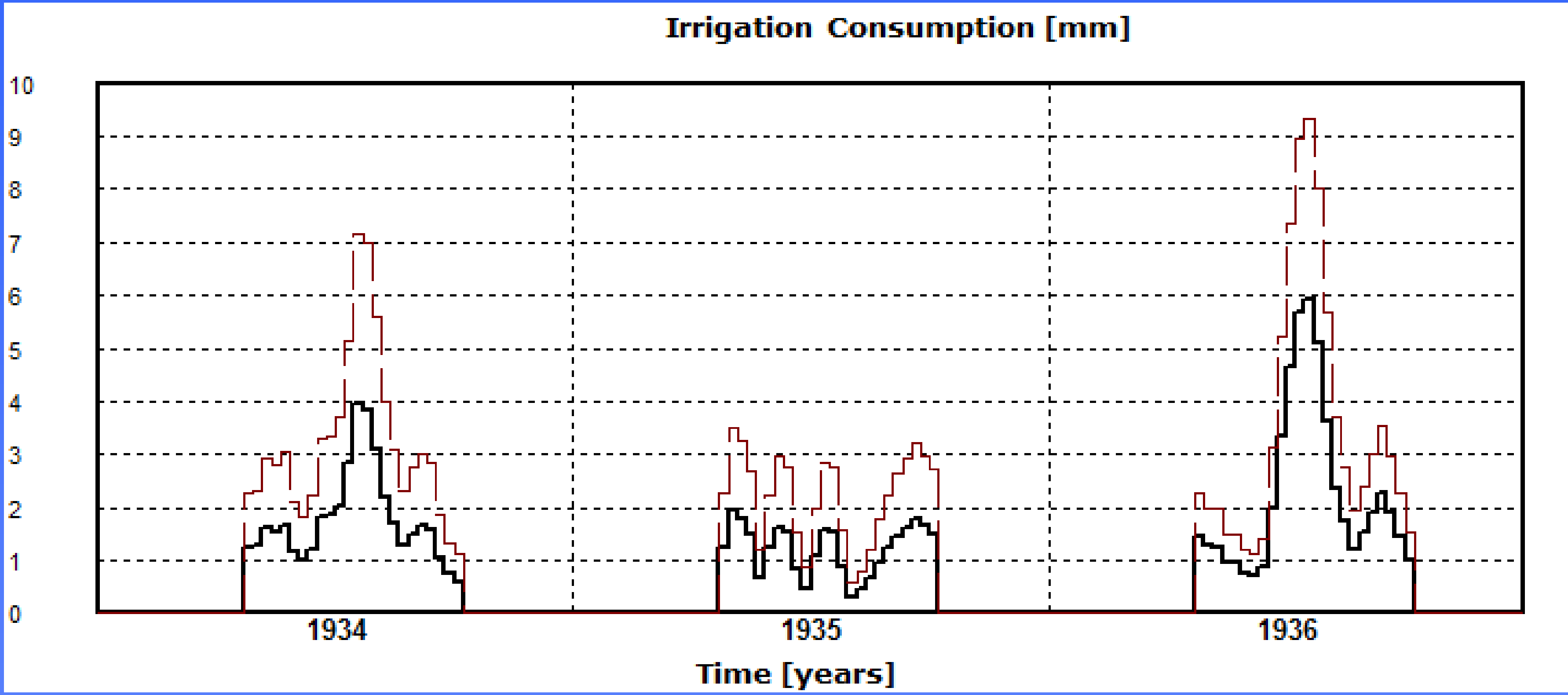
1. Reservoir operating rules are the same for every year, and they are arbitrarily defined by the modeler;
2. Model is typically run in single time step (STO) mode; and,
3. Water demands are based on full licenses (adjusted for precipitation) for each time step. There is no hedging of demands.

Modeling Results under STO Mode

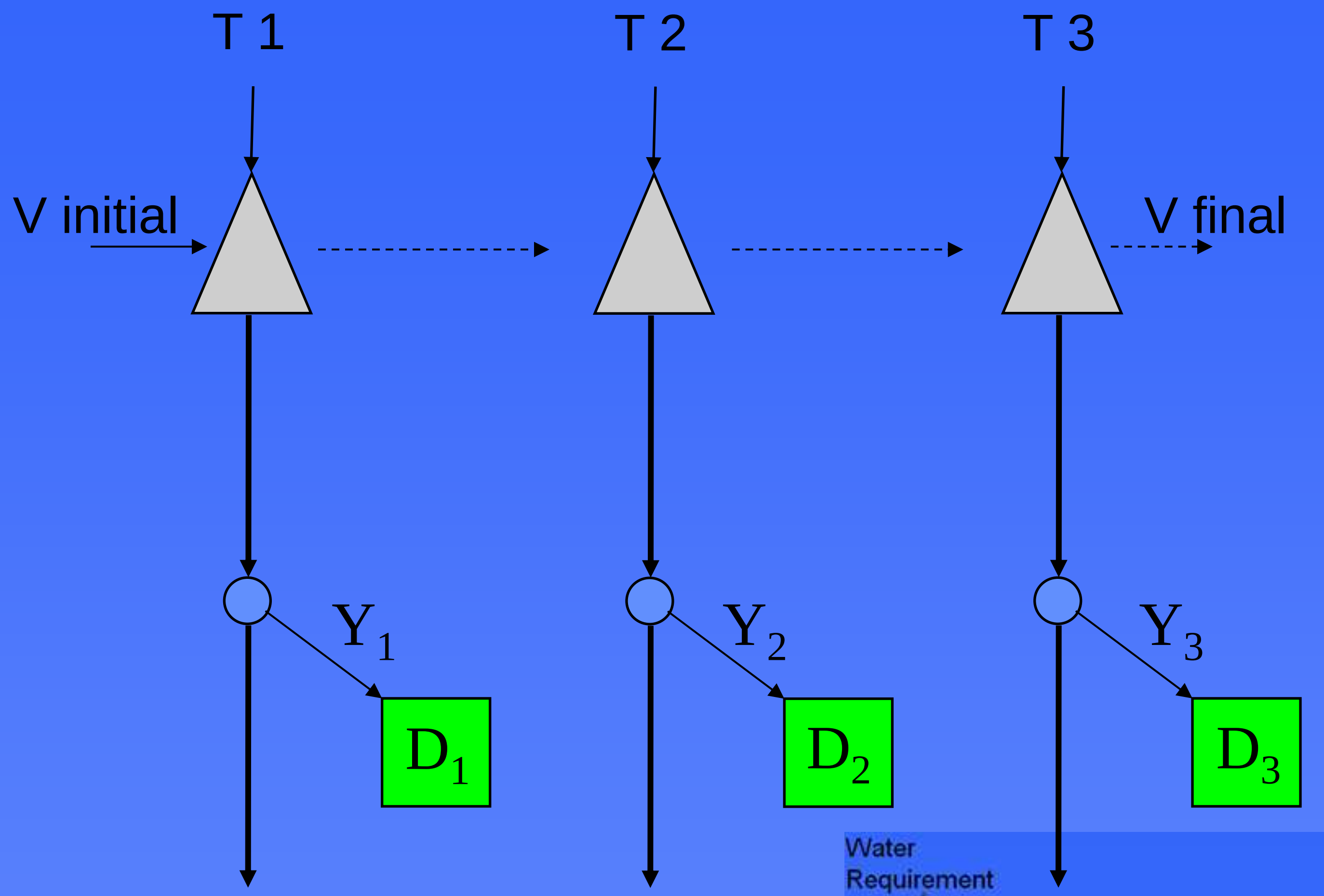




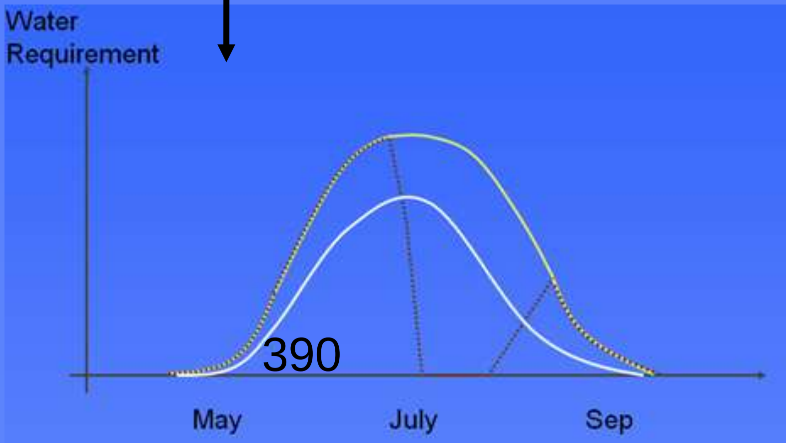
Modeling Results based on Demand Optimization



Multiple Time Step Optimization (MTO)



$$\frac{Y_t}{D_t} = \frac{Y_{t+1}}{D_{t+1}} \qquad for\ t = 0, n-1$$



Shortcomings of MTO

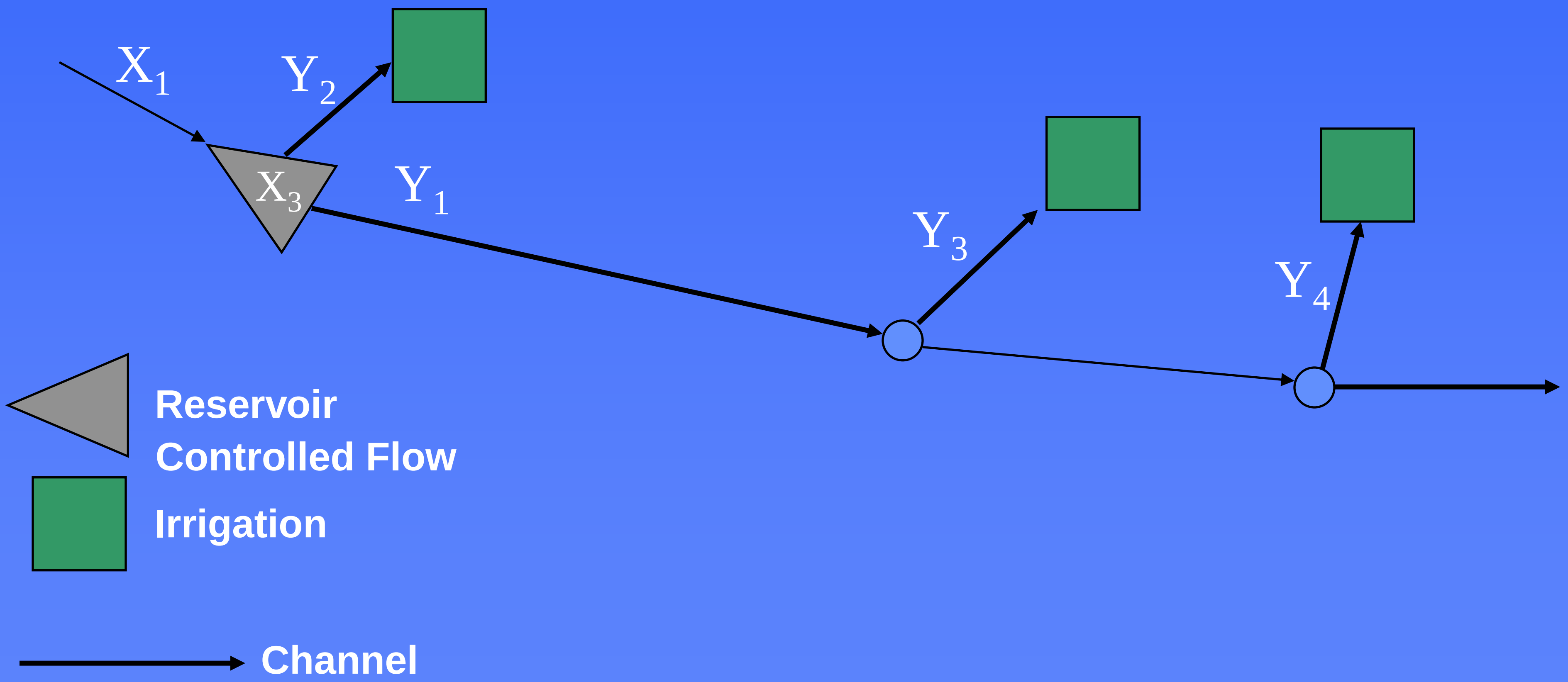
- Much larger solution networks with longer solution times;
- MTO runs are much more difficult to debug if something goes wrong; and,
- When used in combination with some constraints that require binary variables, the solution times may be prohibitive.

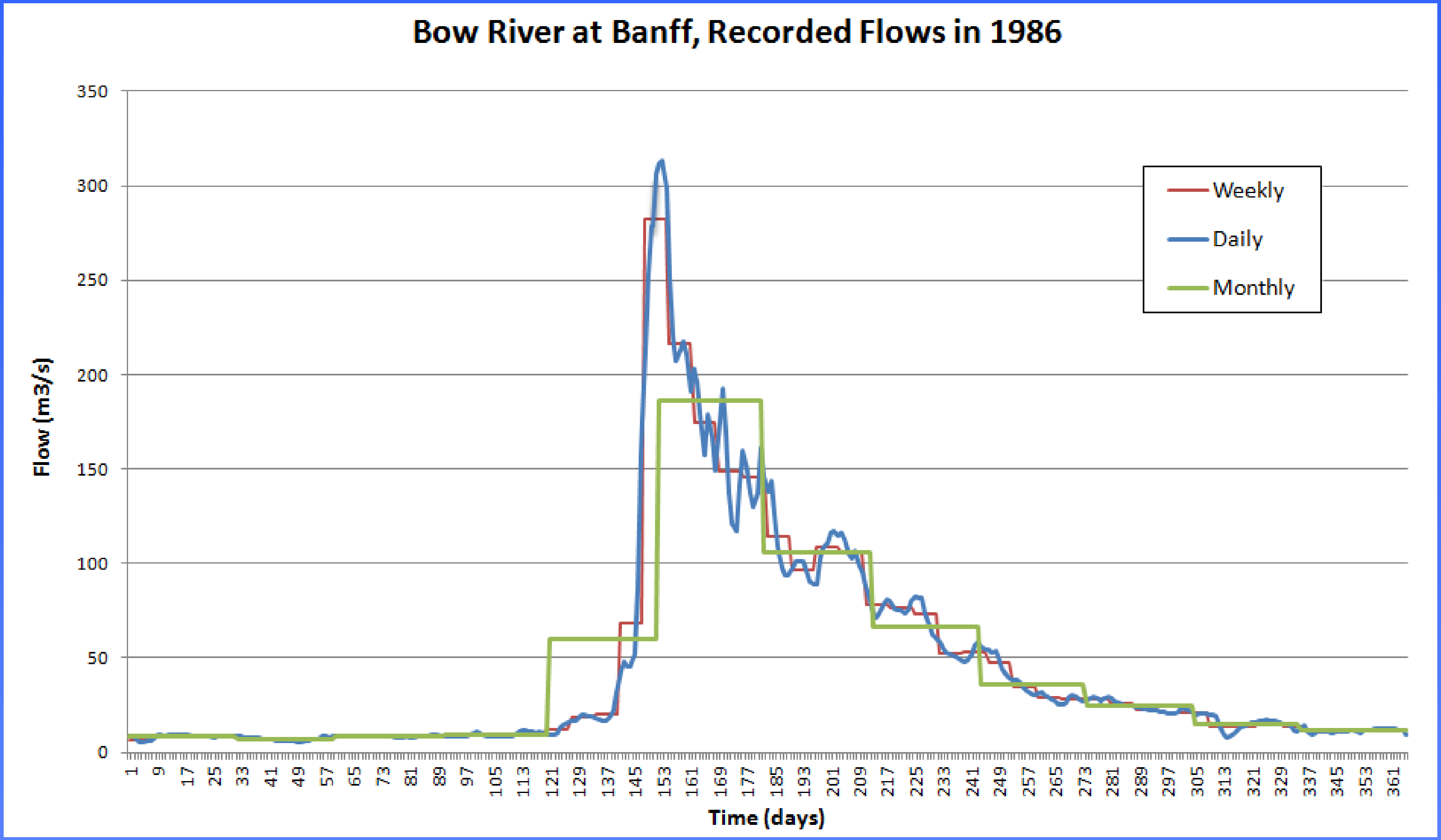
Benefits of MTO

- Solutions include perfect reservoir operating regime developed uniquely for each year by the model;
- Solutions include optimal demand reduction in dry years for all time steps within a year which is a better reflection of the actual management practices; and,
- Solutions over many years provide good basis for inferential development of seasonal operating rules

Time Step Length

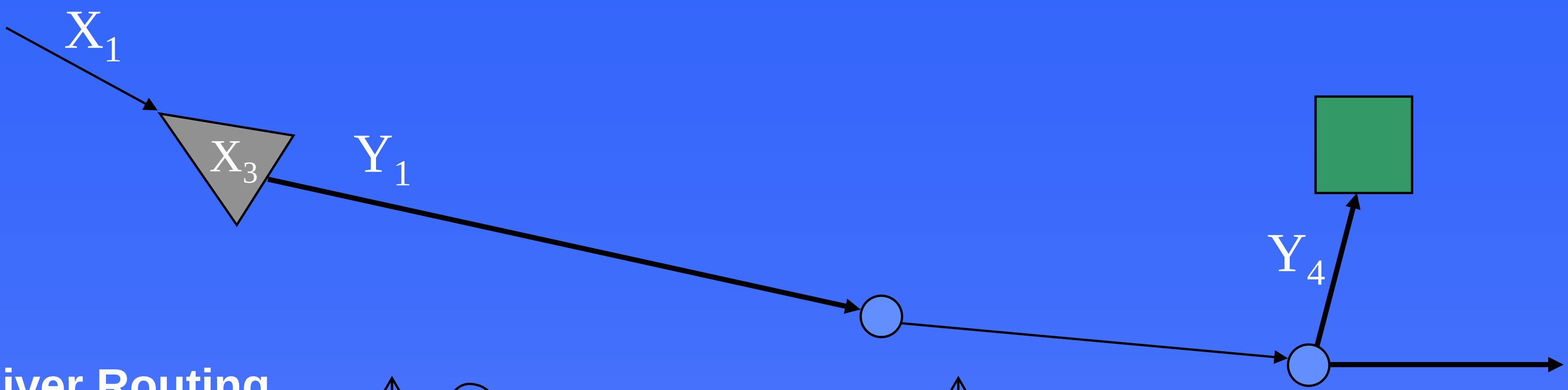
It is assumed that water can reach any user from the most upstream source within a time step. This restricts modeling of large basins to monthly time steps.



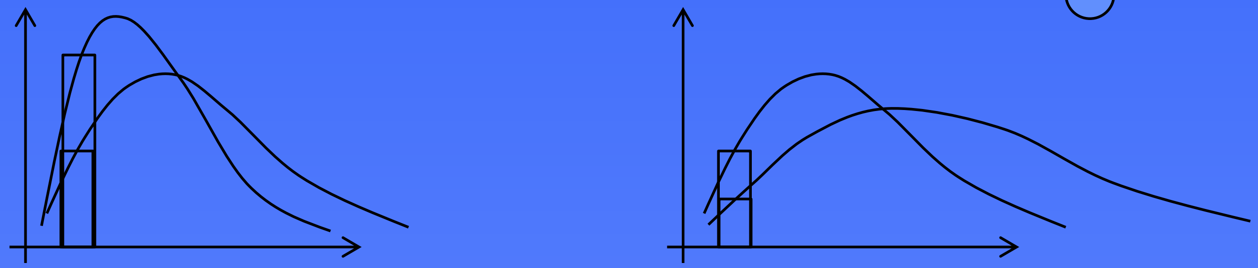


Monthly inflow hydrographs are much easier to manage. The same basins modeled with monthly and weekly time steps showed up to 28% difference in spills.

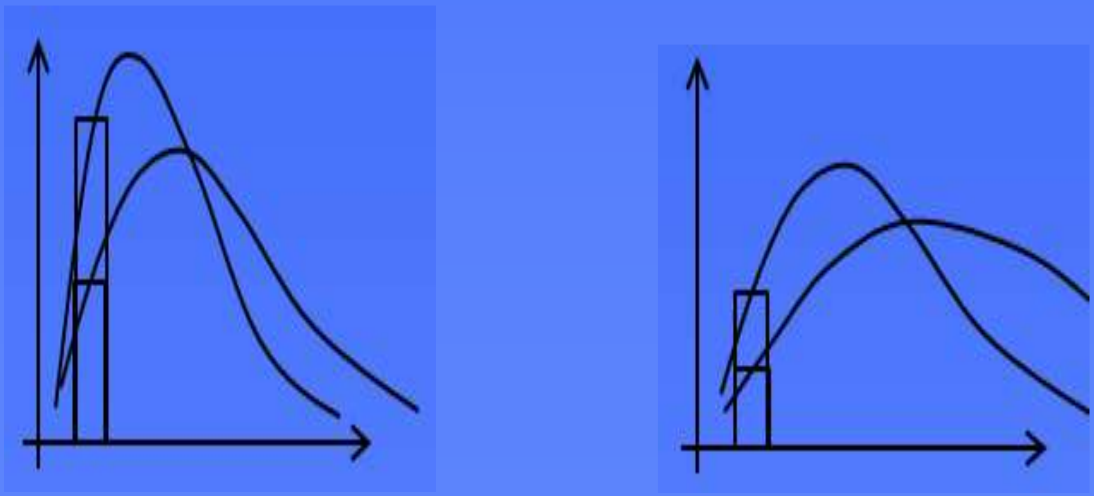
Problems with Channel Routing Constraints



River Routing Effects under normal reservoir release:



River Routing Effects under increased reservoir release:



Time Step Length

Inclusion of hydrologic channel routing as a constraint to optimization requires daily time steps, which introduces problems:

- **model floods the river valley to reduce the downstream deficits[1];**
- **There is no published solution to this problem (which does not mean that there is no solution); and,**
- **Modeling of small (daily) time steps can be done by setting the storage outflow to a fixed user defined value, which turns off the powerful optimization engine that no longer drives the storage releases.**

[1]*Ilich, N. 2008. Shortcomings of Linear Programming in Optimizing River Basin Allocation. Water Res. Research, Vol. 44.*

Time Step Length

There should be guidelines on:

- establishing the proper time step length (not too long to avoid problem with the spills, not too short to avoid problems with routing);
- how to model time steps which are shorter than the total travel time through the basin; and,
- how to model hydrologic river routing within the optimization framework, can it be done within the LP framework and if so, how? The routing coefficients do change with significant flow variations over the year.

$$O_i = C_0 I_i + C_1 I_{i-1} + C_2 O_{i-1}$$

Min Tech. Specifications: List of Constraints

- Storage outlet structure
- Diversion at a weir
- Net Evaporation on Reservoirs
- Return flow channels
- Diversion license volume limit per year
- Apportionment volume limit per year
- Channel routing (?)
- Equal deficit constraints

Model Constraints

There should be guidelines on:

- Establishing which constraints are important and by how much they affect the quality of solutions if they are not modeled;
- How individual constraints should be formulated and included in the model; and,
- Problems with constraints should be formulated as benchmark tests and their solutions should be published such that every model vendor can verify their results by re-running the benchmarks.

Model Objectives

Objective Function: $\sum \sum Y_{i,\,t}\, P_i$

A universally accepted algorithm that determines suitable priority factors *Pi* for a given system based on:

- **a) Network configuration**
- **b) Priorities**
- **c) Constraints**

has yet to be devised. It would be useful to the practitioners.

Summary of Desirable Research Objectives

Further research is needed to address the following issues:

a) How to model time steps that are shorter than the entire basin travel time

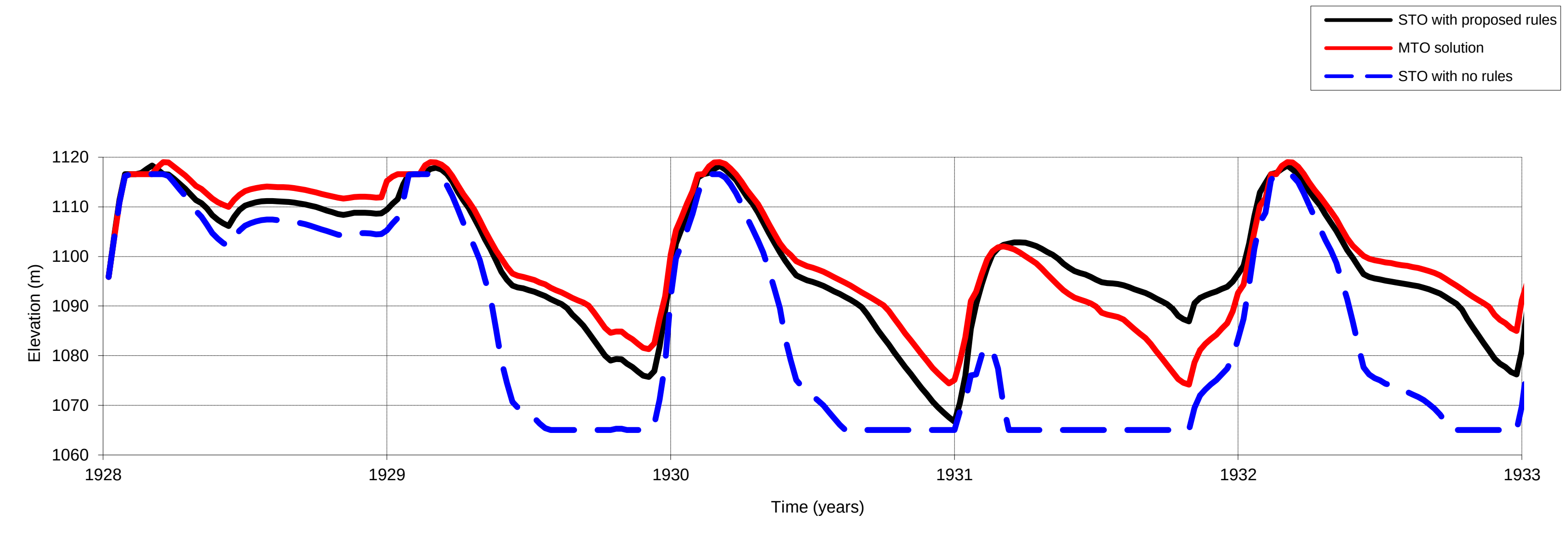
b) Importance of MTO solution framework

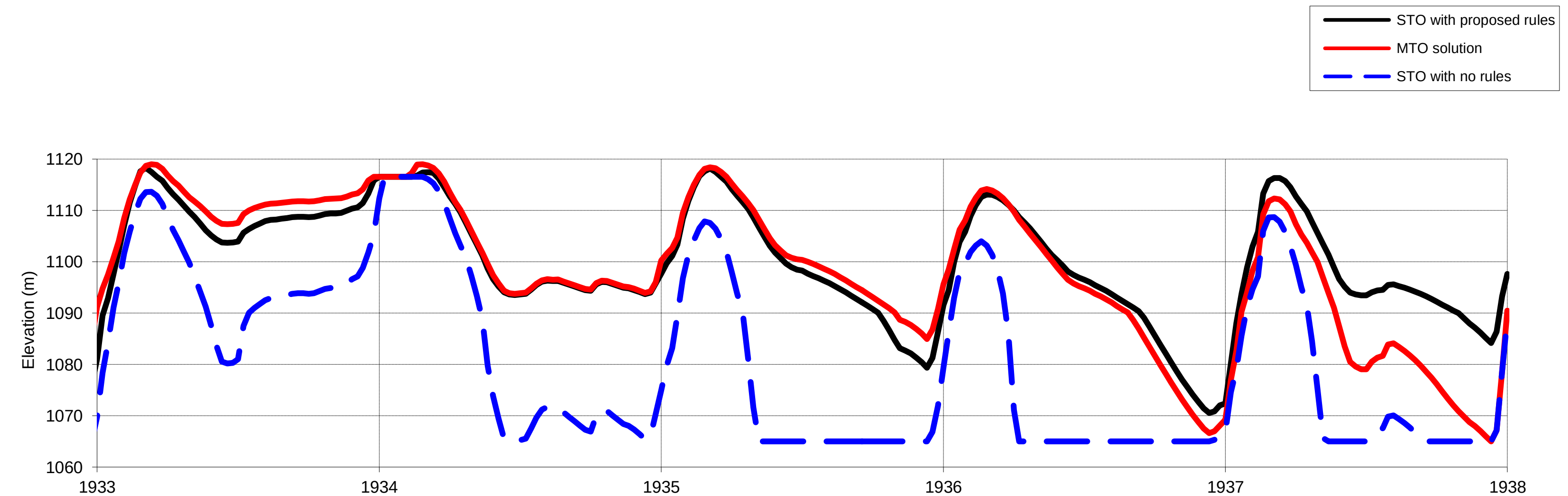
c) Agreement on which constraints are important and how they should be modeled

d) A universal algorithm that finds suitable payout (cost) factors based on network configuration and established priorities

e) General agreement on modeling approach aimed to derive short term operating rules that would be easy to understand and implement.

Use of MTO in Development of Rule Curves
Storage Levels for three Scenarios (1928-1937)





The End

Alberta Government

Dinner

Day 1 – Dinner Key Note

John Pomeroy – University of Saskatchewan

BIOGRAPHY

Dr. John Pomeroy is the Canada Research Chair in Water Resources and Climate Change (Tier 1), Professor of Geography and Director of the Centre for Hydrology at the University of Saskatchewan, an Honorary Professor of the Centre for Glaciology, Aberystwyth University, Wales and Chinese Academy of Sciences, Lanzhou and an Institute Professor of the Biogeoscience Institute of the University of Calgary. He serves as President of the International Commission for Snow and Ice Hydrology, leads the Canadian Rockies Hydrological Observatory and was recently Chair of the IAHS Decade on Prediction in Ungauged Basins, Principal Investigator for the IP3 Cold Regions Hydrology Network and Co-Principal Investigator for the Drought Research Initiative. Dr. Pomeroy has authored over 200 research articles and several books. His current research interests are the impact of land use and climate change on cold and semi-arid region hydrology, snow physics, mountain hydrology, water security and hydrological predictions in Ungauged Basins including floods and droughts.

Day 1 – Dinner Key Note

John Pomeroy – University of Saskatchewan

ABSTRACT

The Canadian Prairie region has presented formidable challenges for hydrological models due to its many internal drainages, large depressional storage, variable contributing area, high infiltration rates, wind redistribution of snow, solar radiation dominated snowmelt, frozen soils and low evapo-transpiration rates. The Canadian Rockies have also presented widespread problems to many models because of many of the aforementioned processes and sublimation of intercepted snow, the impact of slope and aspect on the snowmelt energy balance and sub-canopy radiation effects. Realistic hydrological modelling in western Canada has been hampered by attempts to apply models that were developed for well-drained, temperate or humid regions in our often poorly-drained, cold and sub-humid environment. Such model applications often require setting parameters outside of their physically meaningful range in order to compensate for deficiencies in model structure, conceptualisation and parameterisation. The Cold Regions Hydrological Modelling Platform (CRHM) is a modular hydrological model development platform that was created to explore appropriate structural content, adapt model structure to specific process scales, and increase the physical basis of hydrological models. It has been developed based on western Canadian basin research. In CRHM the user assembles a hydrological model from a selection of hydrological process modules (parameterisations). CRHM's modularity provides the possibility to change process parameterisations from simpler to more complex ones and to emphasize prairie, forest or mountain processes. It is also possible to rapidly update parameterisations as advances in hydrological understanding occur, or to run models in parallel to compare the impact of differing parameterisations, parameter or driving data availability on model results. Recent CRHM advances include integration with the WISKI data management environment. The impact of these parameterisations on the predictive performance of models created with CRHM is discussed using case studies from the prairie and Rocky Mountains in Alberta. For some basins these are the first successful hydrological process simulations ever conducted and can be used to examine hydrological sensitivity to future land use, wetland drainage, drought, flood and climate change scenarios. The next steps are to apply models created from CRHM for these impact scenarios and to couple them to operational, climate and water resource models for a wider variety of applications from small to large scales.

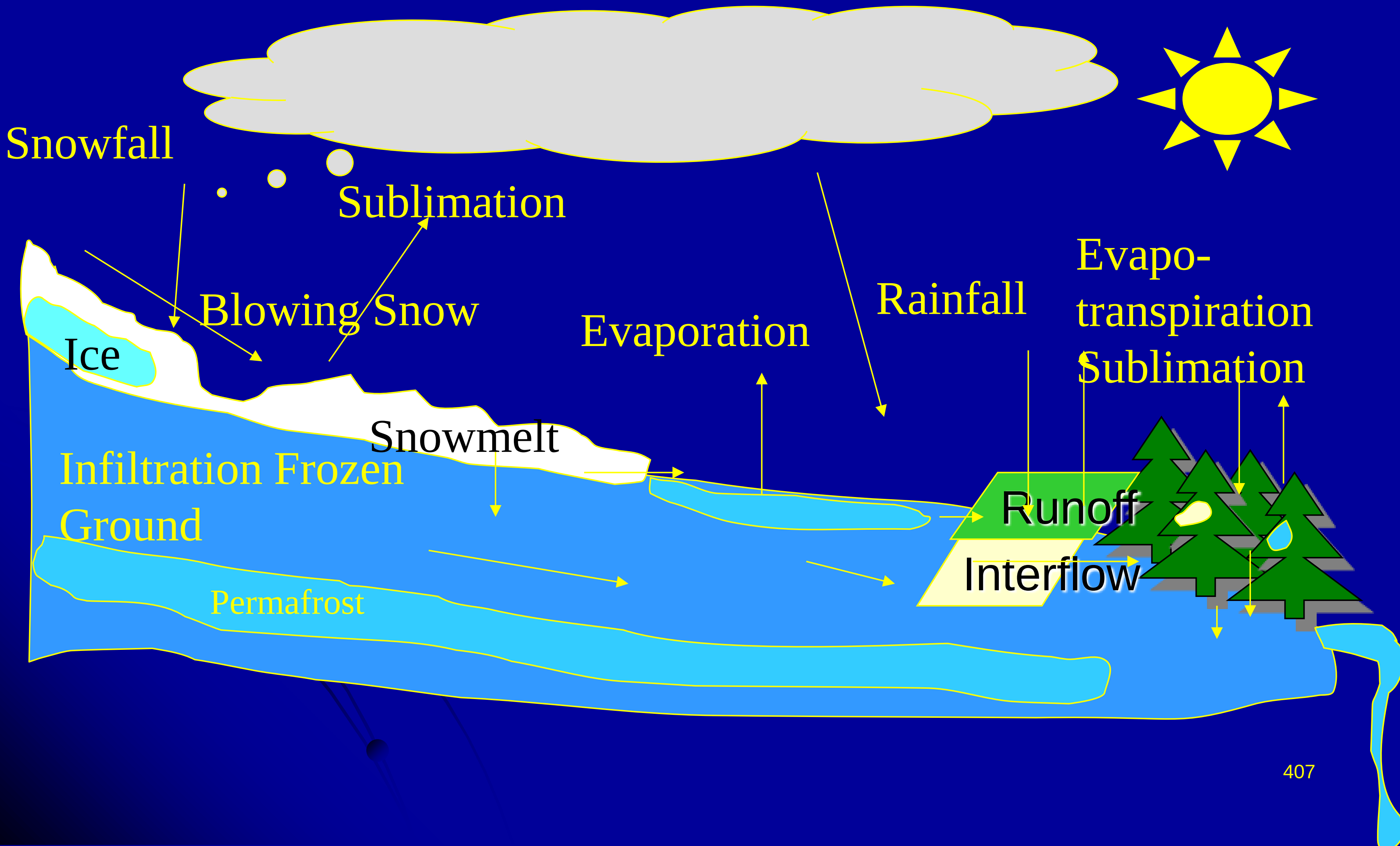
Multiscale Modelling of Mountain, Forest and Prairie Hydrology

John Pomeroy, Kevin Shook, Xing Fang, Tom Brown

Centre for Hydrology,
Univ. of Saskatchewan,
Saskatoon & Kananaskis (Coldwater Laboratory)

www.usask.ca/hydrology

Cold Regions Hydrological Cycle



Why Physically-based Hydrological Modelling?

- **Robust - can be more confidently extrapolated to different climates and environments and performs better in extreme situations (floods, droughts).**
- **Scientifically Satisfying - represents a compilation of what is understood about hydrology.**
- **Flexible – permits assessment of land use and climate change impacts on streamflow regime, soil moisture, wetlands, snowpack, groundwater, chemistry, etc.**
- **Can interface with chemistry and ecology - aquatic chemistry and hydroecological modelling require a sound hydrophysical base.**
- **Elevates hydrological *practice* to hydrological *science.***

Information Needs to Design Models

- Identification of the principles governing the primary physical processes responsible for most water movement in basin (**processes**).
  - Governs model structure
- Fundamental boundary and initial conditions that affect these processes (**parameters**).
  - Governs model parameterisation
- Length scales for self-similarity and variability associated with the properties affecting these processes (**scale**).
  - Governs model spatial discretization.

Observations Clustered in Small Basins Improve Understanding

Appropriate Hydrological Modelling

- Model structural complexity needs to be appropriate for primary governing processes, parameter & meteorological data availability.
- Detailed parameter information is normally limited outside of research basins
- Basin discretization using hydrological response length scales found to be very useful
- Accurate interpolation of meteorological variables is critical.
- Structure, parameters and scale are informed by the results of process studies and distributed modelling at a network of research basins.

Cold Regions Hydrological Model Platform: CRHM

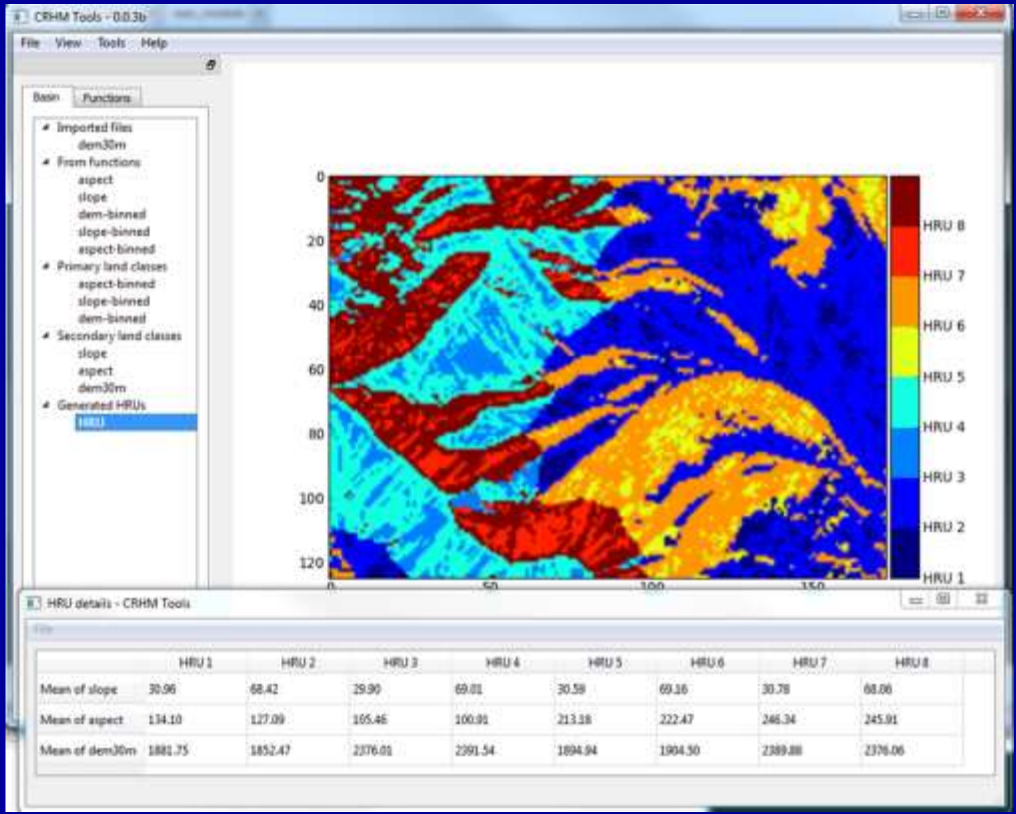
- Modular – purpose built from C++ modules
- Parameters set by knowledge rather than optimization
- Hydrological Response Unit (HRU) basis
  - landscape unit with characteristic hydrological processes/response
  - single parameter set
  - horizontal interaction along flow cascade matrix
  - Model tracks state variables and flows for HRU
- Coupled energy and mass balance, physically based algorithms applied to HRUs via module selection
- HRUs connected aerodynamically for blowing snow and via dynamic drainage networks for streamflow
- Flexible - can be configured for prairie, mountain, boreal, arctic basins
- Sub-basins connected via Muskingum routing
- Visualisation tools, GIS interface
- Model failure is embraced and instructive

Pomeroy et al., 2007 *Hydrol. Proc.*

Tom Brown, CRHM Modeller

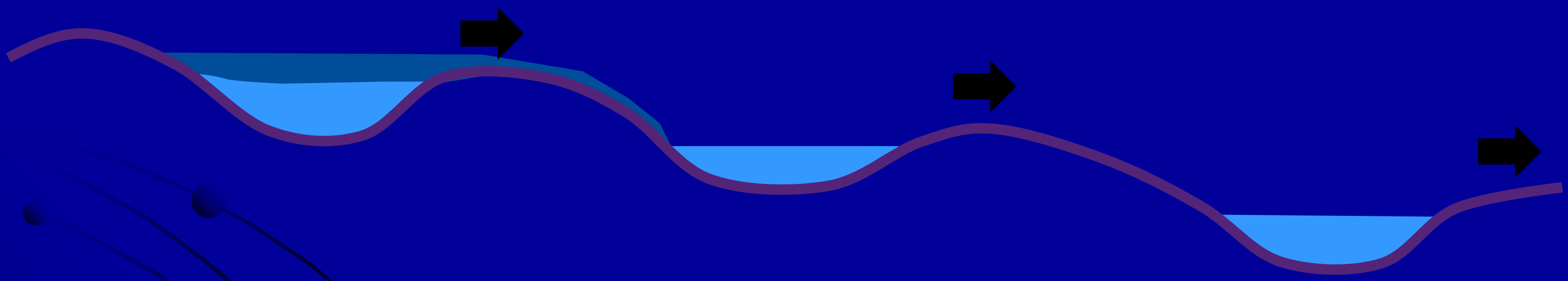
Hydrological Response Units (HRU)

- **A HRU is a spatial unit in the basin described by a single set of parameters, defined by**
  - **biophysical structure - soils, vegetation, drainage, slope, elevation, area (determine from GIS, maps)**
  - **hydrological state – snow water equivalent, internal energy, soil moisture, depressional storage, lake storage, water table (track using model)**
  - **hydrological flux - snow transport, sublimation, evaporation, melt discharge, infiltration, drainage, runoff. Fluxes are determined using fluxes from adjacent HRU and so depend on location in a flow sequence.**



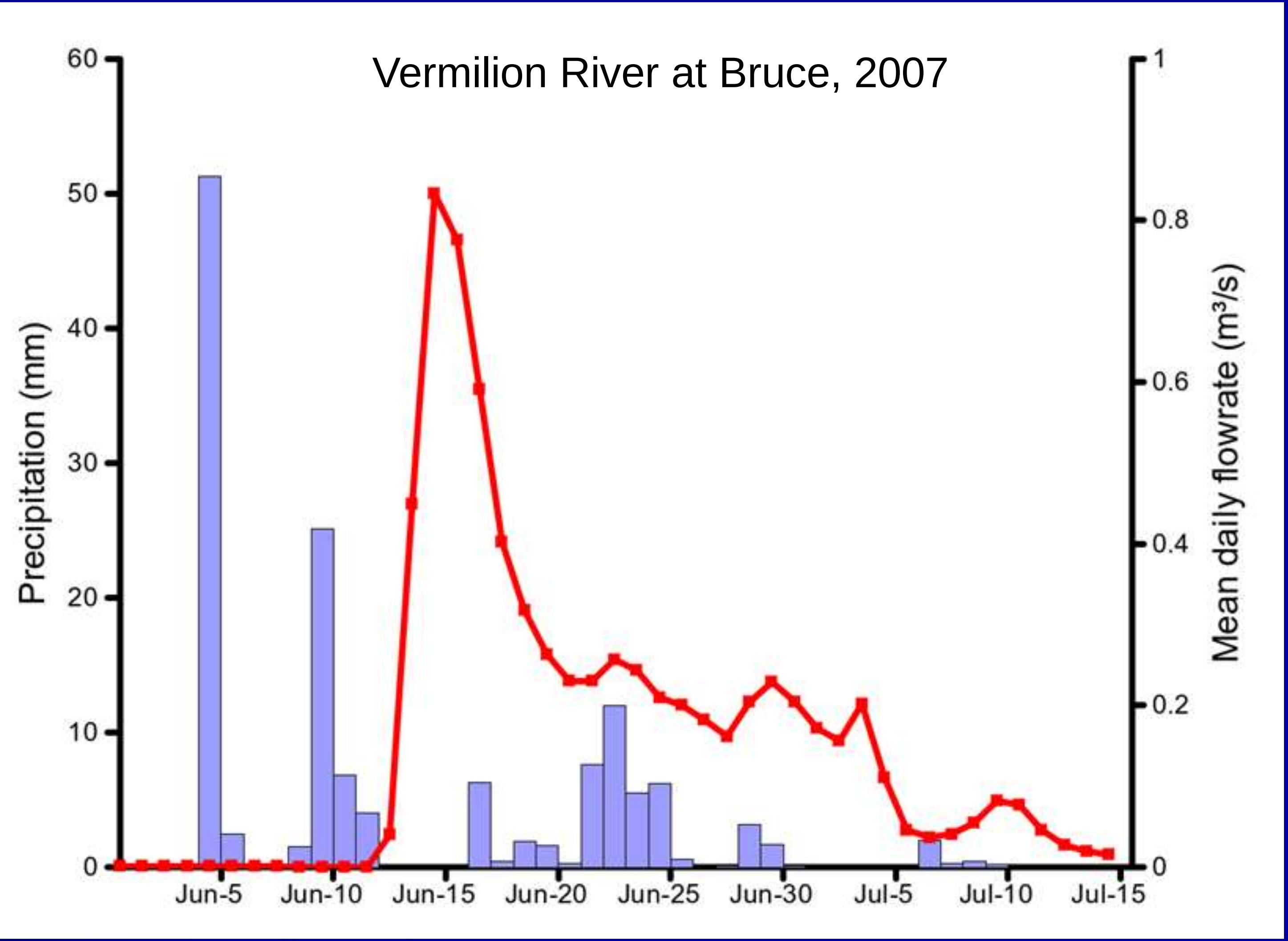
Prairie Hydrological Connectivity

The 'fill and spill' hypothesis



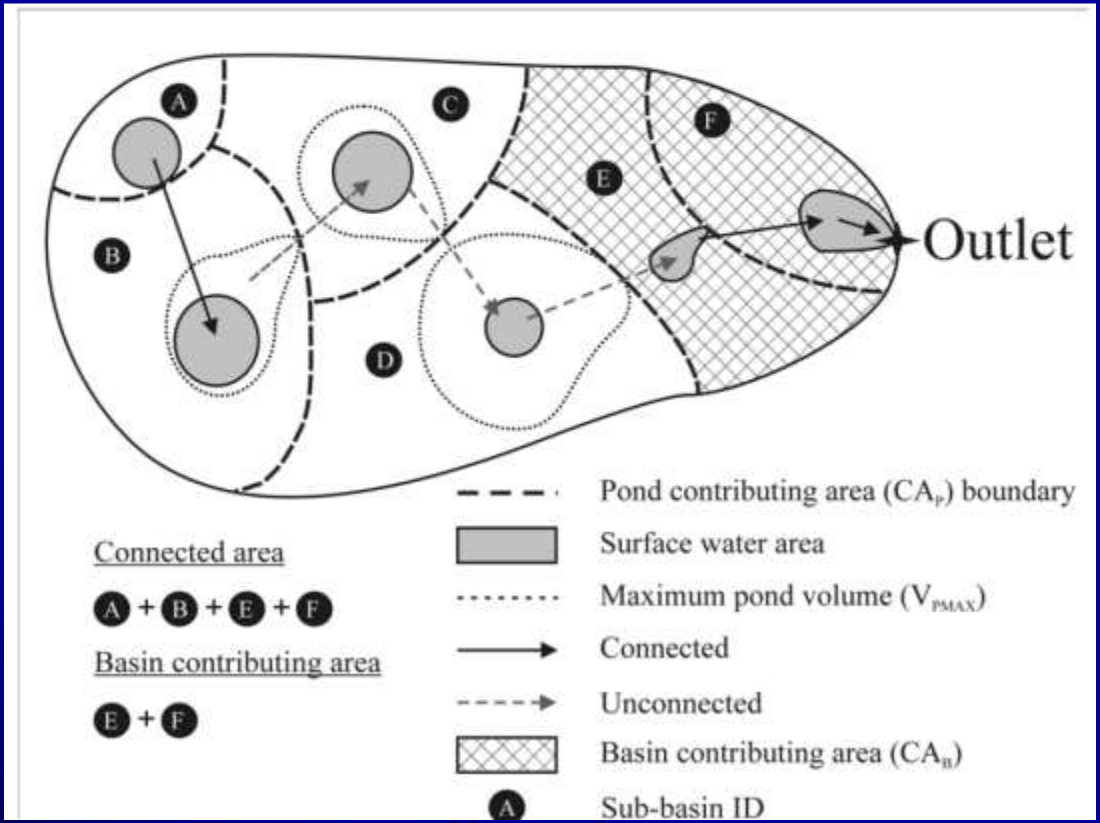
Lack of groundwater connections in this landscape – heavy tills

Impact of Fill and Spill on Hydrological Response to Precipitation

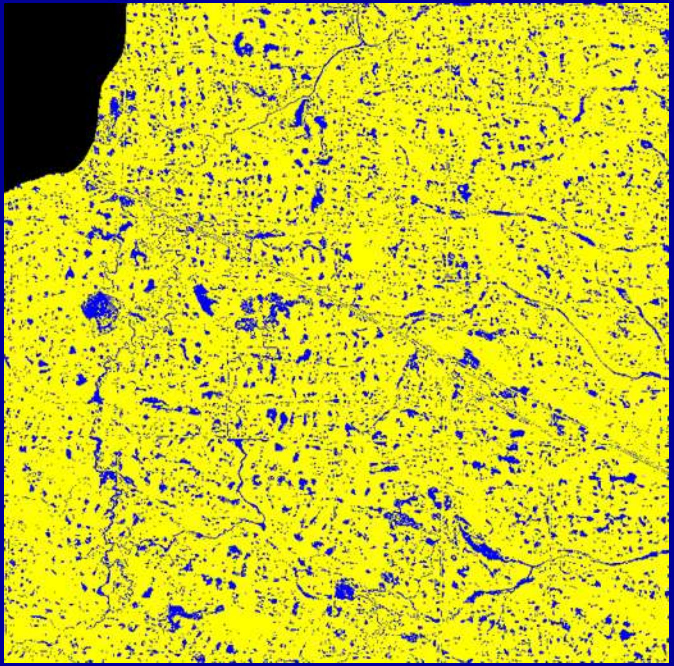


Fill and Spill Leads to Variable Contributing Area

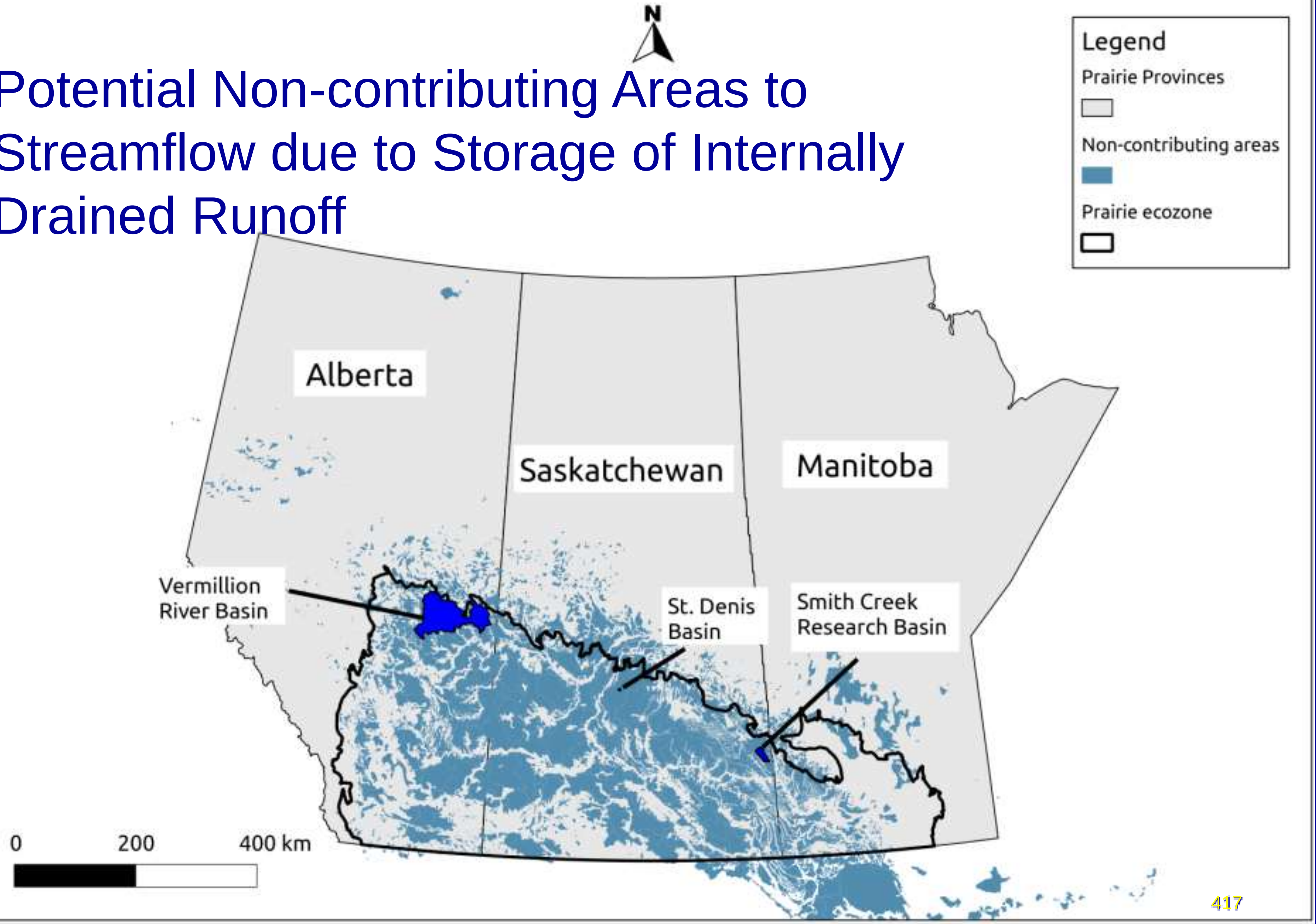
Conceptual View – Dean Shaw



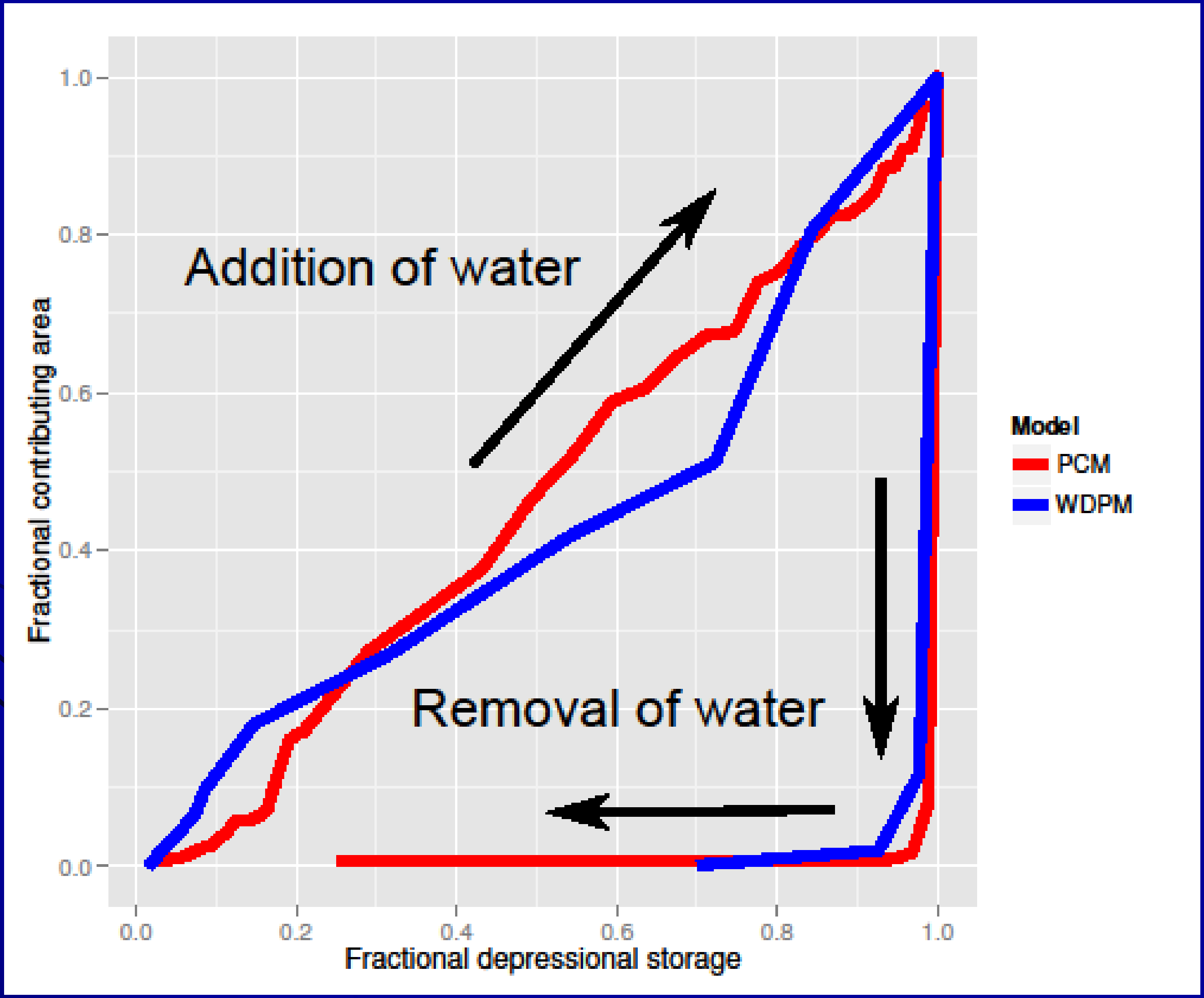
Real Wetlands,
Vermilion River Basin



Potential Non-contributing Areas to Streamflow due to Storage of Internally Drained Runoff

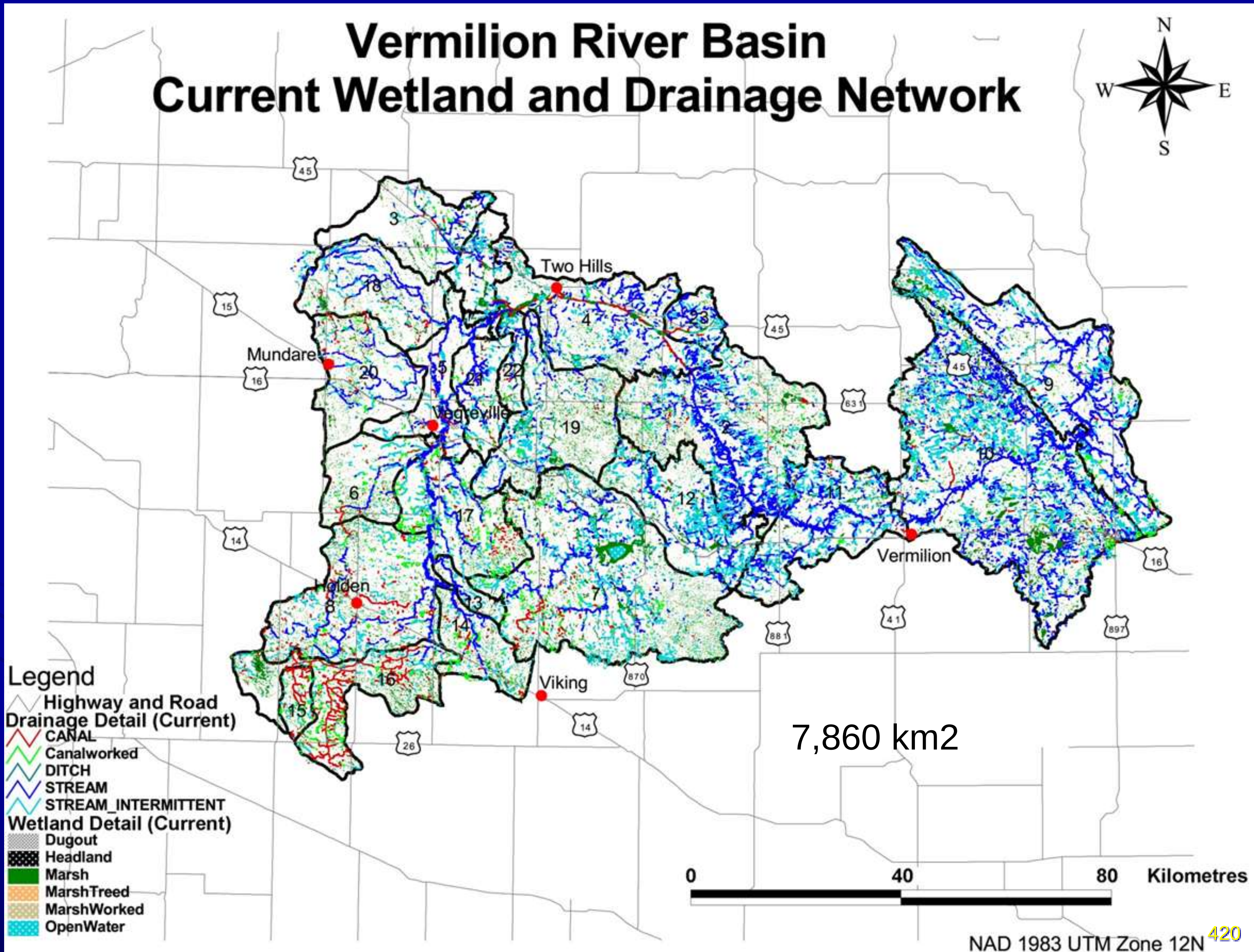


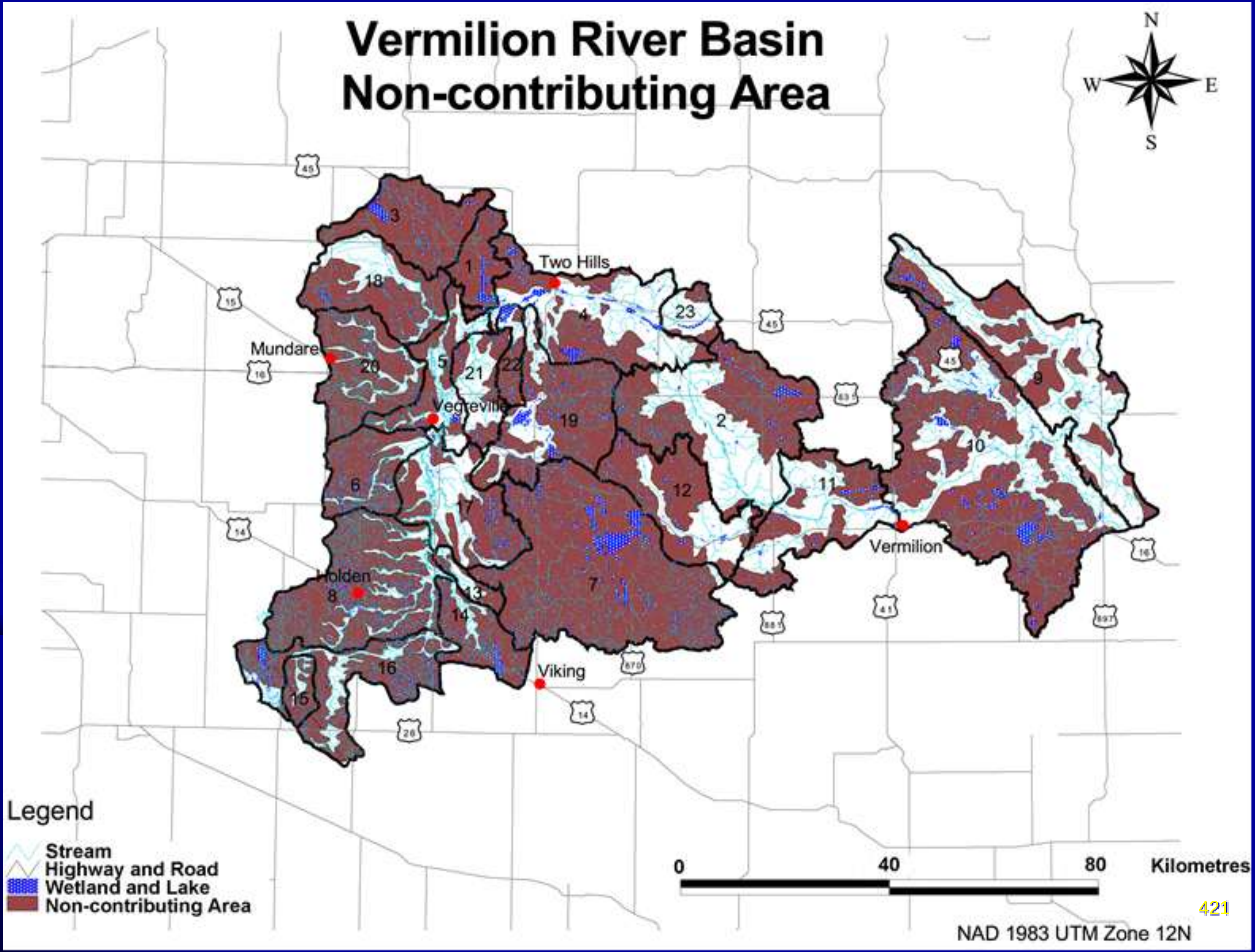
Depressional Storage – Basin Contributing Area Relationship



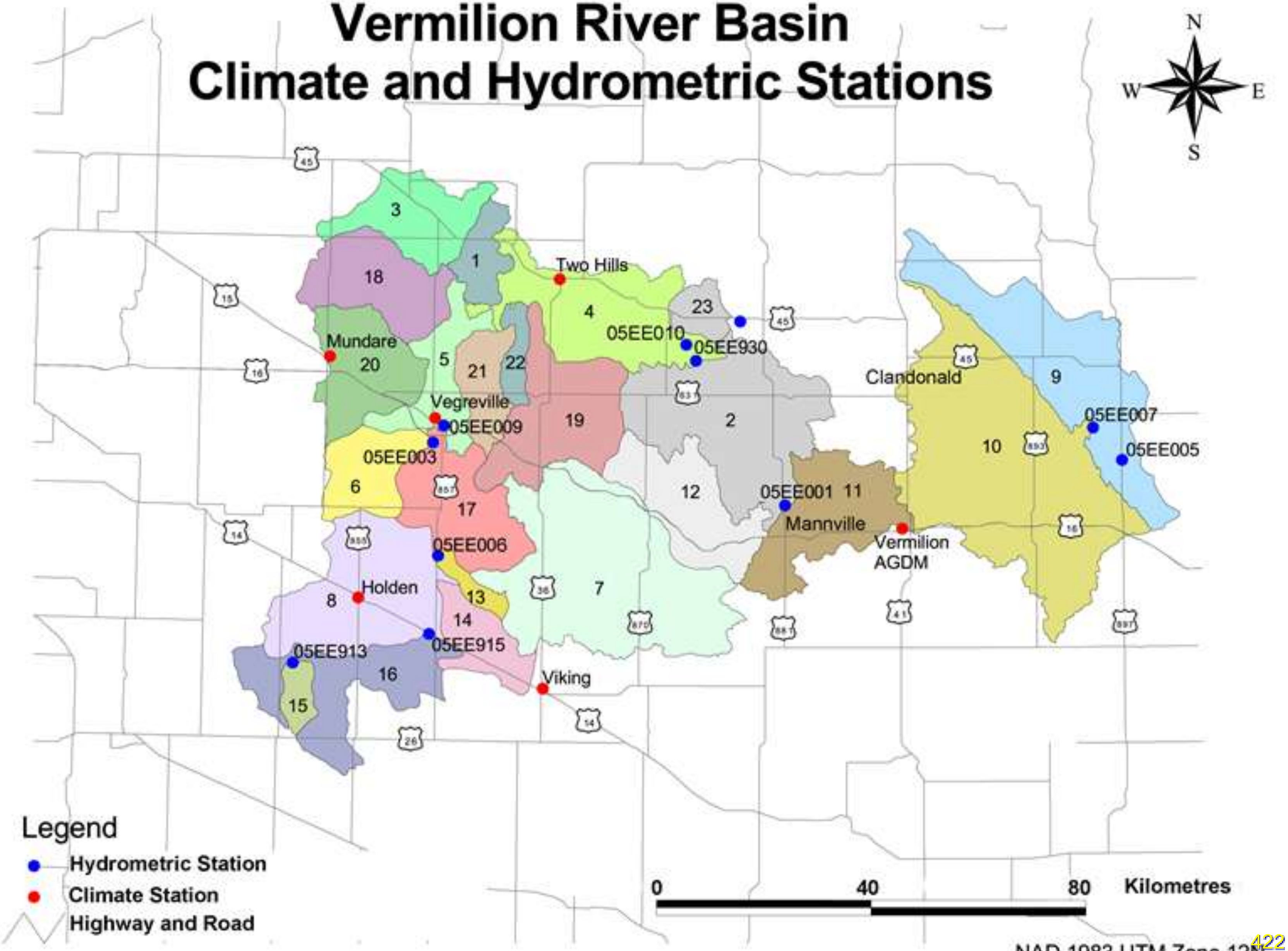
Objective

- Develop a model that can demonstrate the role of surface water storage on the hydrology of Prairie river basins.
- Apply the model to simulate streamflow.
- Modify the representation of wetlands in the model to show the impact of restoration and drainage on basin hydrology.


Vermilion River Basin
Current Wetland and Drainage Network
N
W
E
S
Two Hills
Mundare
Vegreville
Holden
Viking
Vermilion
Legend
Highway and Road
Drainage Detail (Current)
CANAL
Canalworked
DITCH
STREAM
STREAM_INTERMITTENT
Wetland Detail (Current)
Dugout
Headland
Marsh
MarshTreed
MarshWorked
OpenWater
7,860 km2
0
40
80
Kilometres
NAD 1983 UTM Zone 12N


Vermilion River Basin
Non-contributing Area
N
W
E
S
Two Hills
Mundare
Vegreville
Holden
Viking
Vermilion
Legend
Stream
Highway and Road
Wetland and Lake
Non-contributing Area
0
40
80
Kilometres
NAD 1983 UTM Zone 12N

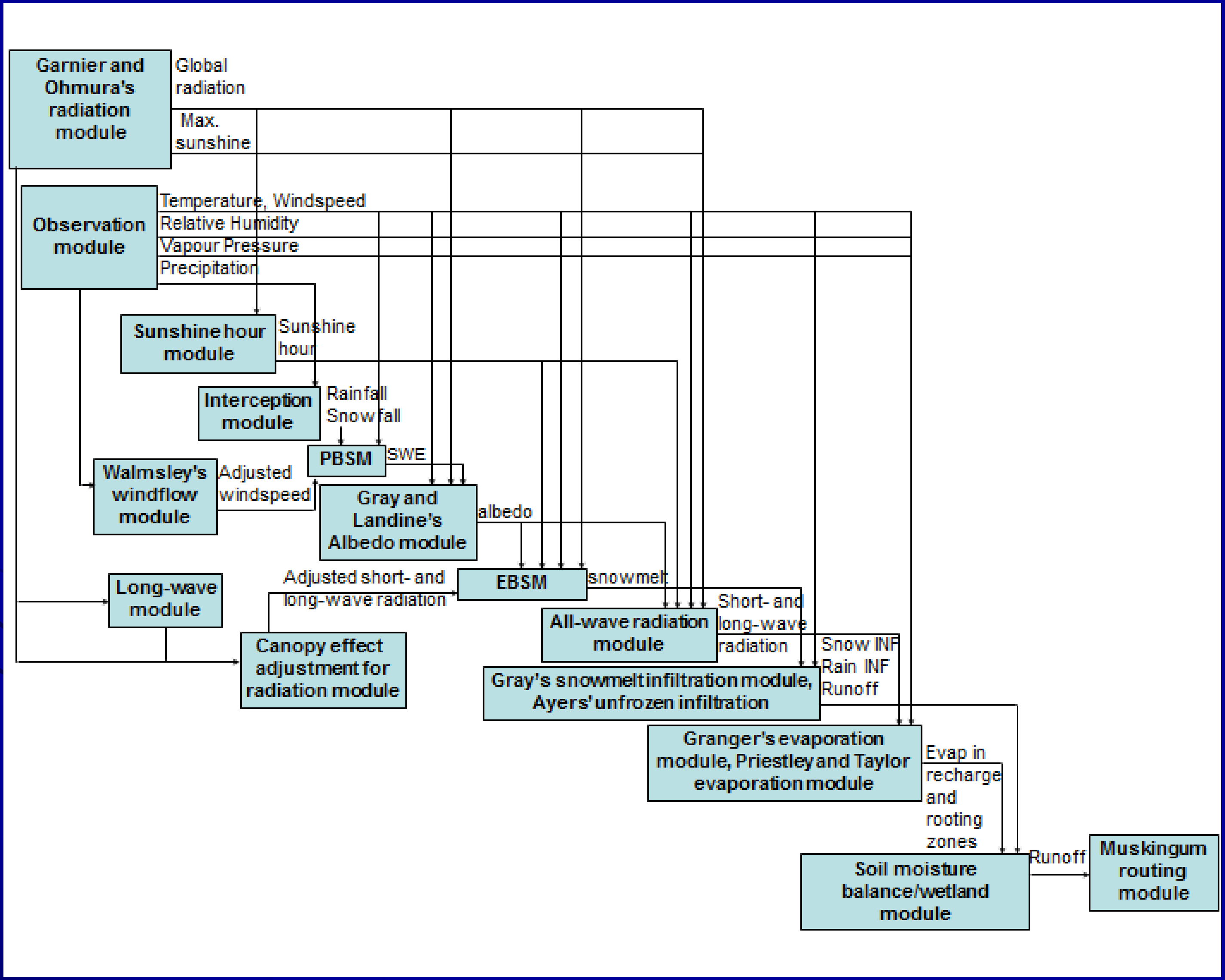
Vermilion River Basin
Climate and Hydrometric Stations



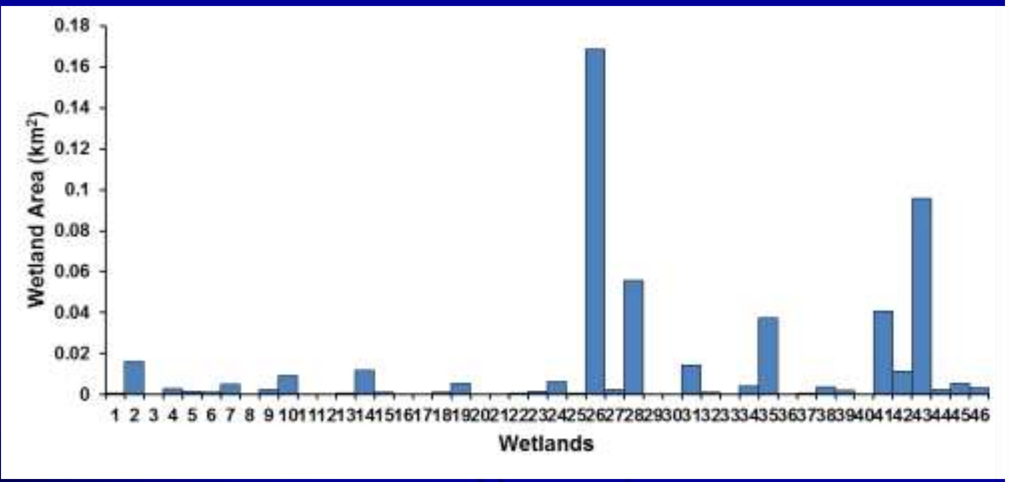
Model Setup

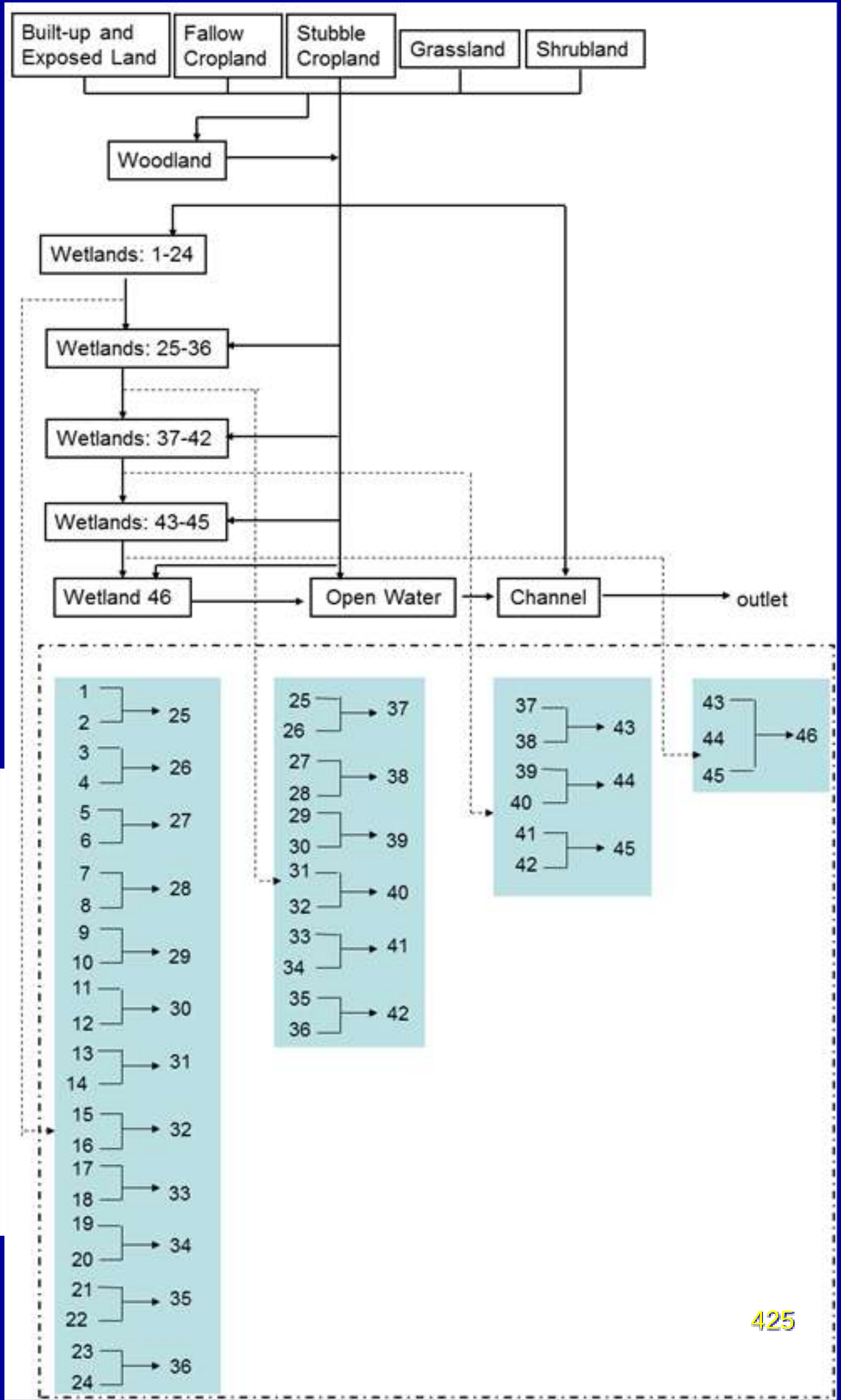
- Cold Regions Hydrological Modelling Platform (CRHM)
- Modules selected to describe hydrological processes operating in the basin.
  - Snow accumulation and melt
  - Wetland storage, drainage
  - Soil moisture storage, evapotranspiration and runoff
  - Stream routing
- Sub-basins broken into “hydrological response units” HRU corresponding to land use, drainage and soil zones.
- Sub-basins aggregated via routing module to describe total basin behaviour

Prairie Module Structure

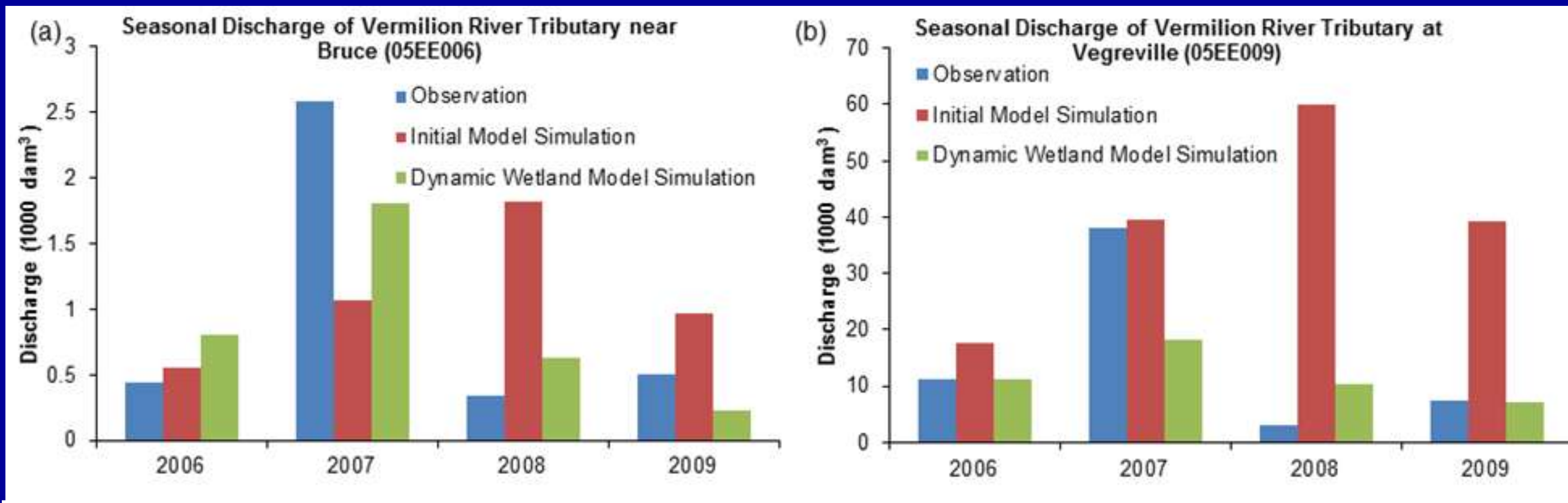


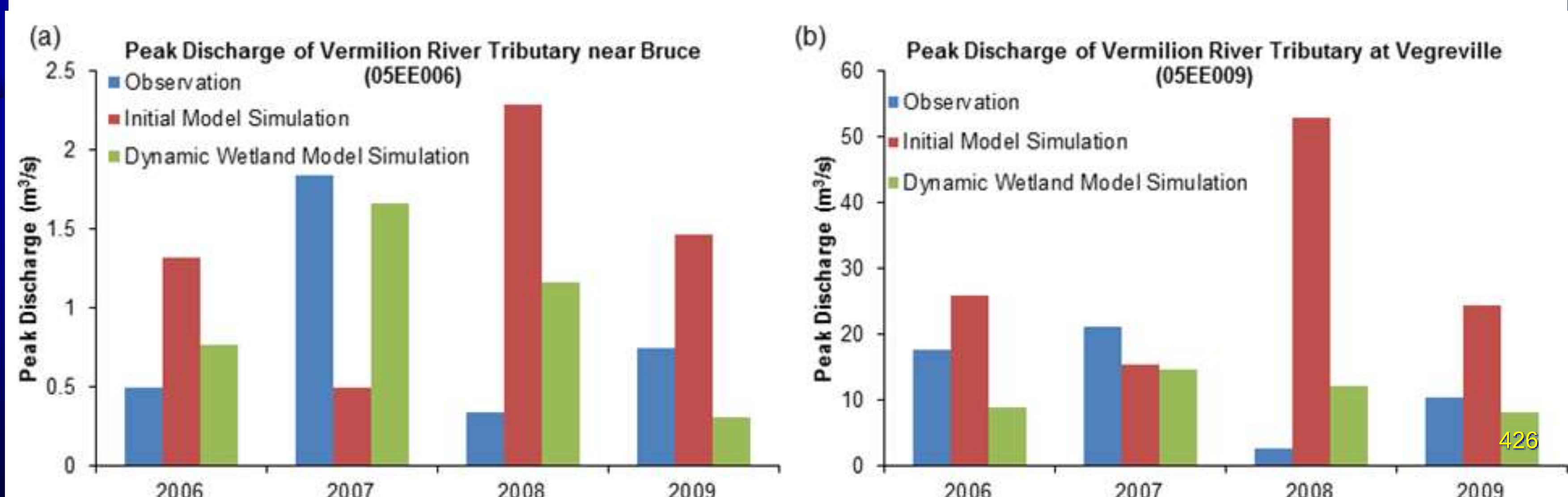
Basin and Wetland Representation





Dynamic Modelling of Wetlands Needed for Accurate Simulations

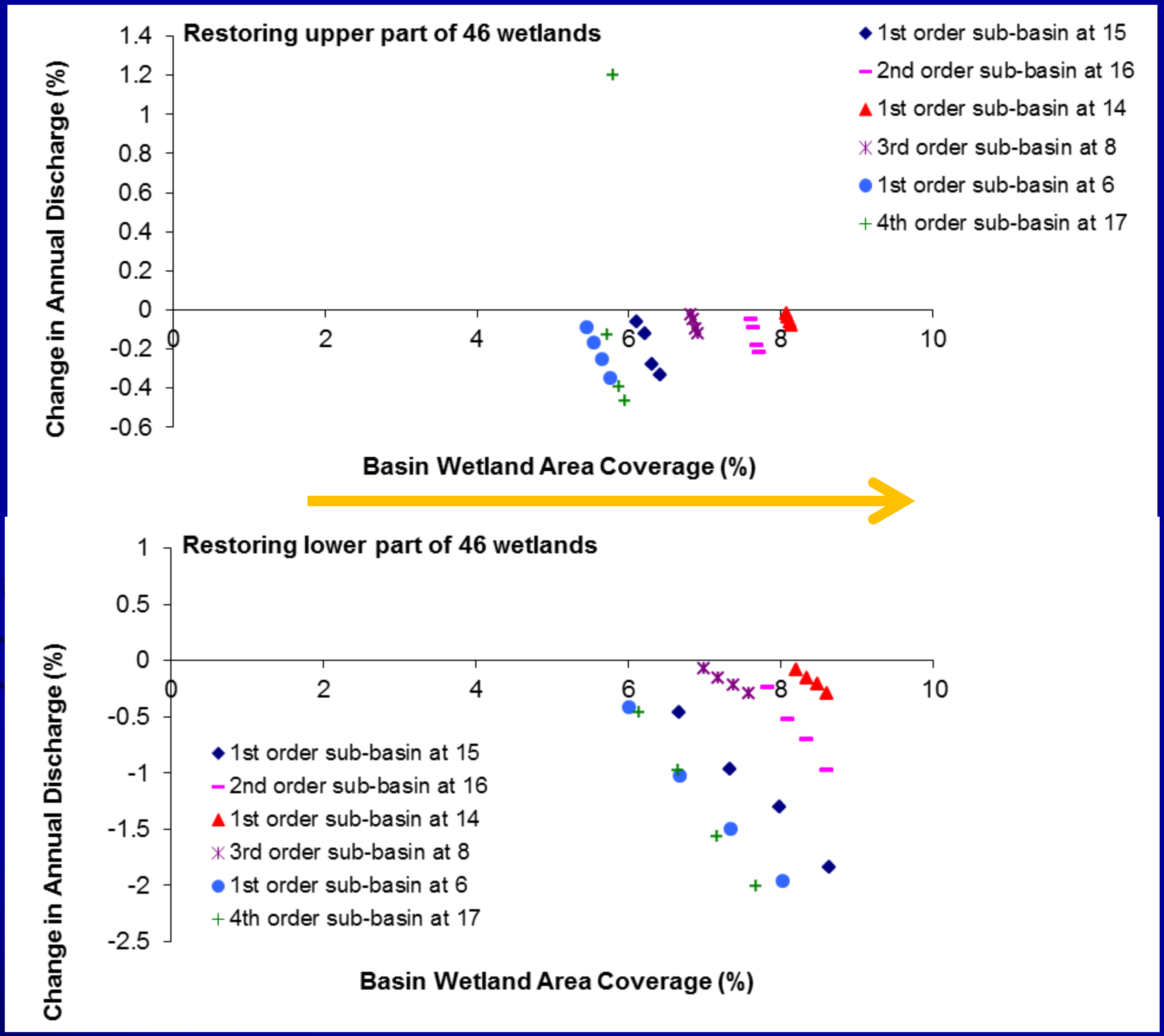




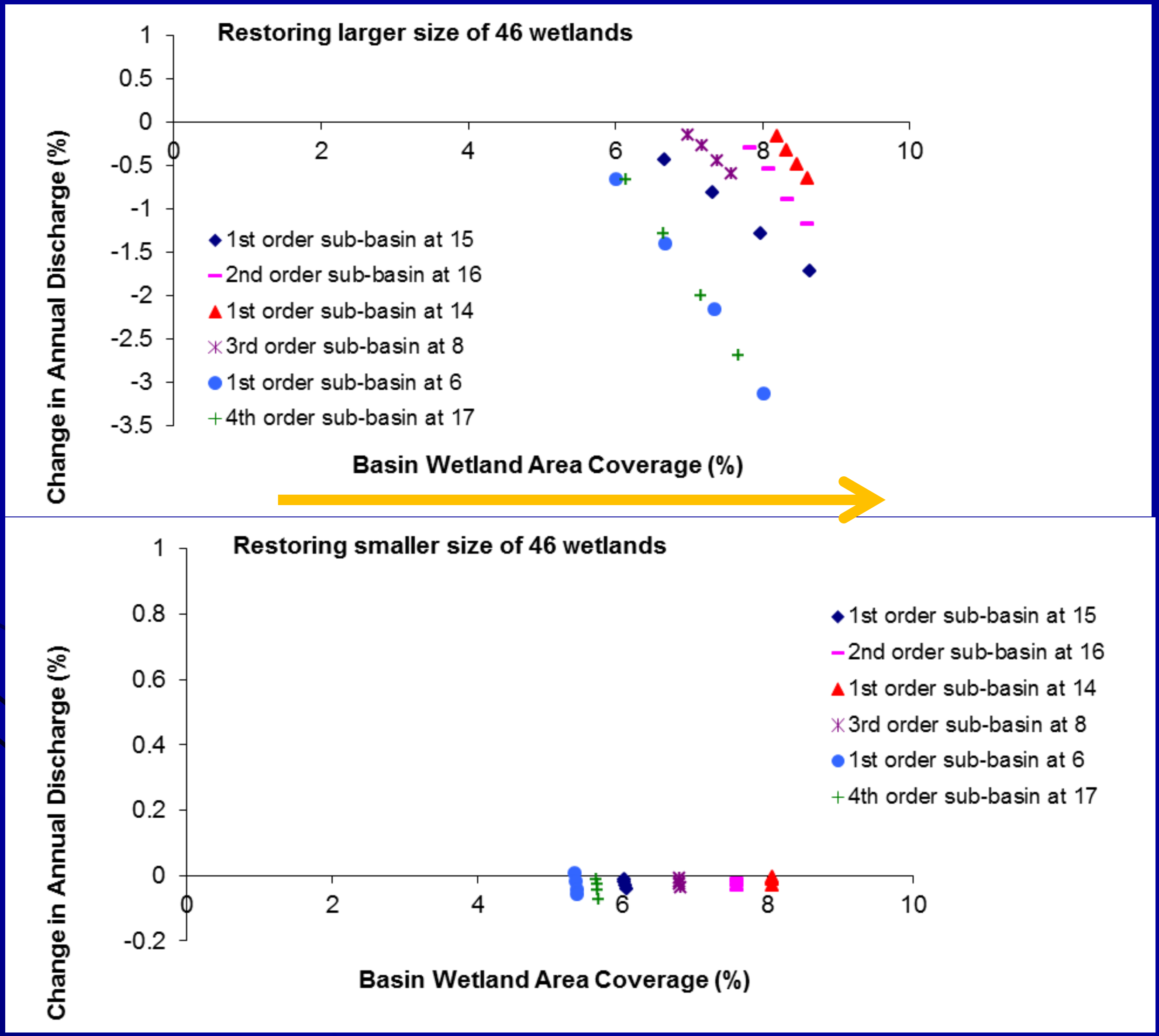
Sensitivity Analysis

- Modelled sub-basins 6, 8, 13, 14, 15, 16, 17
- Years 2005-2009 with earlier spin-up years
- Wetland Restoration – all wetlands restored to 1949 levels
  - Spatial Wetland Restoration – upper vs lower basin
  - Wetland Size Restoration – large vs small
- Wetland Drainage – all wetlands drained
  - Spatial Wetland Drainage – upper vs lower
  - Wetland Size Drainage – large vs small
- Note relatively small area of wetlands (6%) and little apparent drainage since 1949 (then 7.4%)

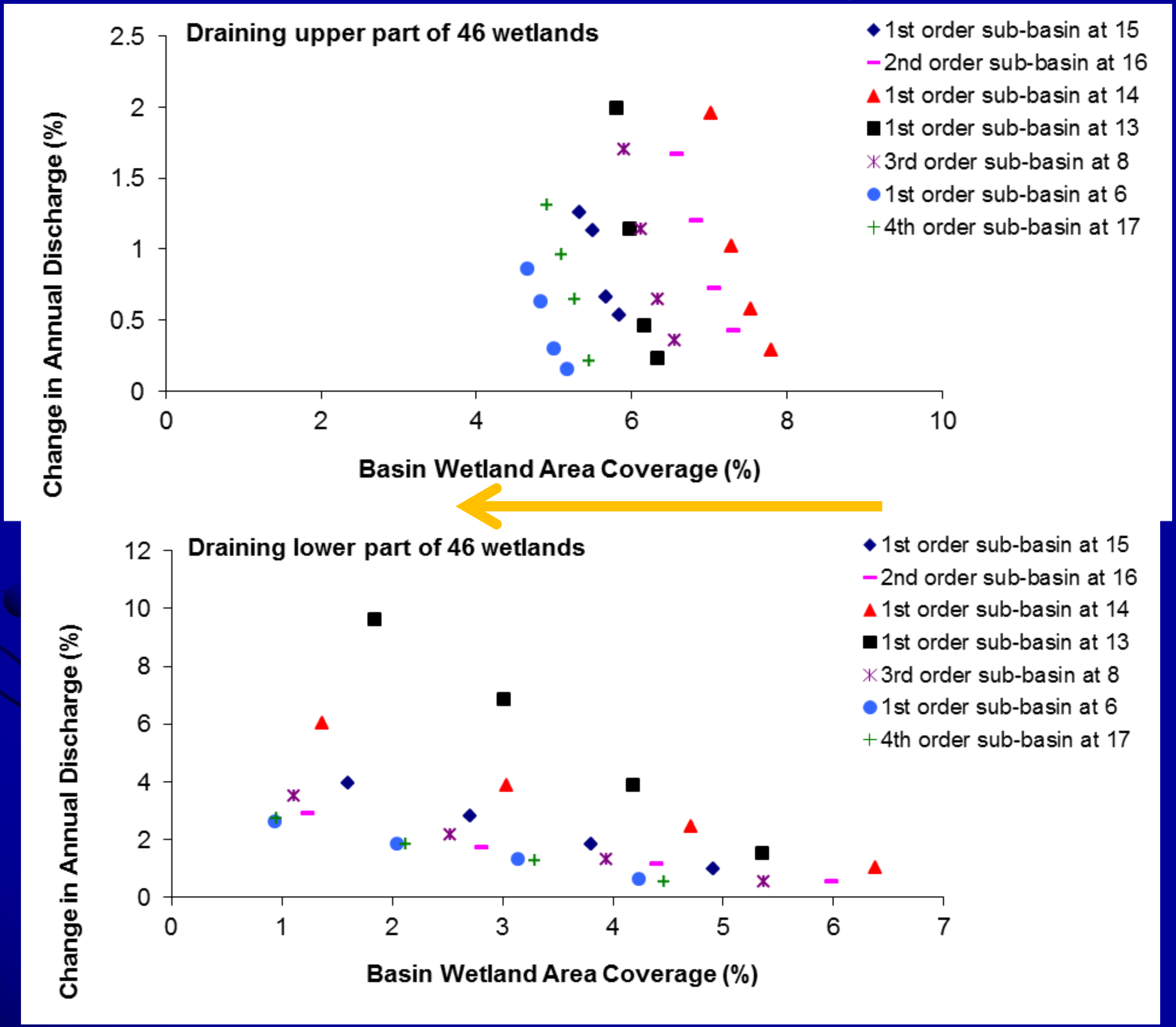
Upper vs Lower Sub-Basin Location Wetland Restoration



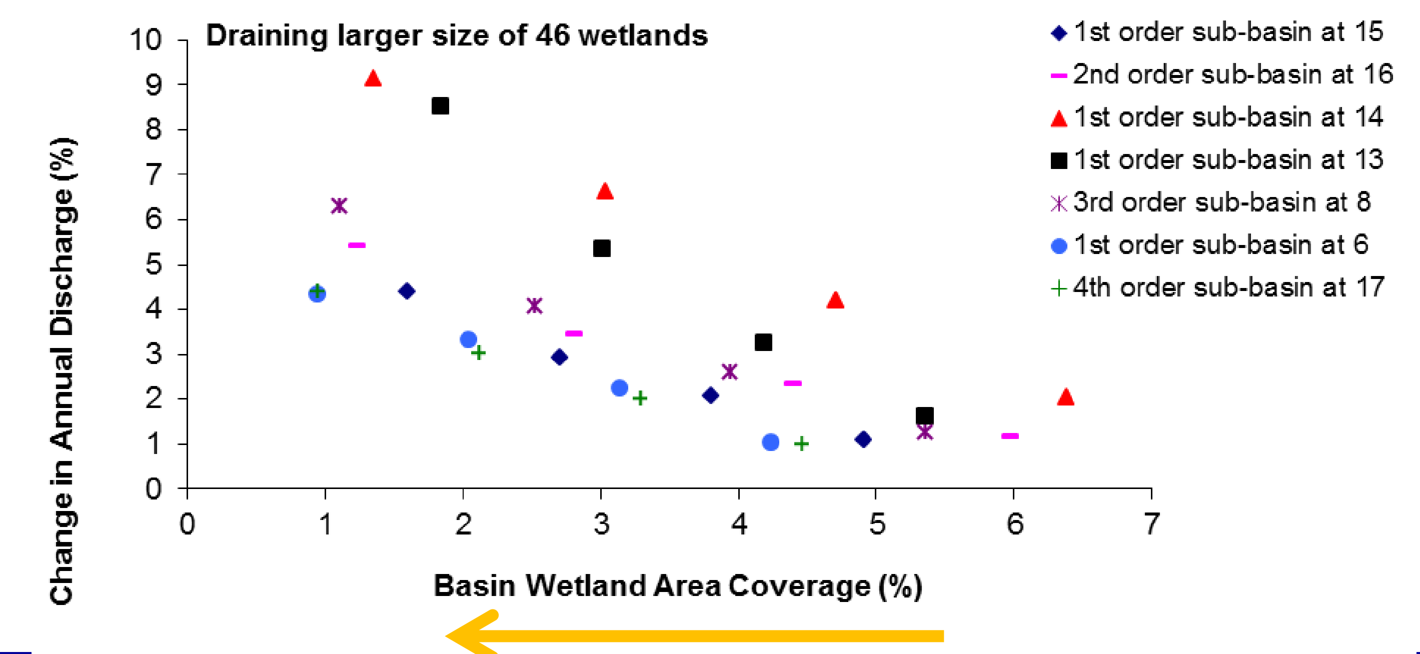
Large vs Small Size Wetland Restoration

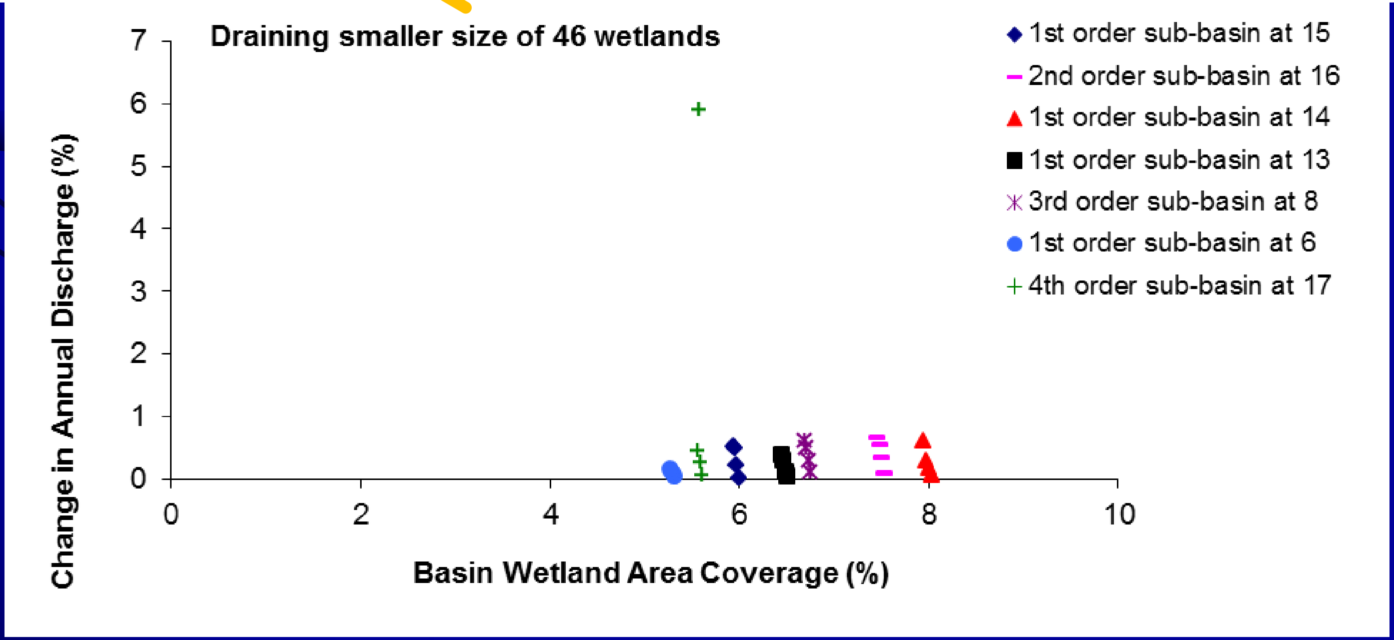


Upper vs Lower Sub-basin Location Wetland Drainage



Larger vs Smaller Wetland Drainage

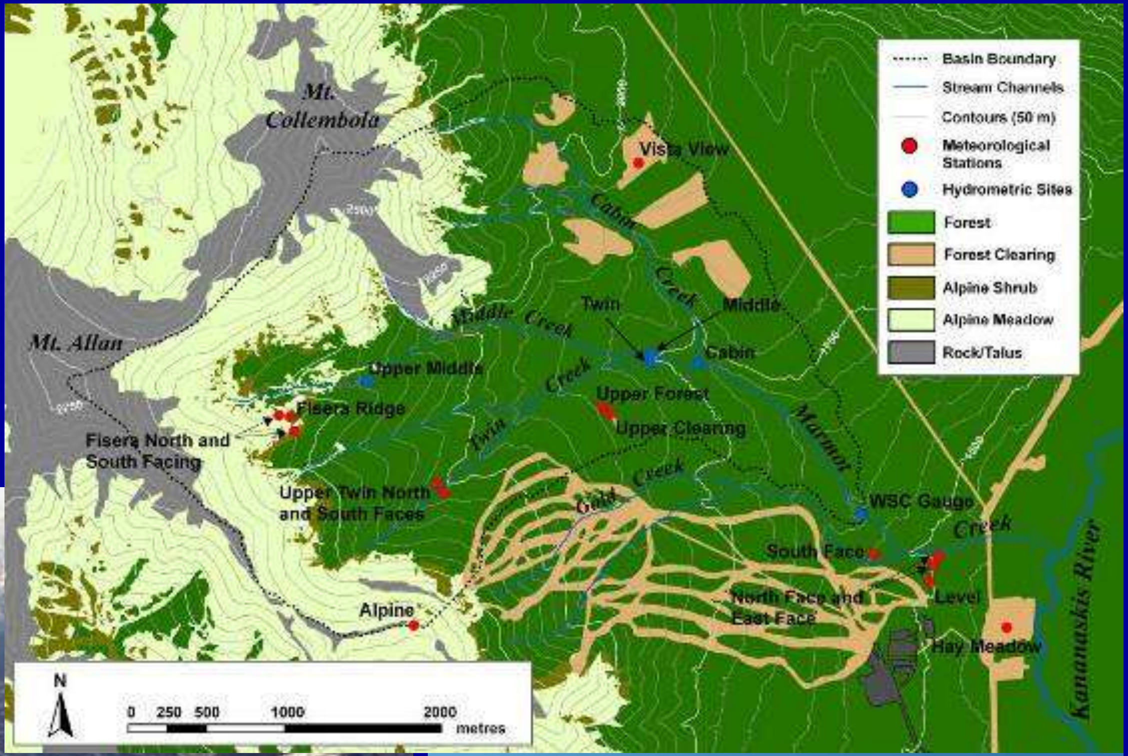


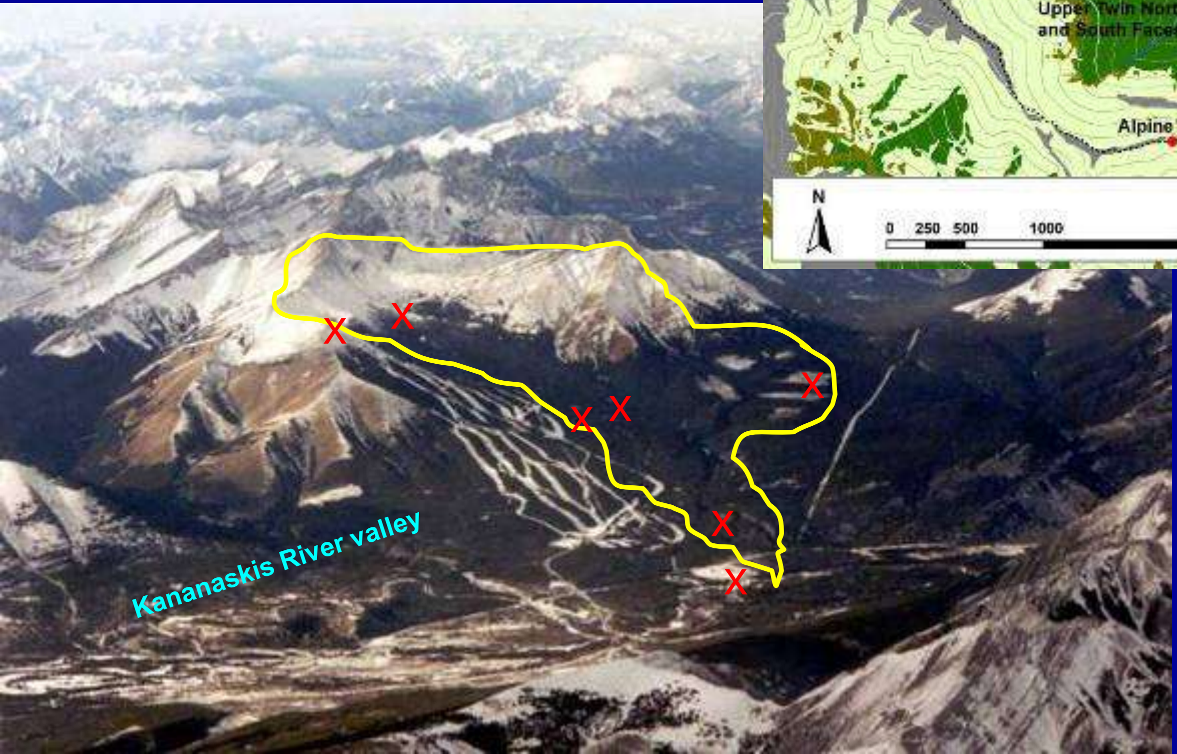


Vermilion River Basin Wetland Modelling Findings

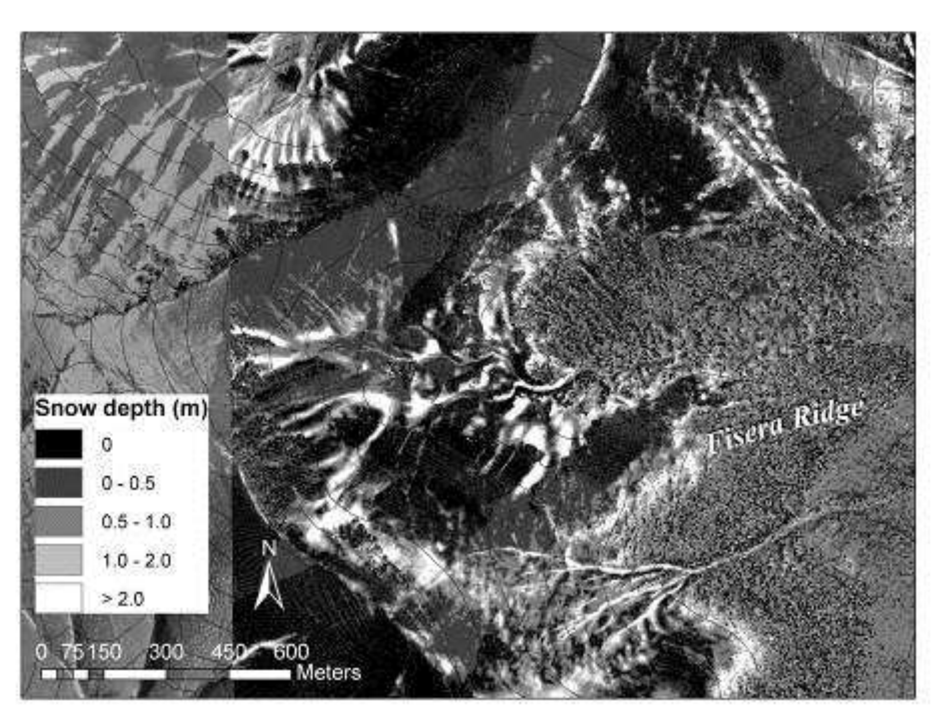
- Hysteresis affects the relationship between wetland water storage and contributing area, requiring explicit modelling of wetland dynamics in Prairie hydrology.
- Wetland restoration in the lower part of the sub-basins and for larger wetlands is most effective in reducing streamflows.
- Wetland drainage in the lower sub-basin and for larger wetlands is most effective in increasing streamflows.

Marmot Creek Research Basin

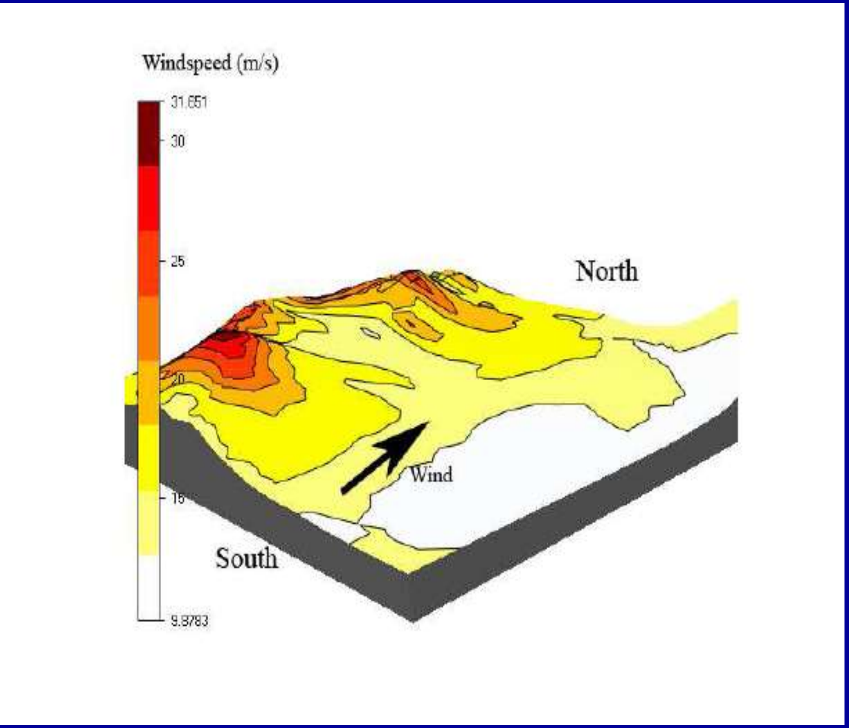




How to Determine HRU for Mountain Snow Redistribution?



LiDAR derived snow depth: subtraction of summer elevations from late winter elevations provides alpine snow depth

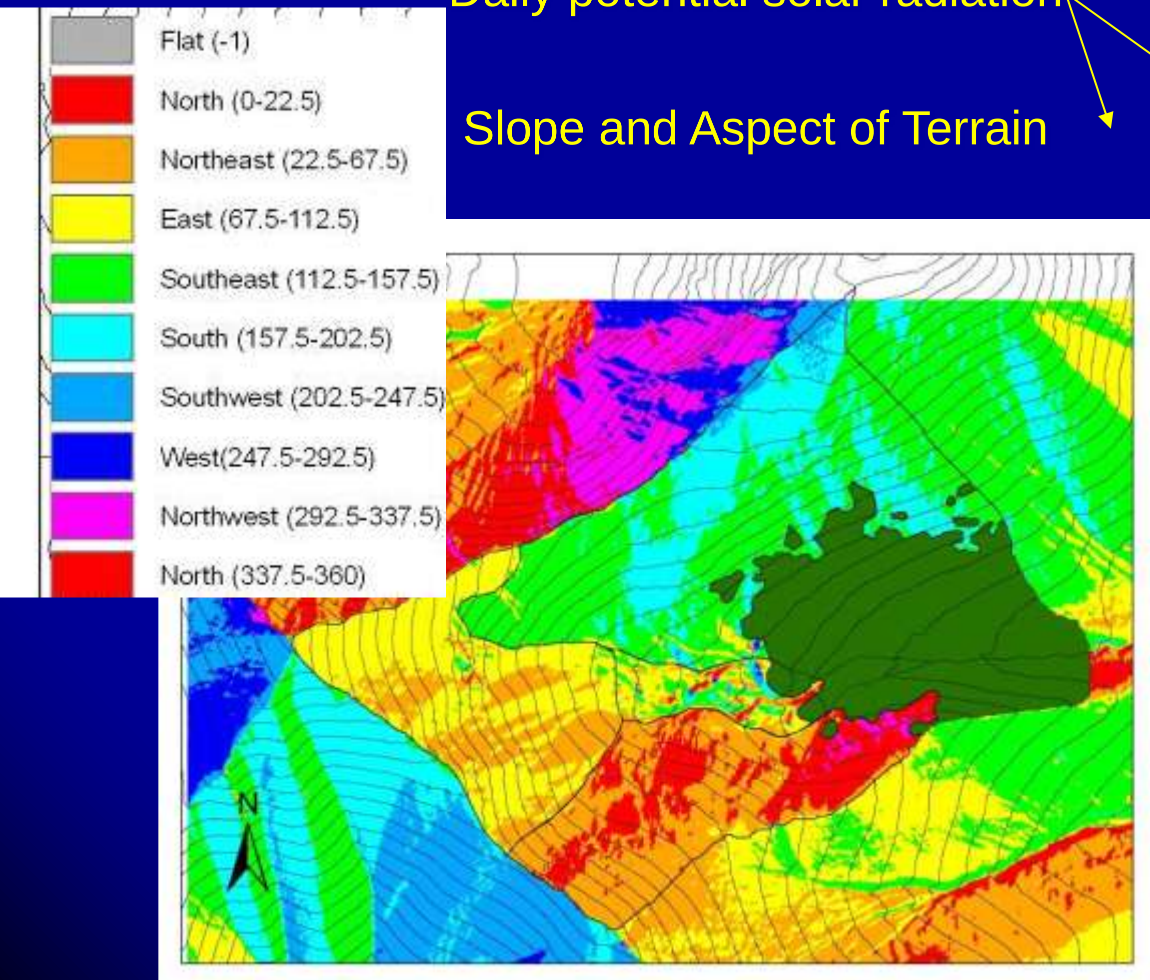


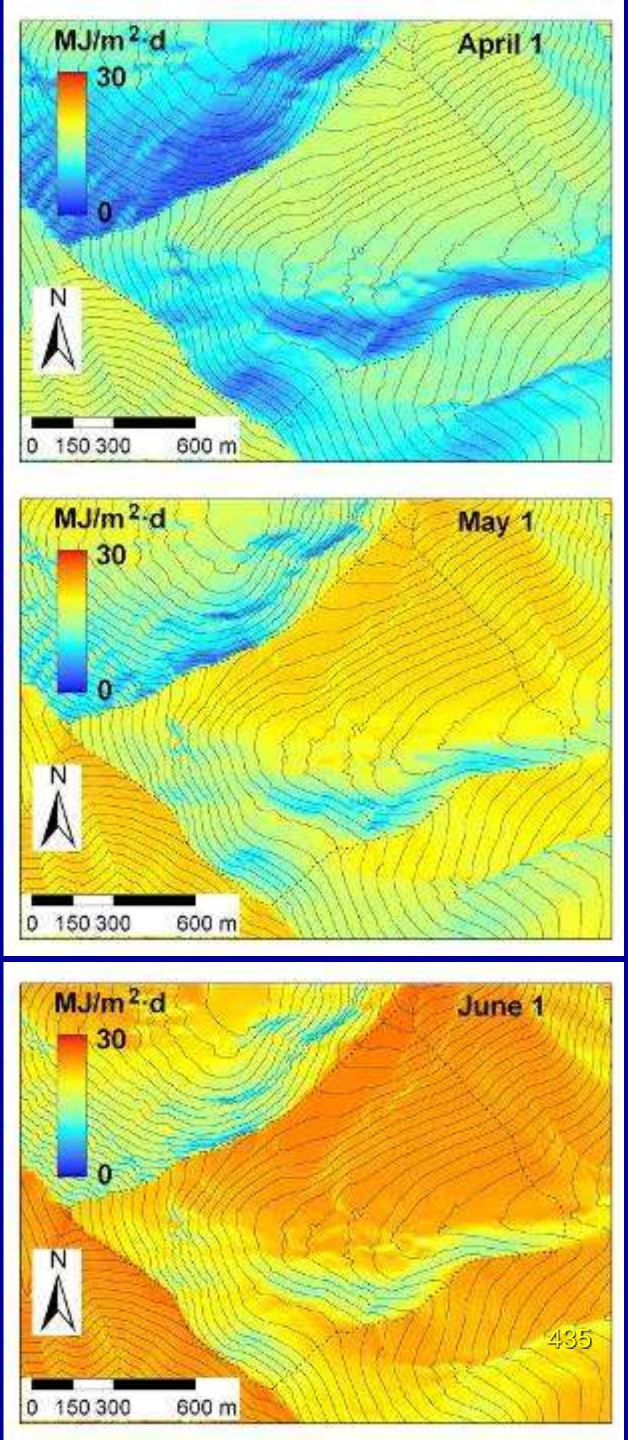
3D Reynolds averaged Navier-Stokes equations used for wind flow modelling over Marmot Creek topography (WindSim)

How to Determine HRU for Snow Melt?

Daily potential solar radiation

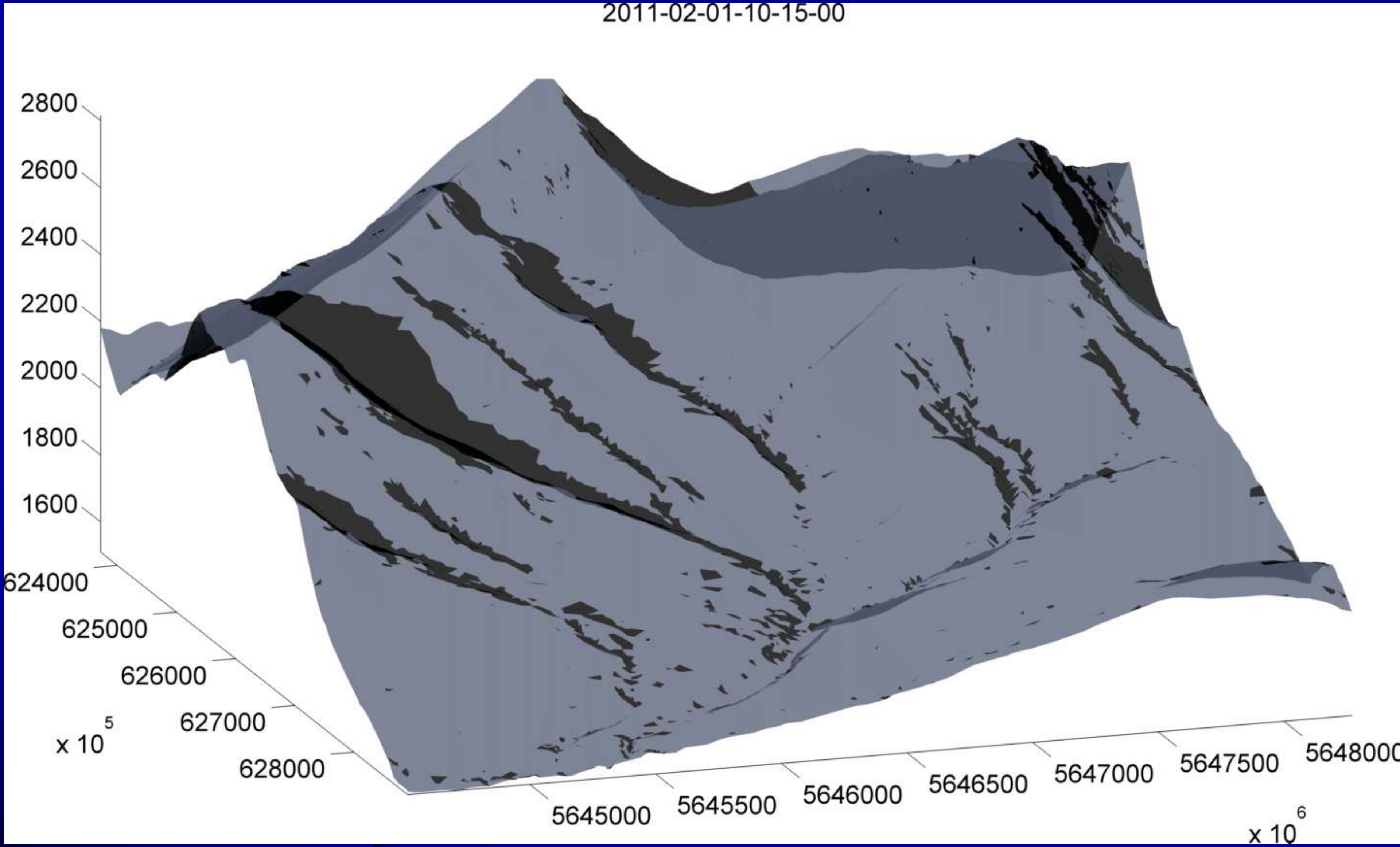
Slope and Aspect of Terrain





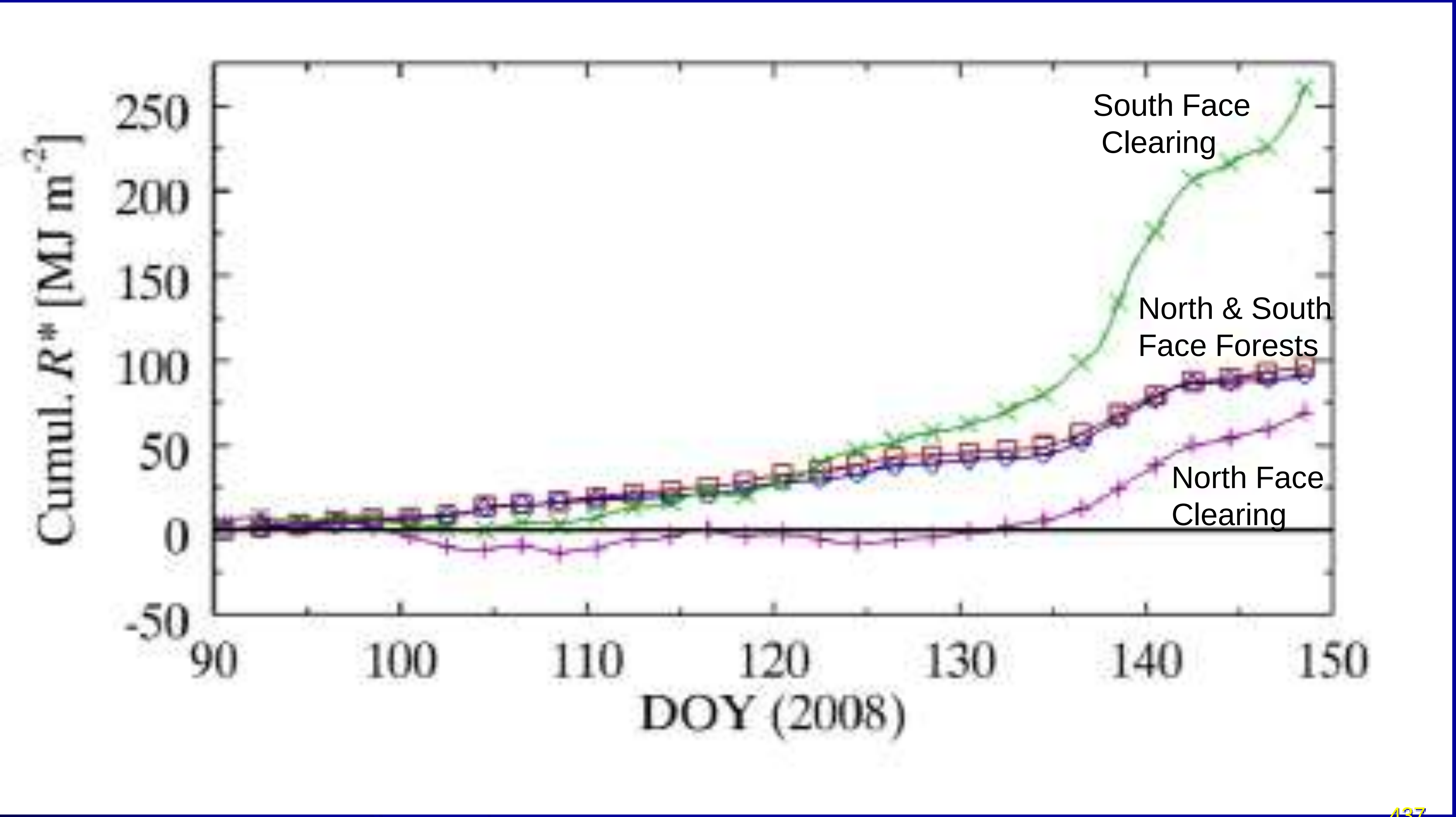
DeBeer

Shadow Migration Over a Day in Early Feb



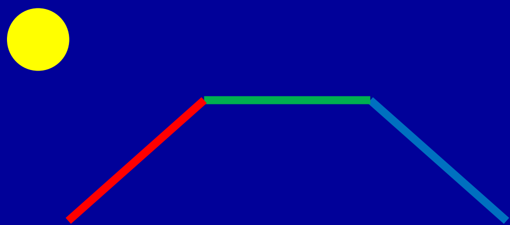
Chris Marsh, PhD

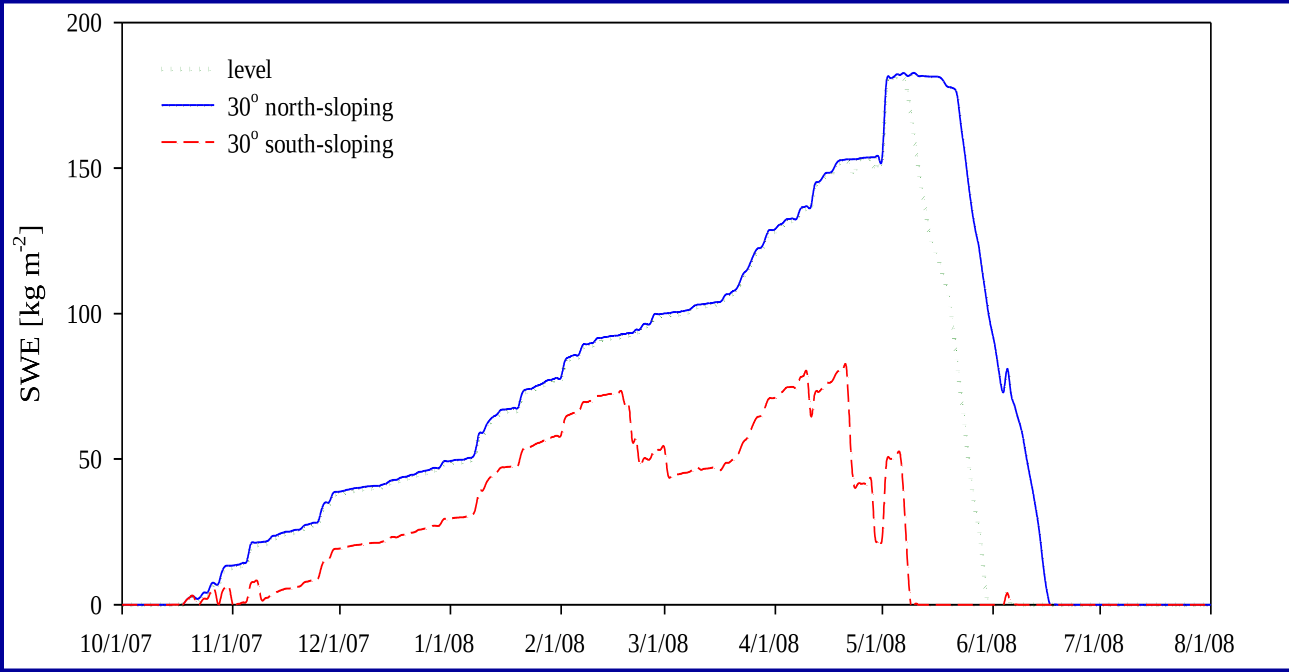
Net Radiation to Forests: Slope Effects



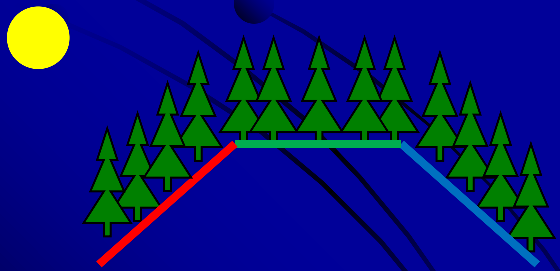
Ellis

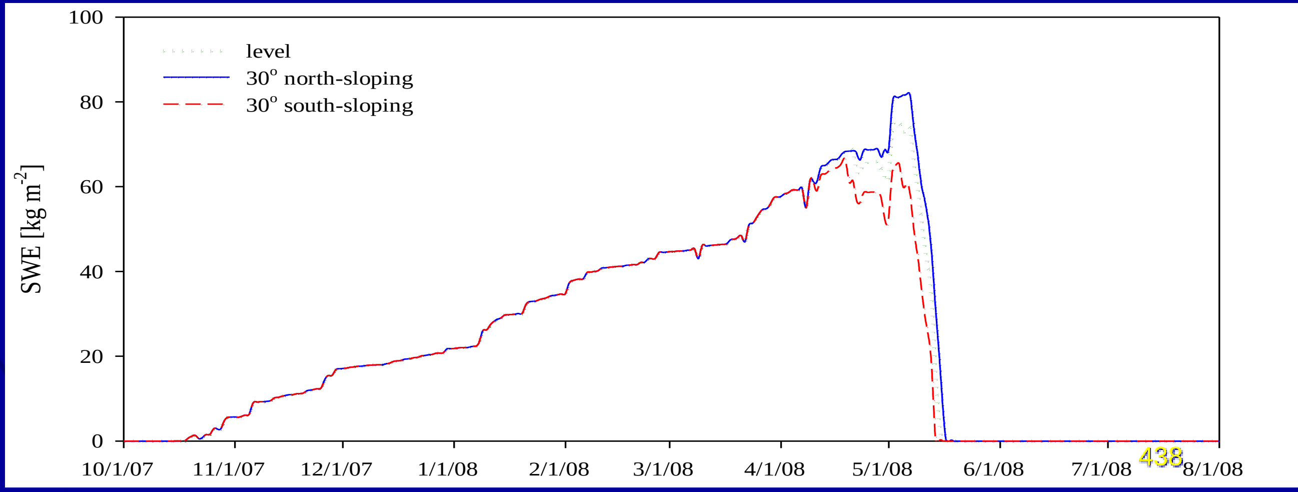
Forest Snow Regime on Slopes



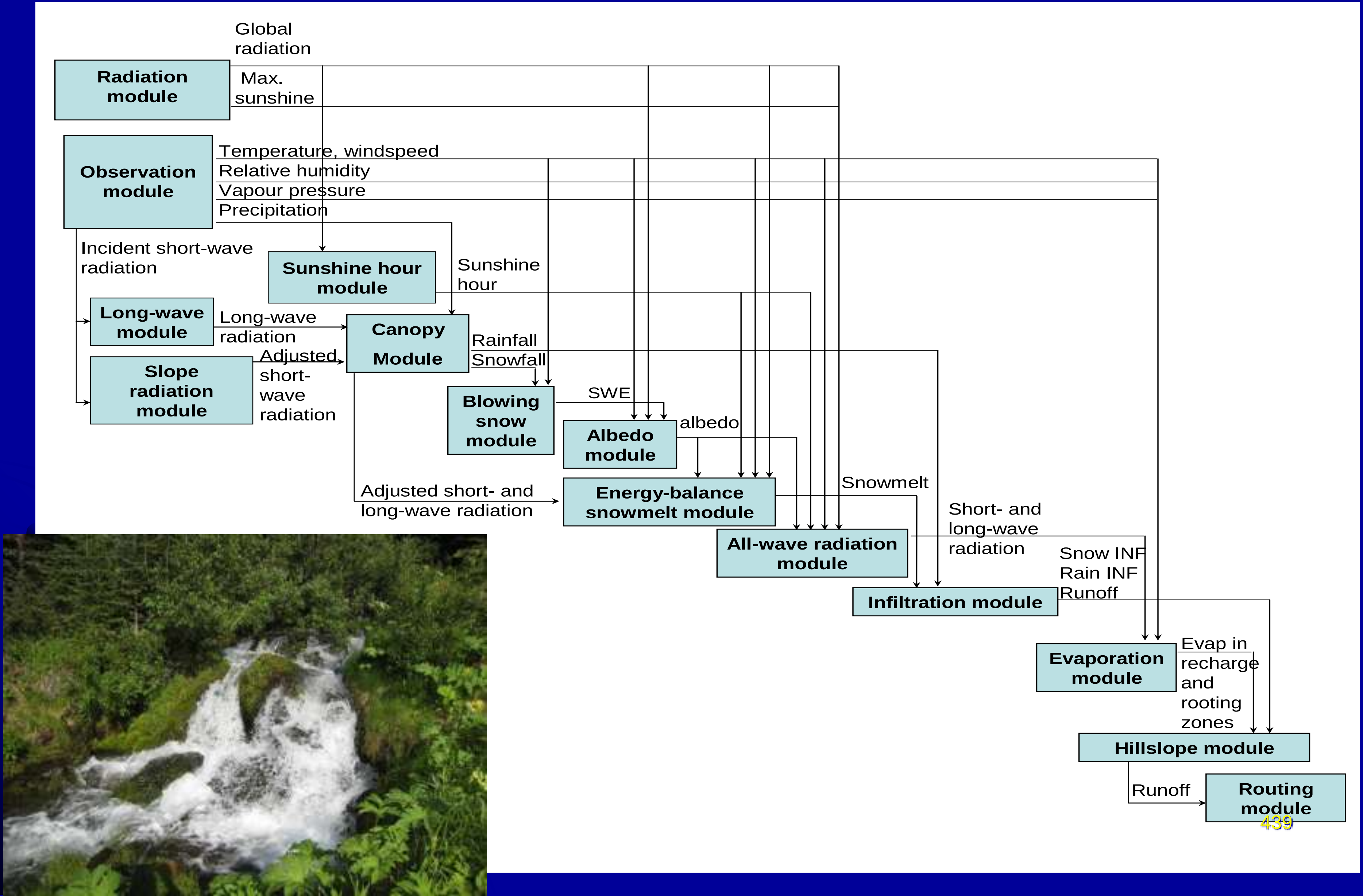


Open slopes highly sensitive to irradiation difference, forests are not

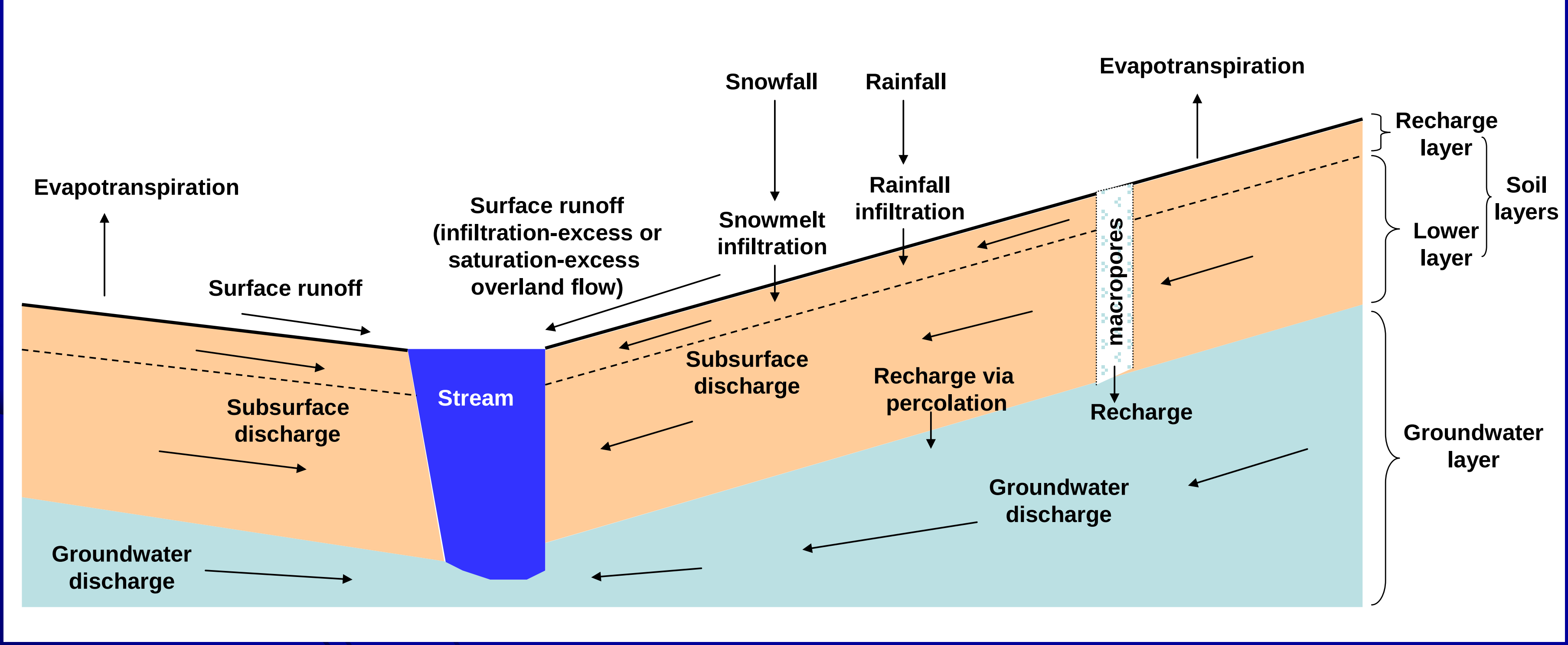


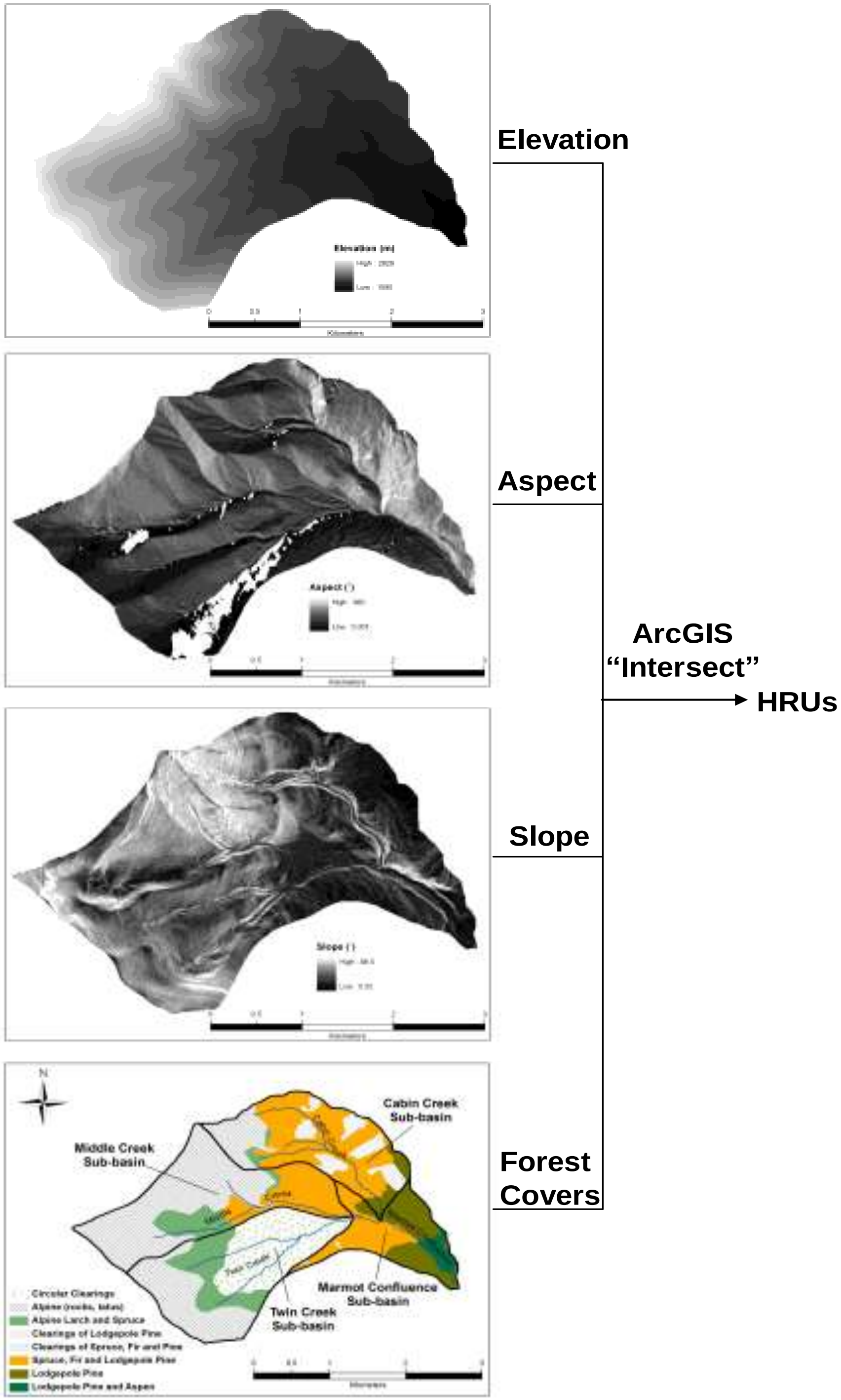


CRHM Mountain Structure



Mountain Hillslope Hydrology

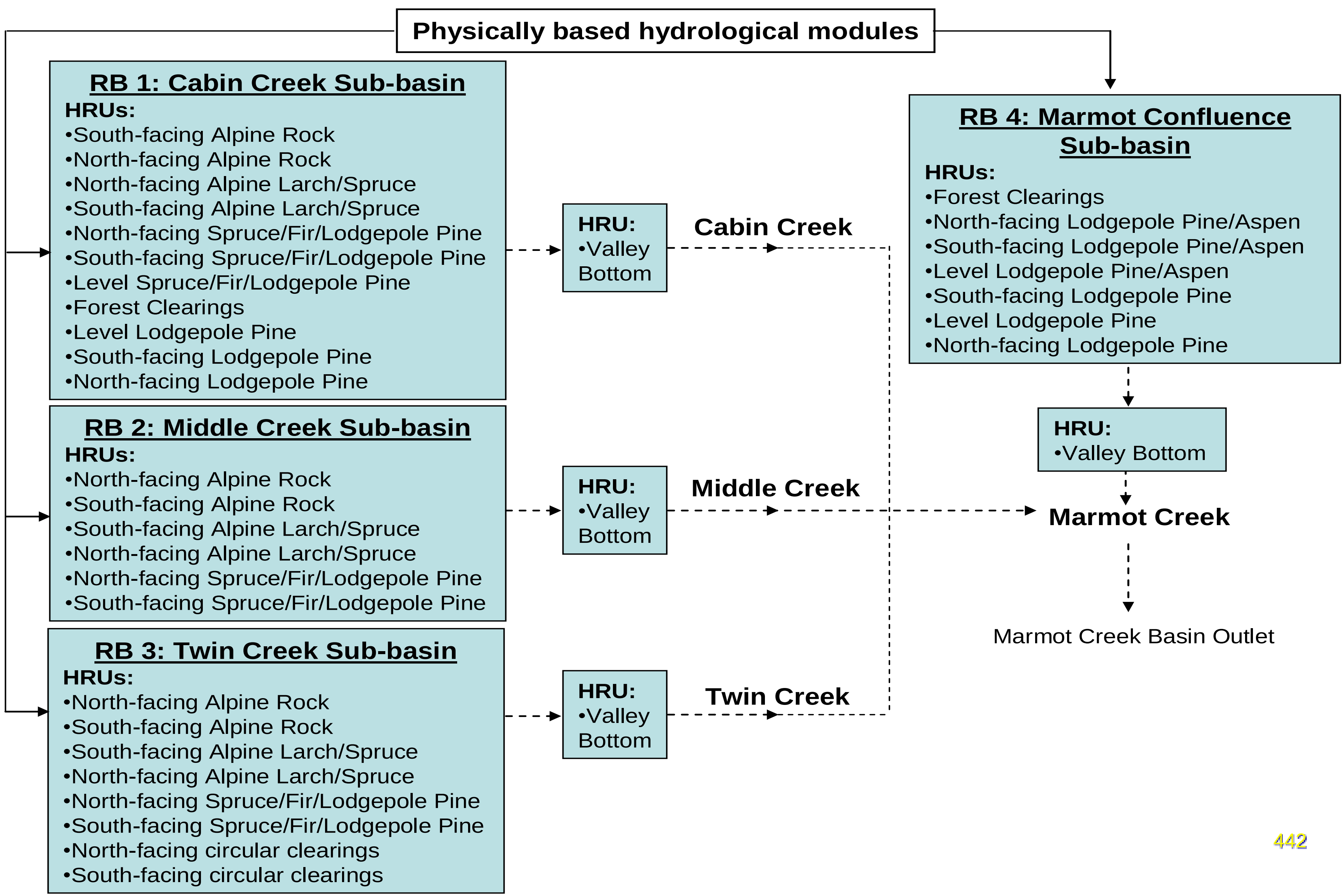




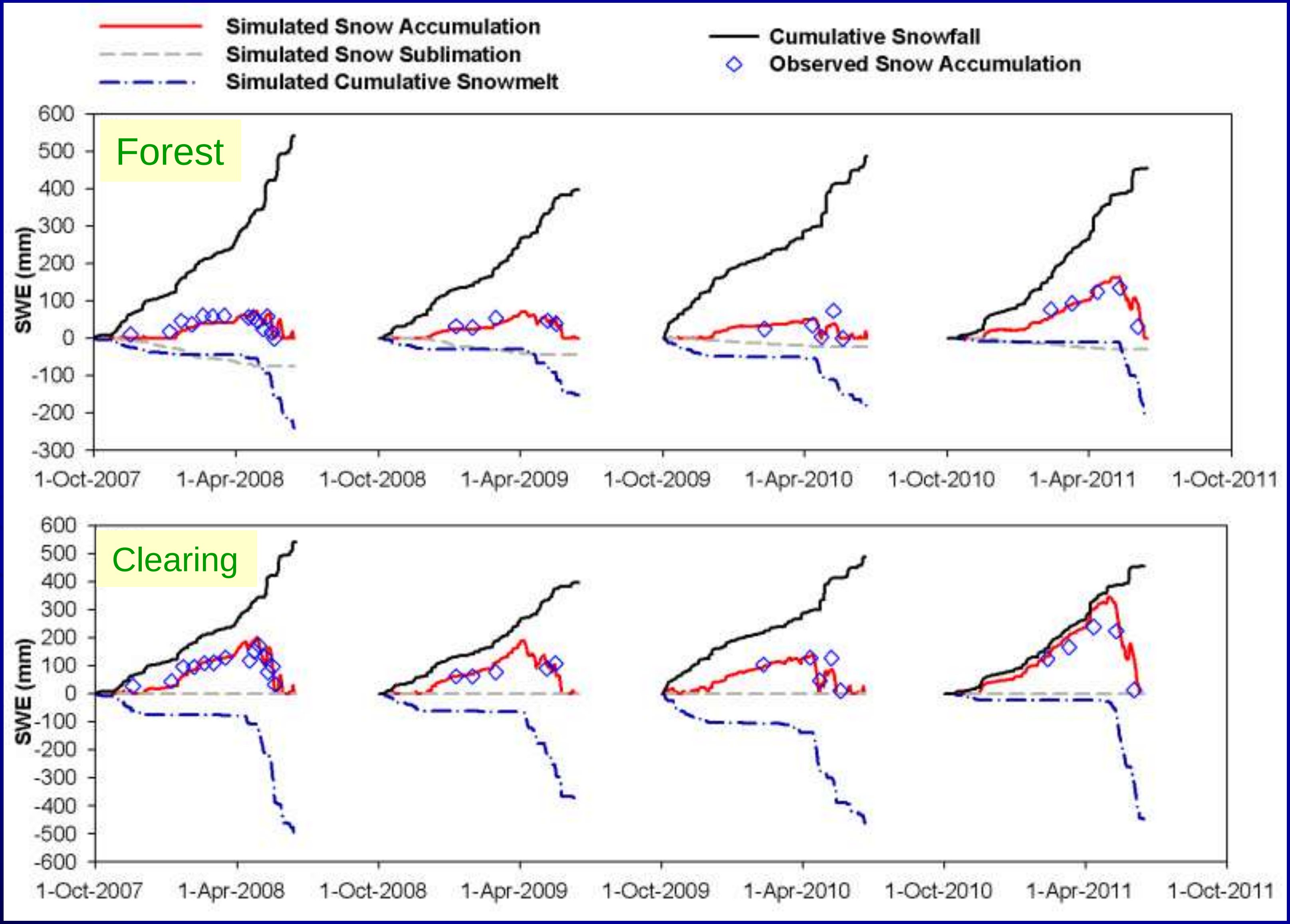
HRU Delineation

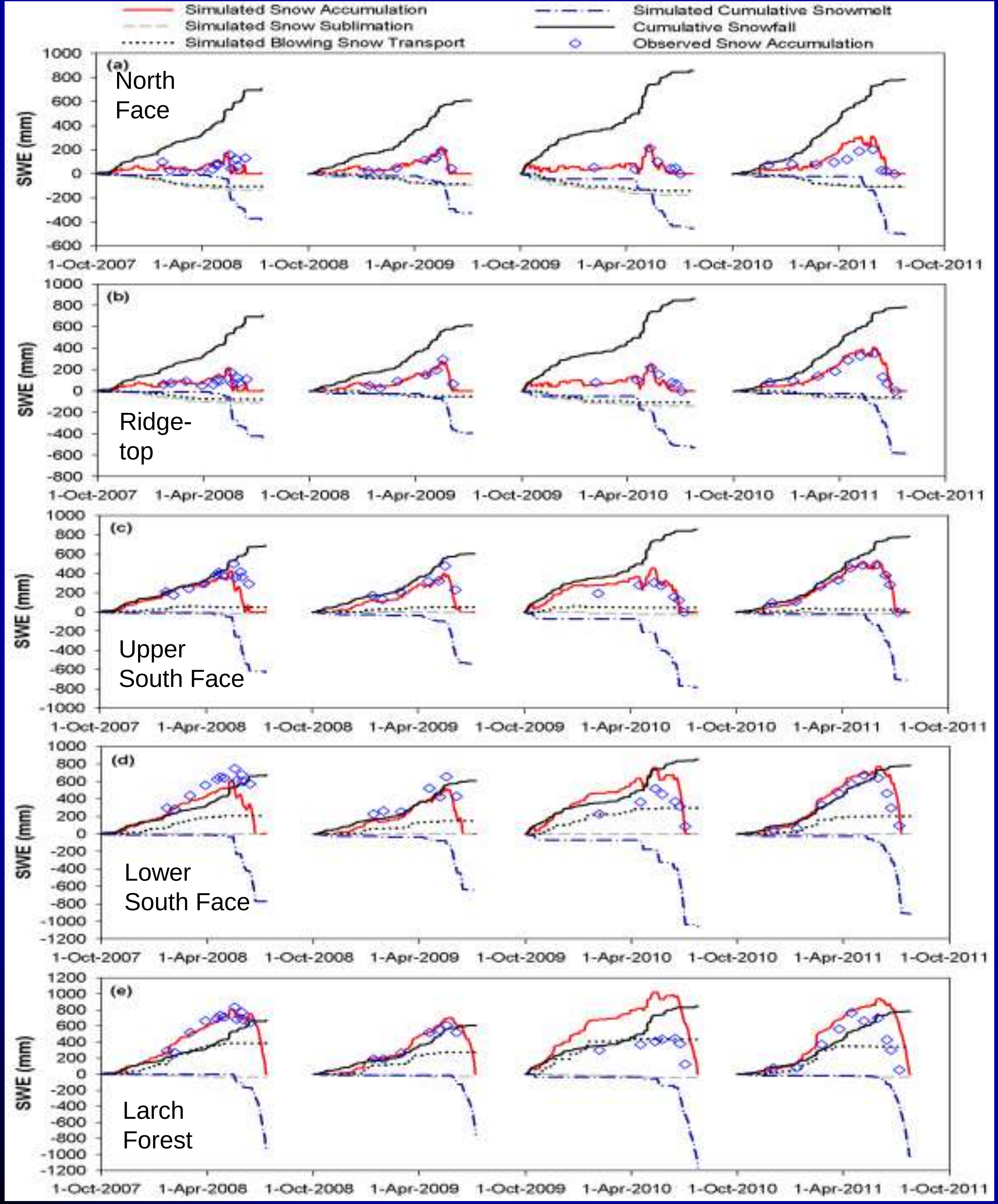
- Driving meteorology: temperature, humidity, wind speed, snowfall, rainfall, radiation
- Blowing snow, intercepted snow
- Snowmelt and evapotranspiration
- Infiltration & groundwater
- Stream network

Model Structure



Forest Snow Dynamics Simulations



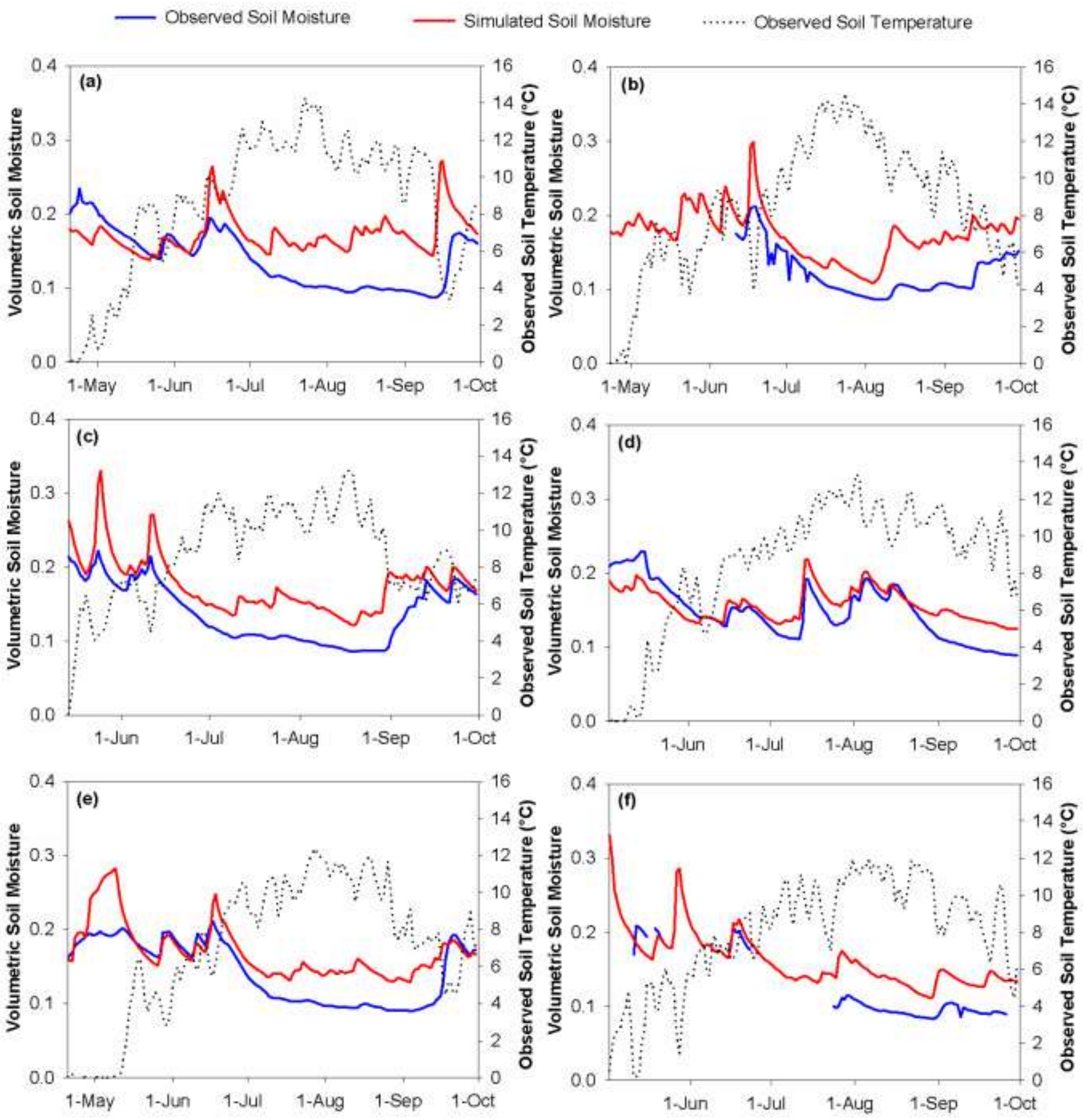


Alpine Snow Dynamics Simulations

Snow redistribution from north face and ridgetop to south face and larch forest

uncalibrated

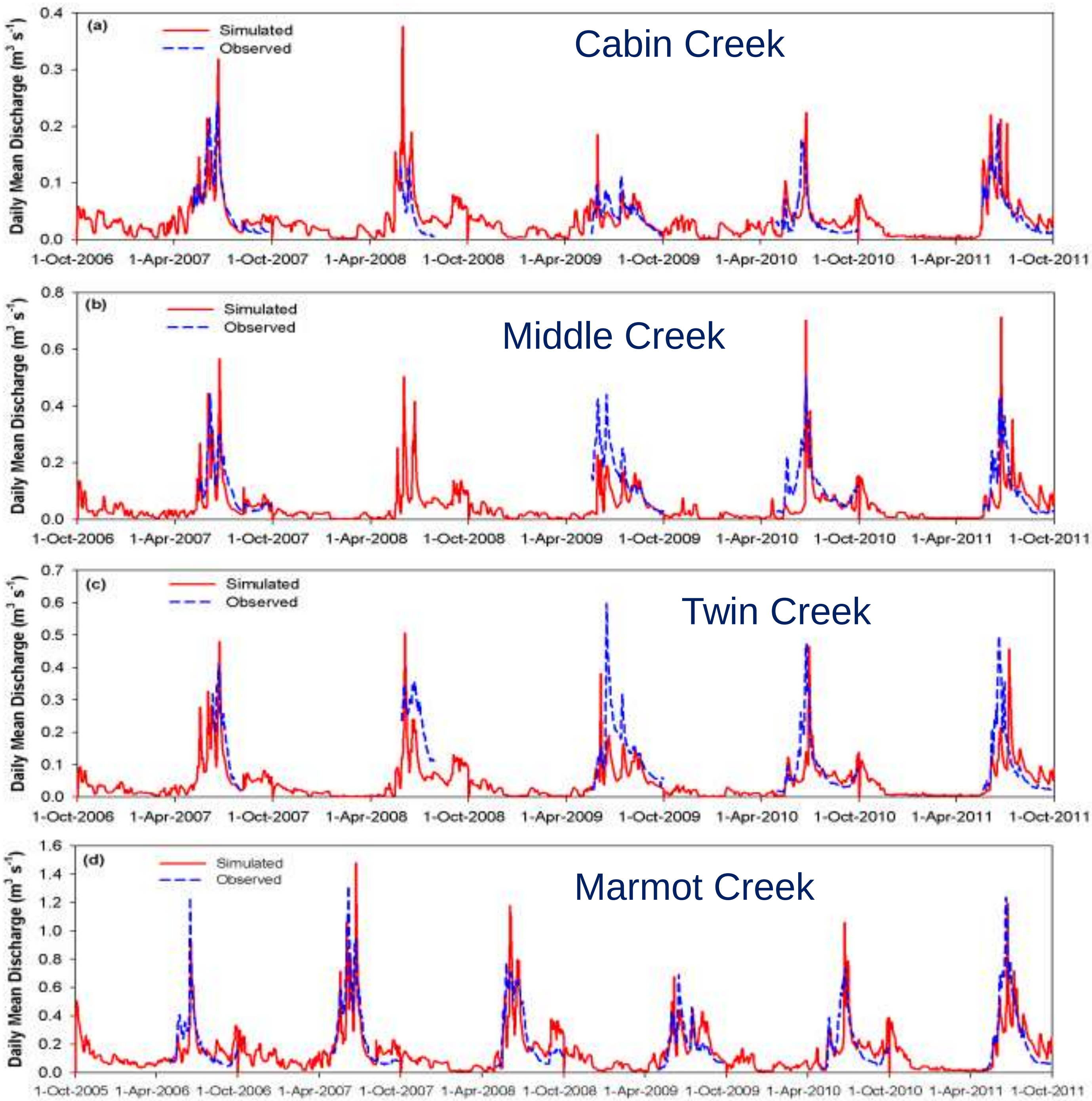
Model Tests: Soil Moisture



2006-2011

Level Forest Site

Uncalibrated



Uncalibrated Streamflow Simulation

N-S increases with basin scale to 0.58

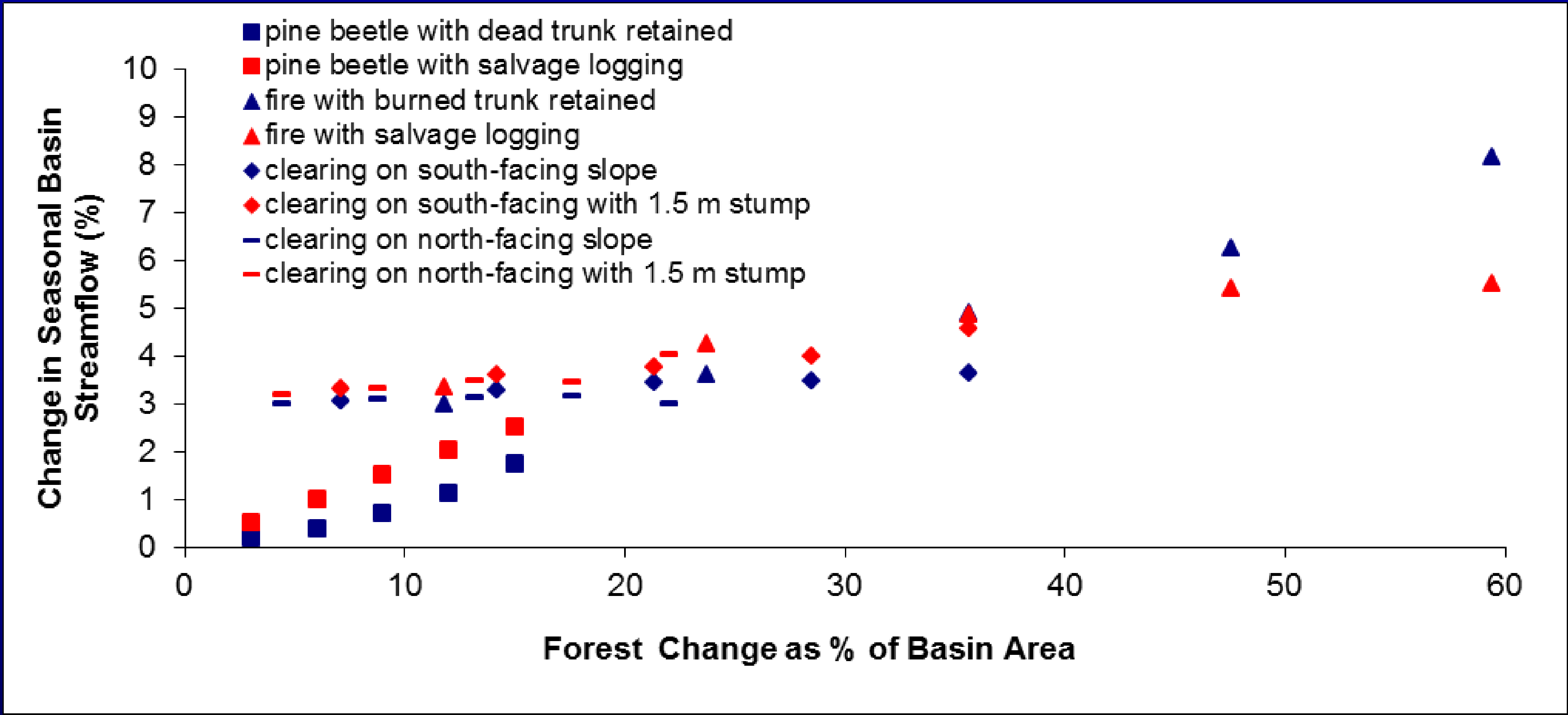
MB = 0.01 for Marmot Creek

Fang et al. HESS 2013 in review

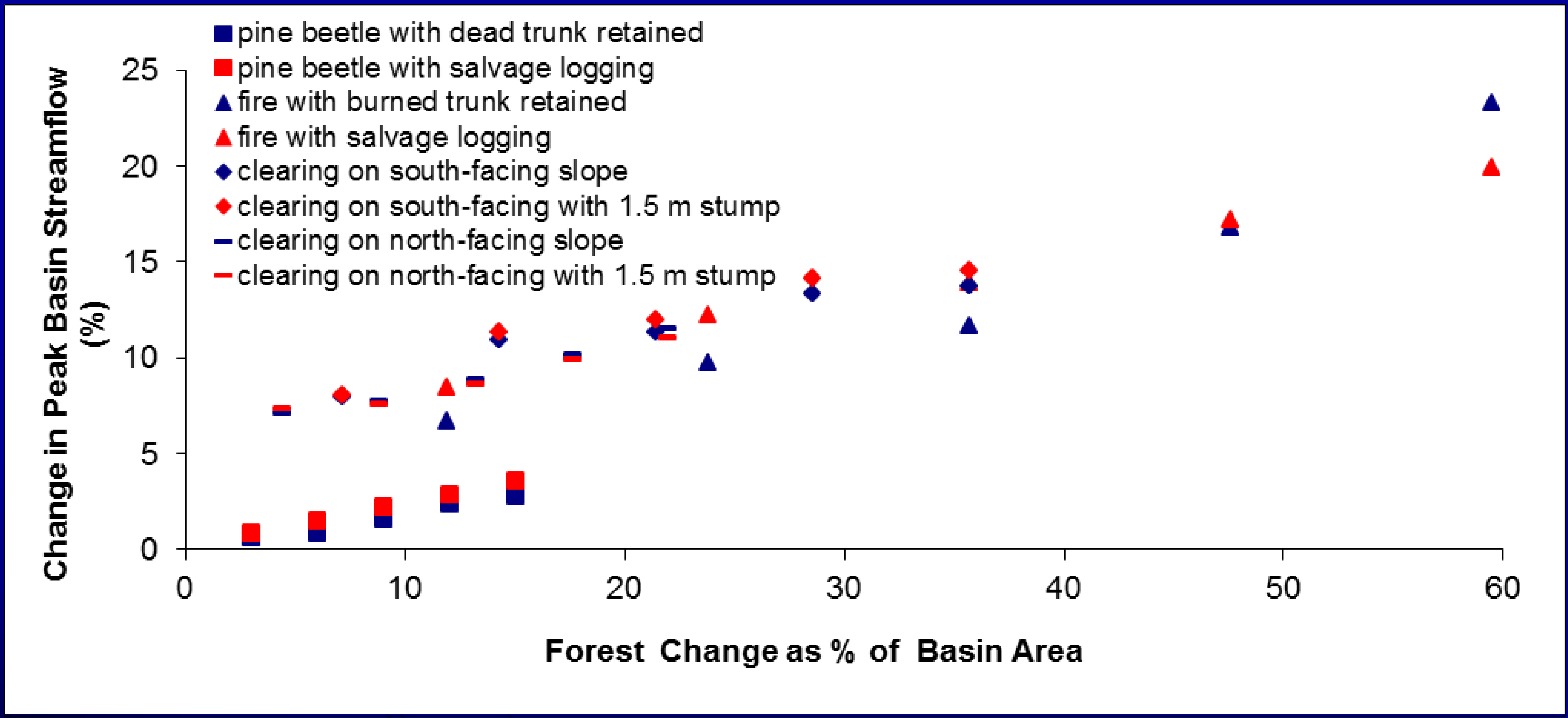
Application: Forest Cover & Climate Change

- Progressive canopy removal due to
  - Pine beetle removal of lodgepole pine canopy
  - Burning of all canopy, with and without salvage logging
  - Selective harvesting of canopy on north and south facing slopes, with and without 1.5 m trunk retention after harvesting
- Climate change: sensitivity analysis to rising air temperatures

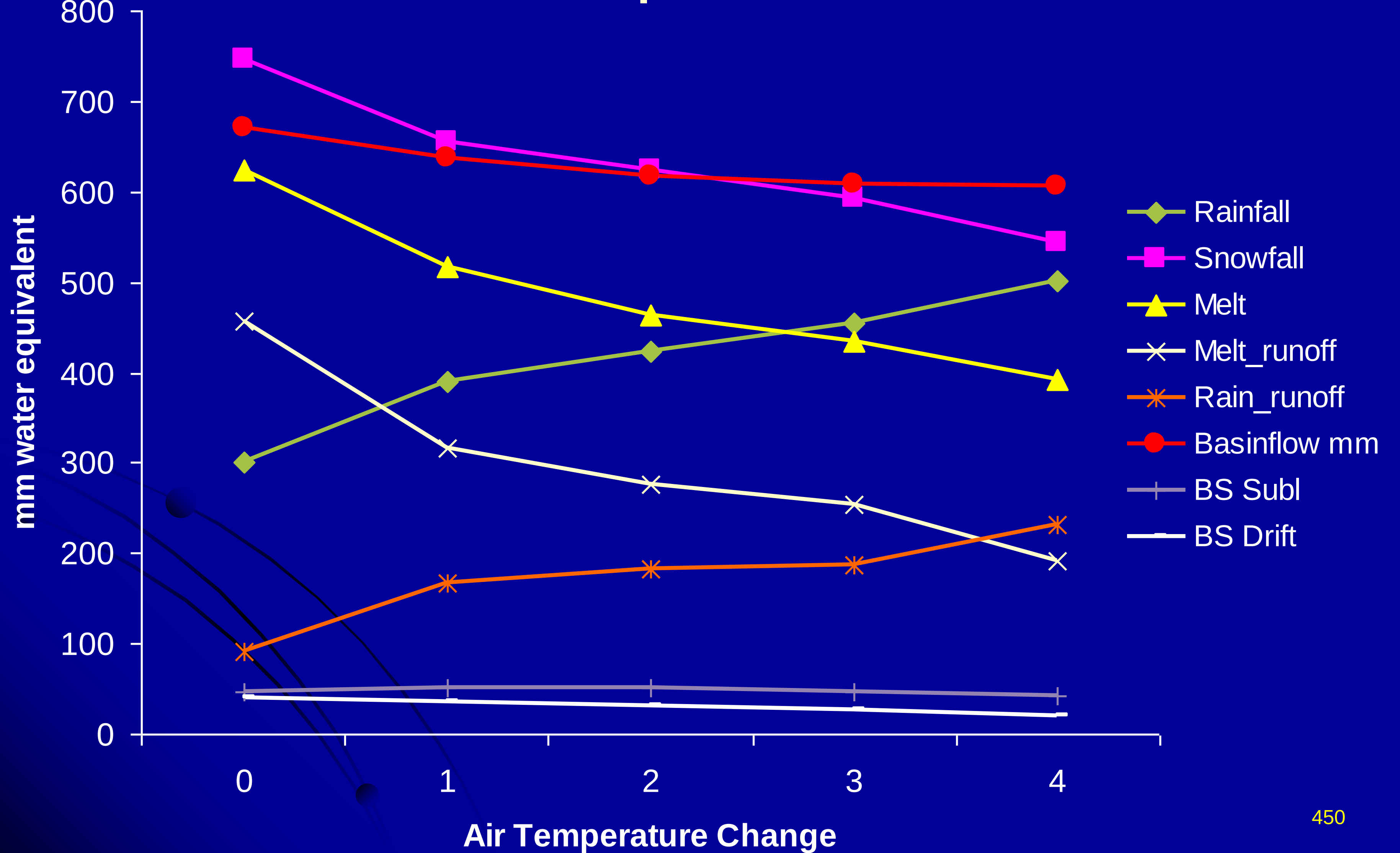
Forest Cover Disturbance Impact on Seasonal Streamflow



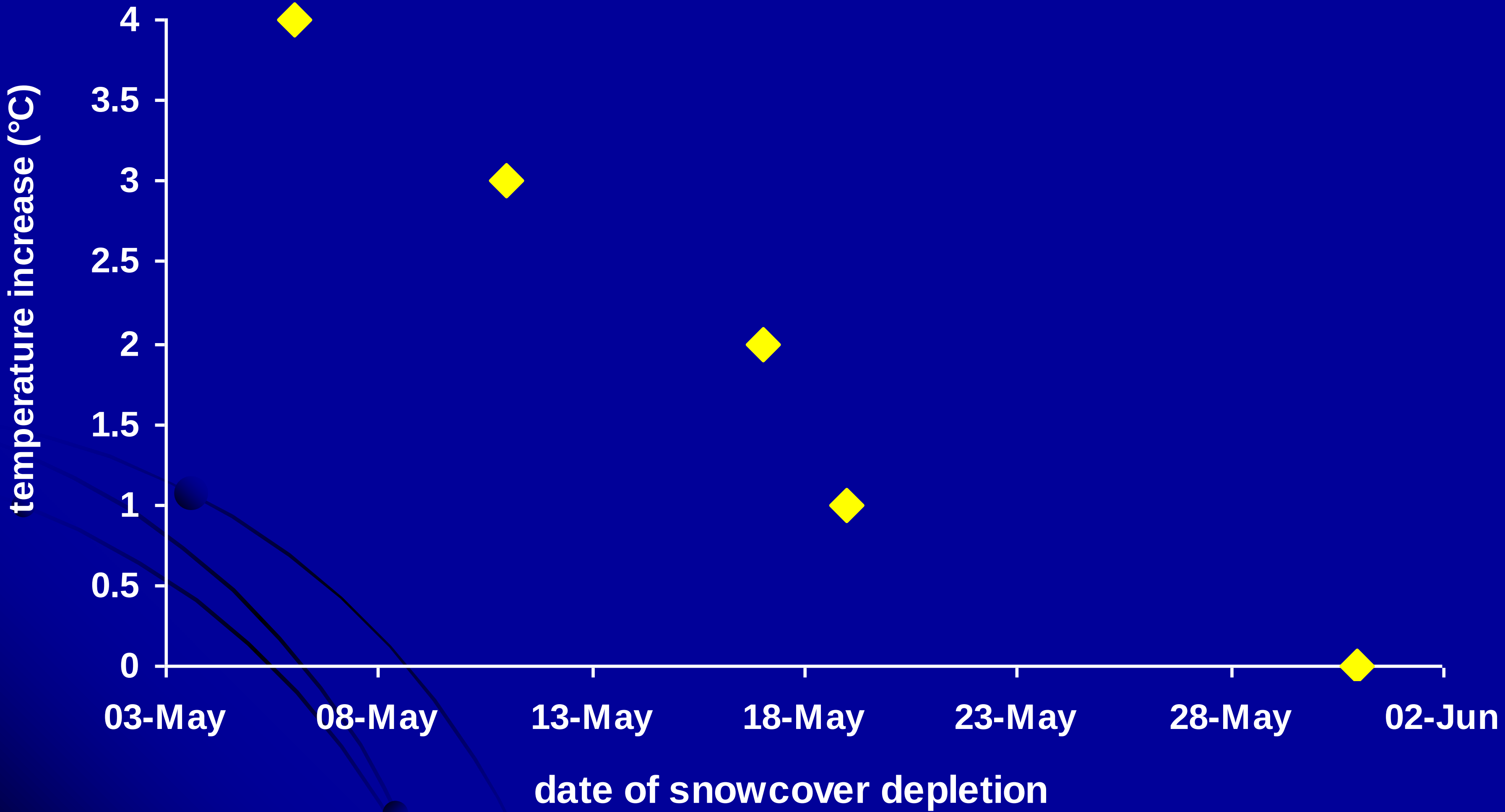
Forest Cover Disturbance Impact on Peak Streamflow



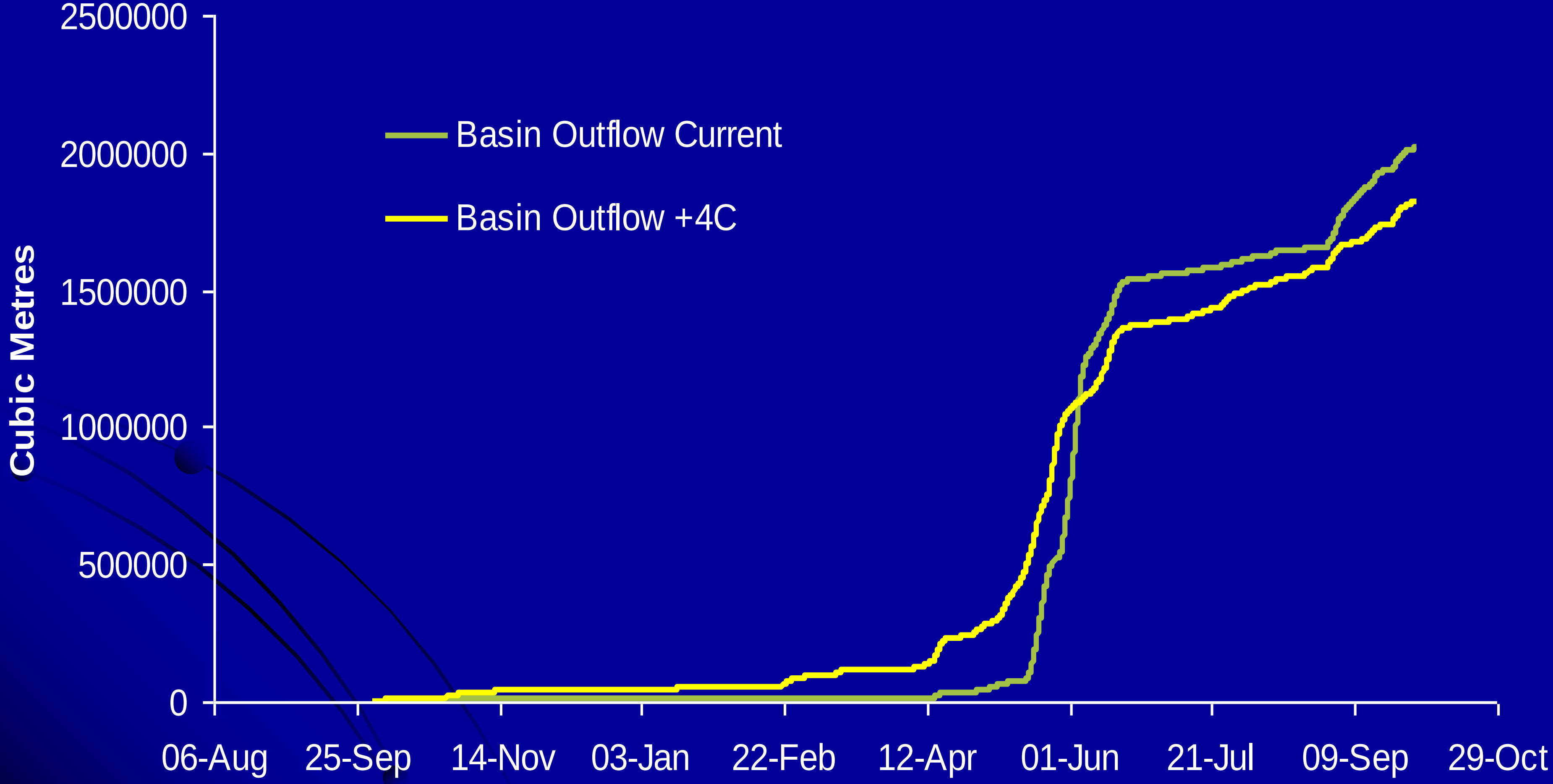
Alpine Hydrology Change with Rising Temperature



Impact of Winter Warming on Date of Snowpack Depletion



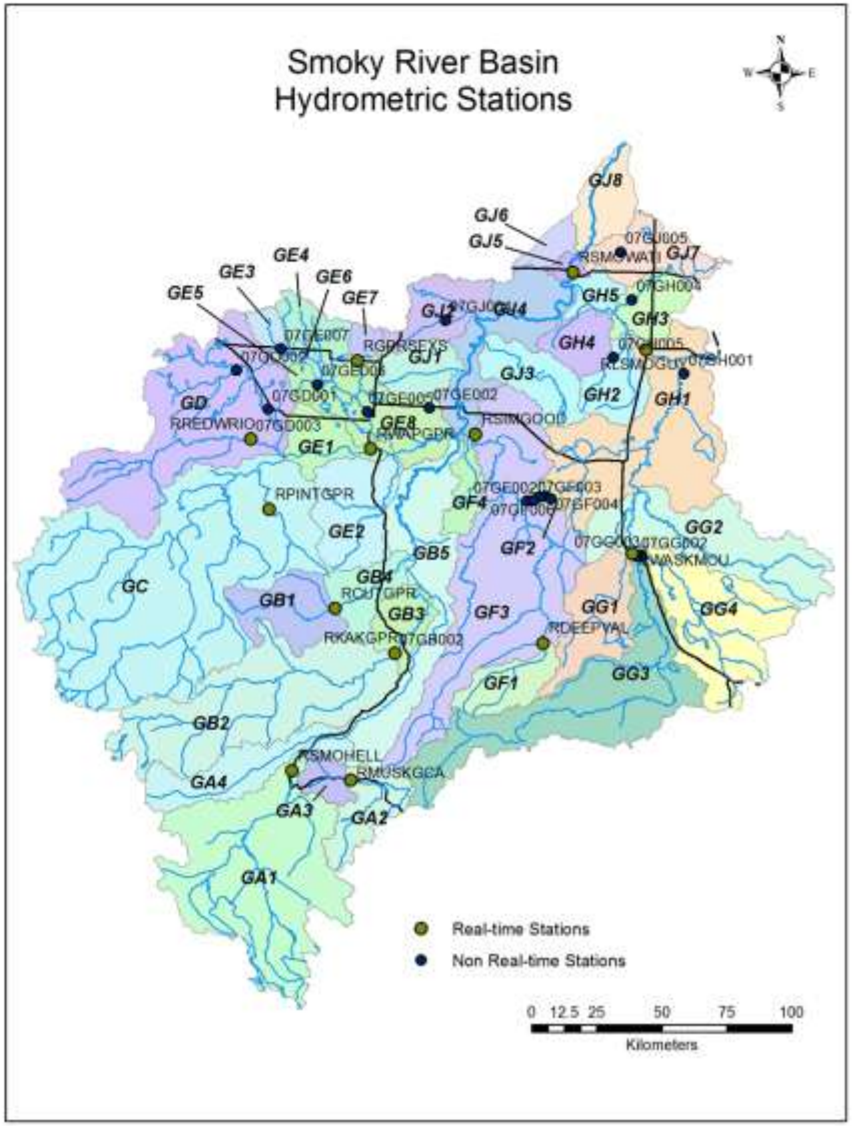
Change in Alpine Basin Discharge

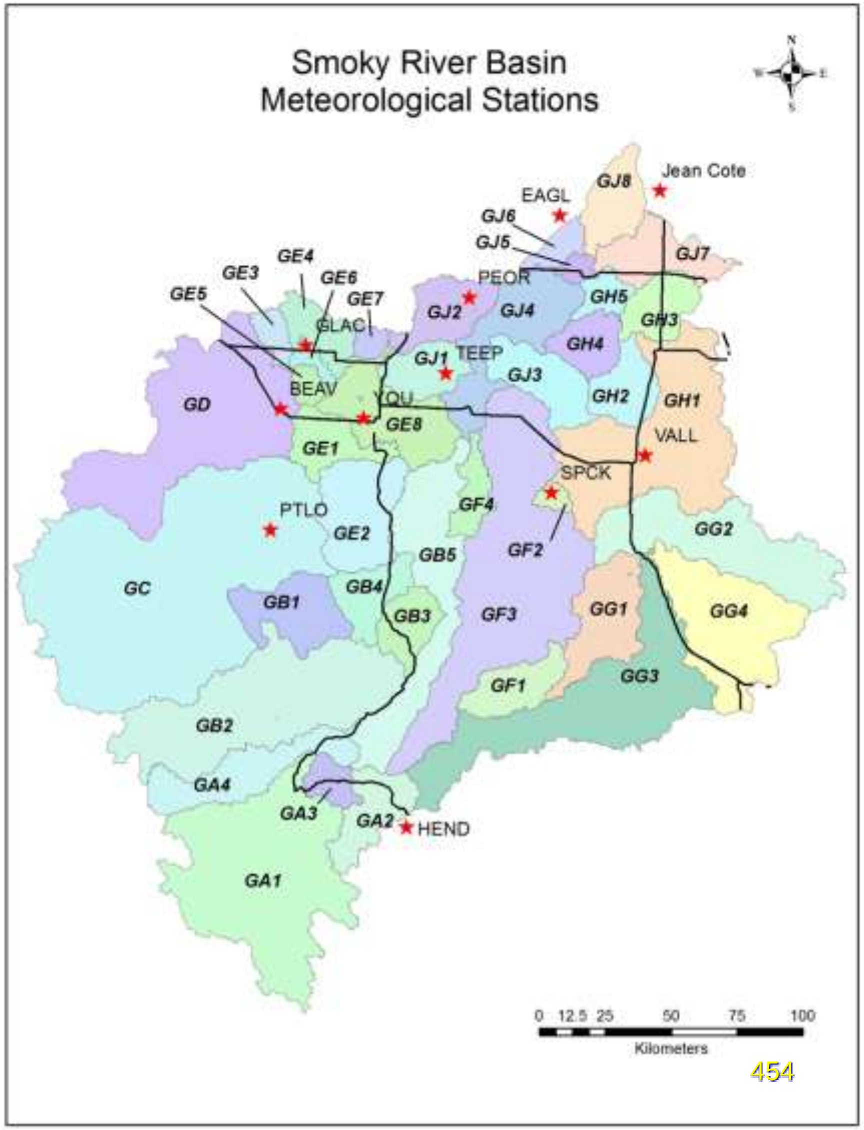


Application: Operational Forecasting of Ungauged Flows

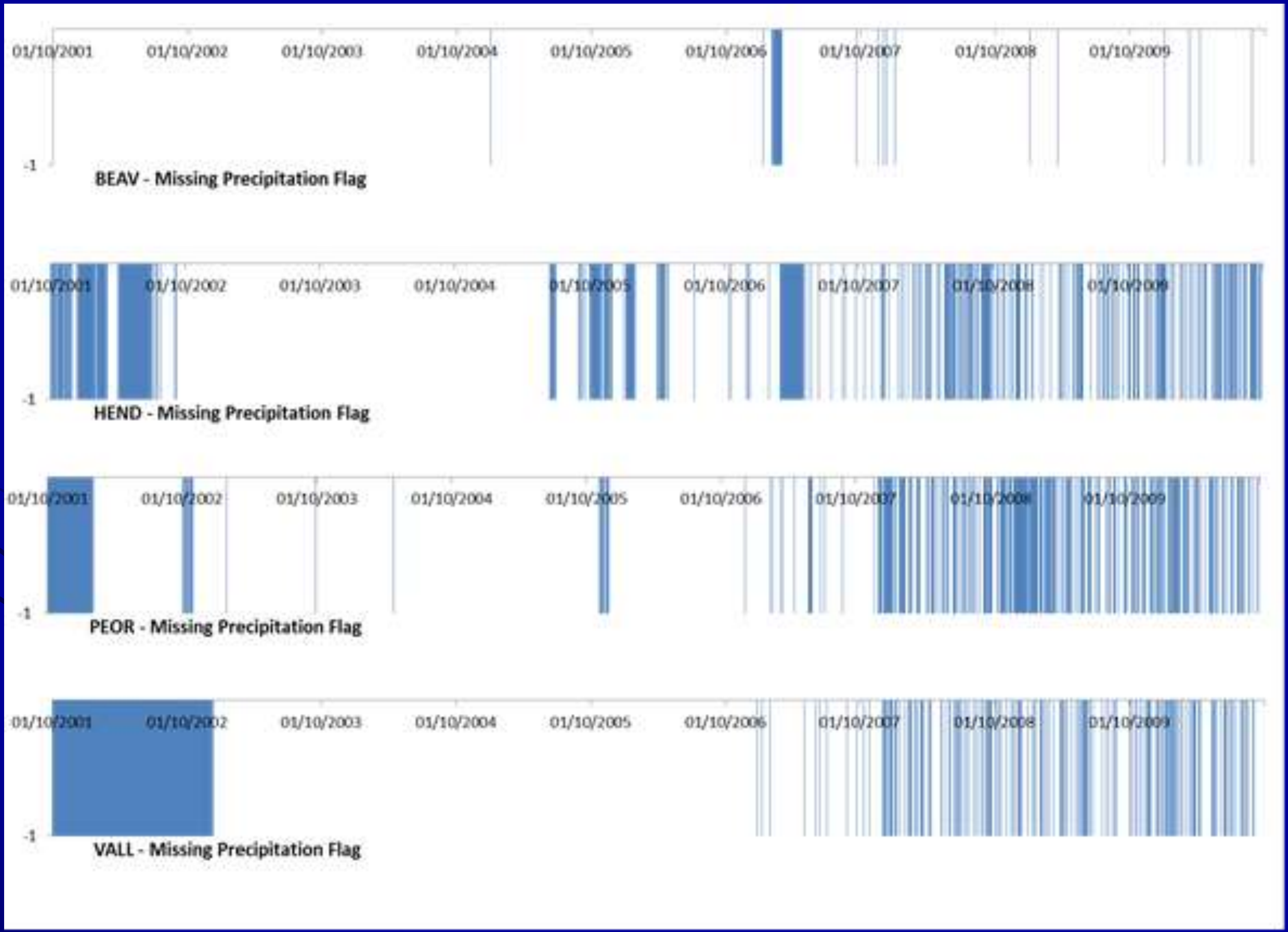
- Smoky River Basin is 46% ungauged
- Need to simulate spring streamflow from the ungauged basin area (23,769 km^2) in order to forecast Smoky River contribution to the Peace River
  - Run model on a daily basis during flood forecast period – update ungauged flows
  - Use daily updates of meteorological model forecast data to run for the future
  - Route ungauged with gauged flows for forecast

Smoky River Basin: 51,839 km^2



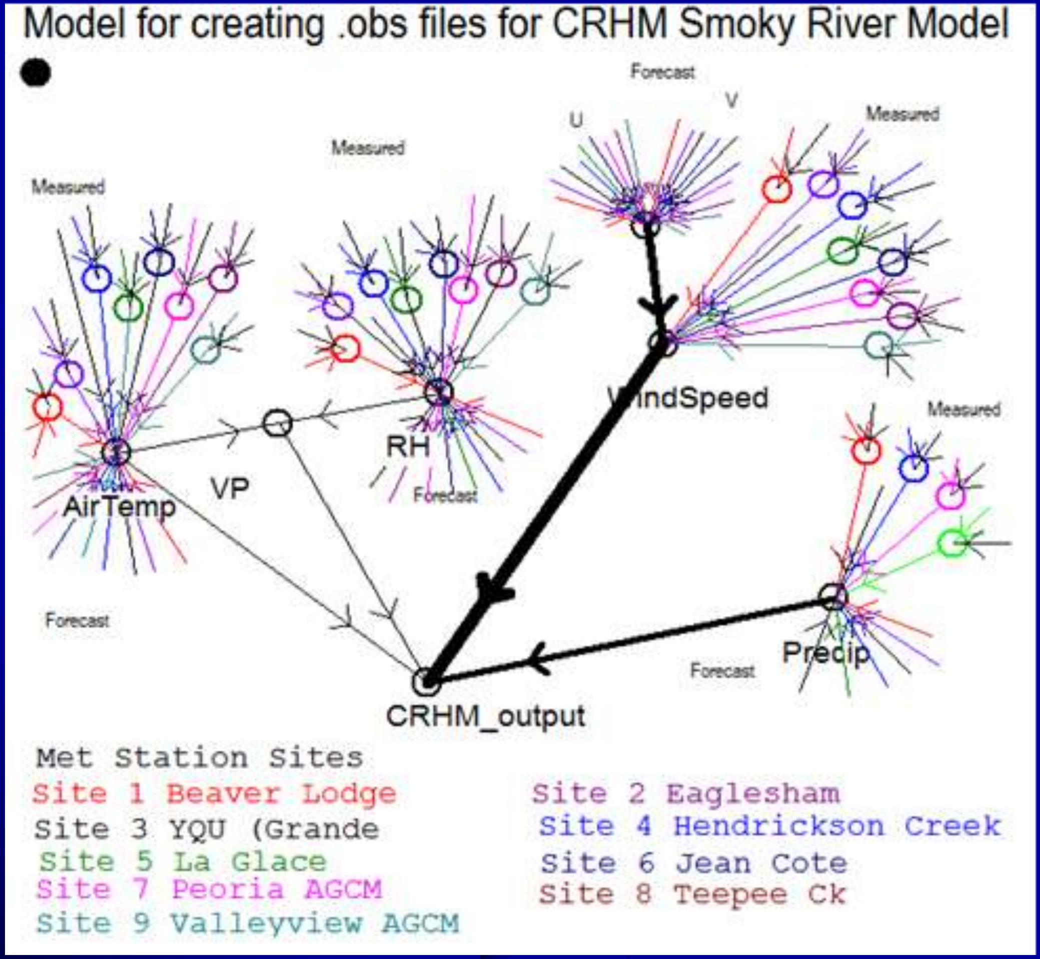


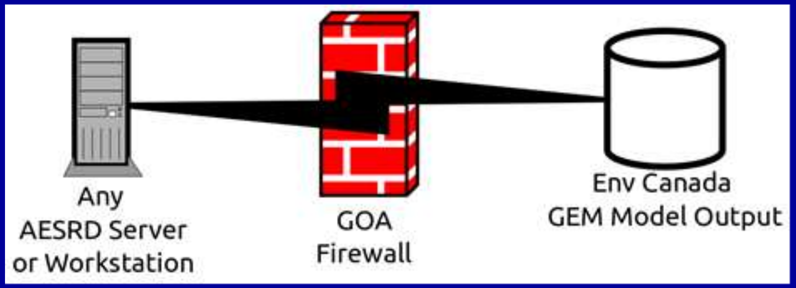
Challenge: Reliable Meteorological Observations and Forecasts

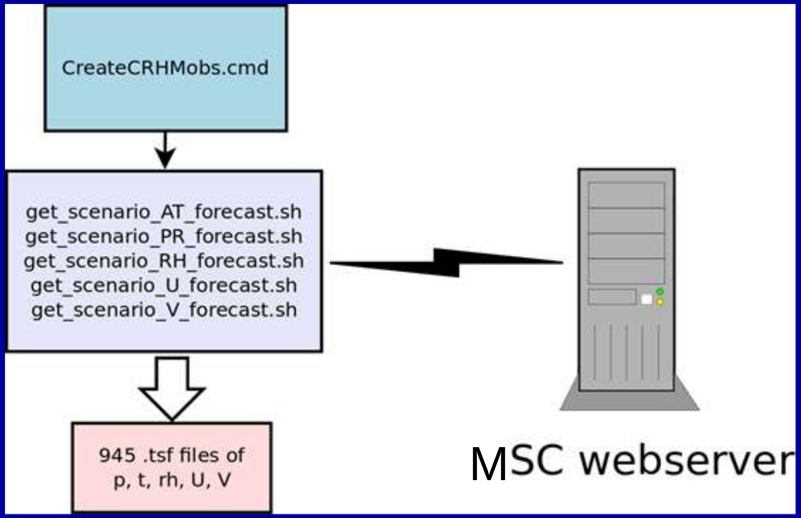


Interpolate and Predict

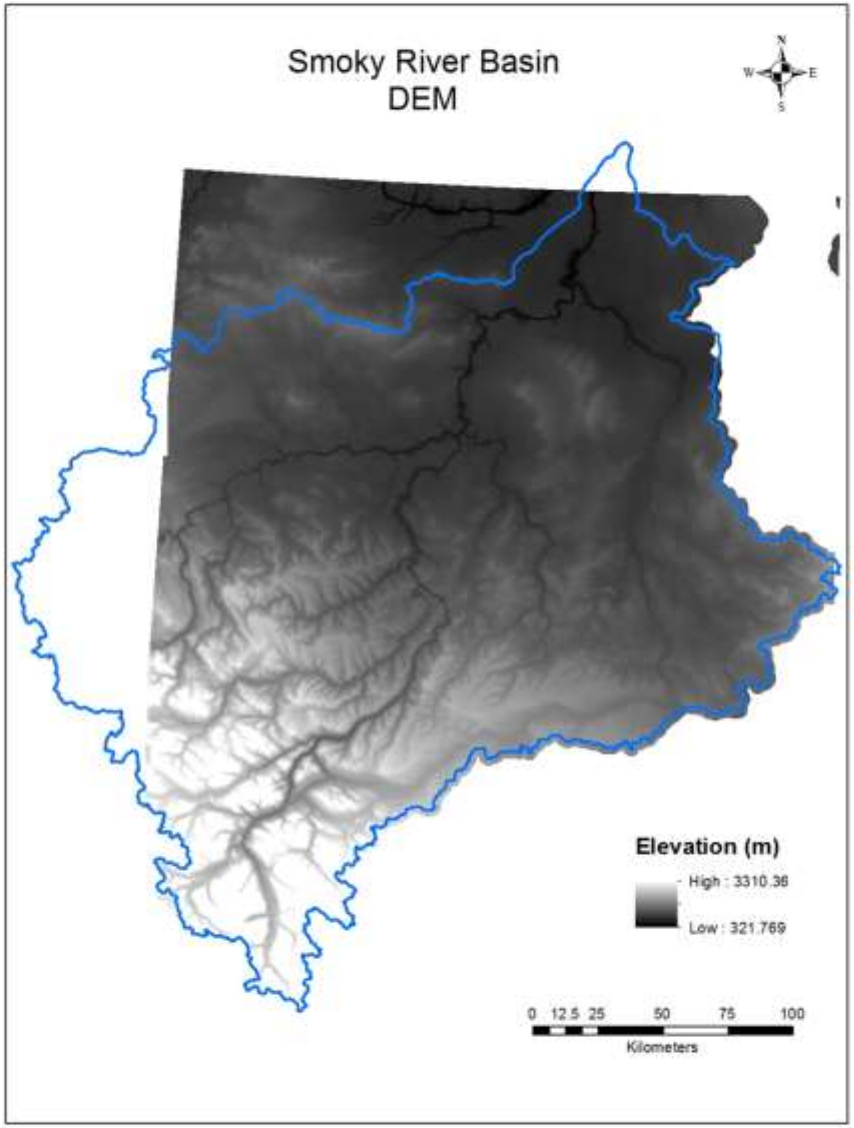
GEM-WISKI-CRHM

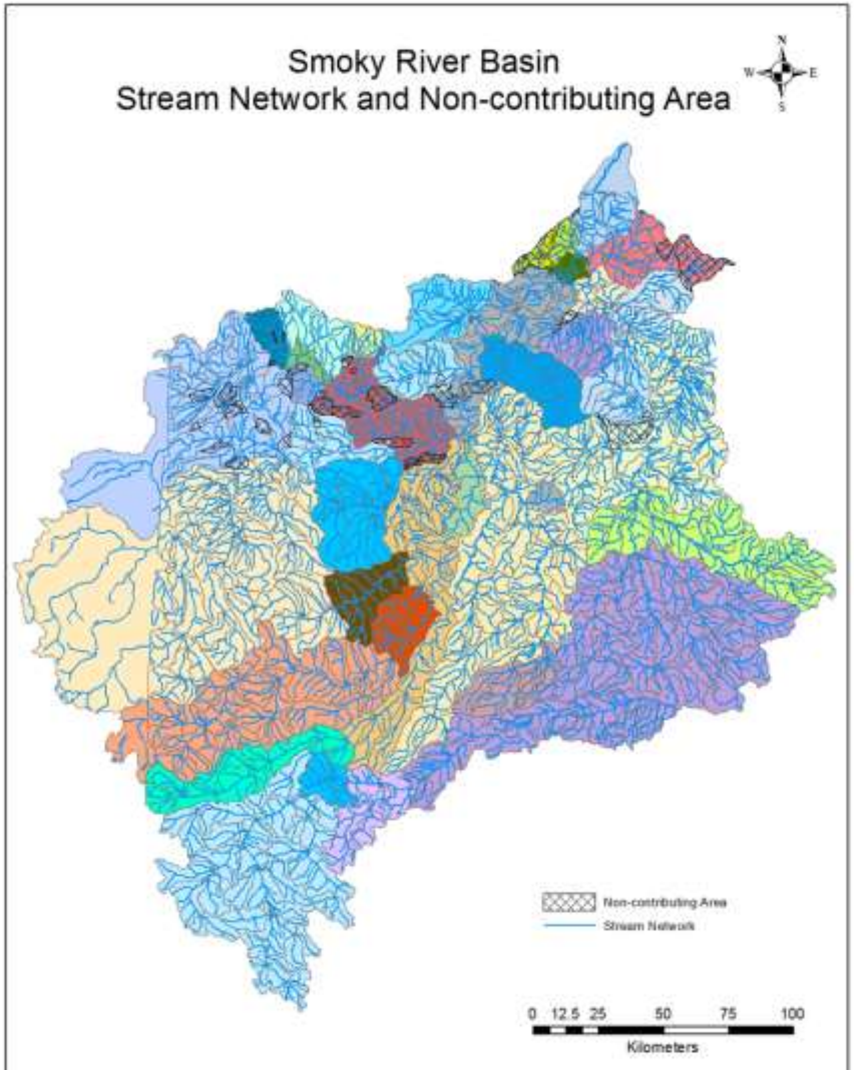




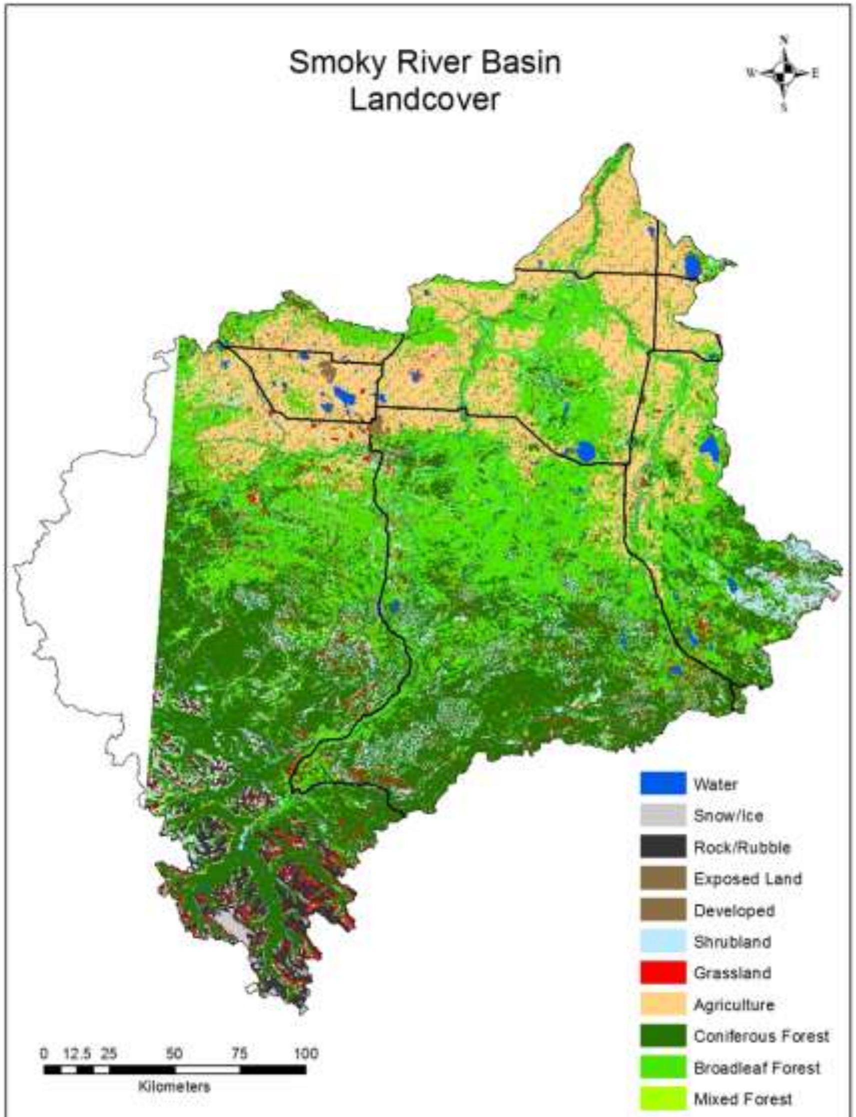


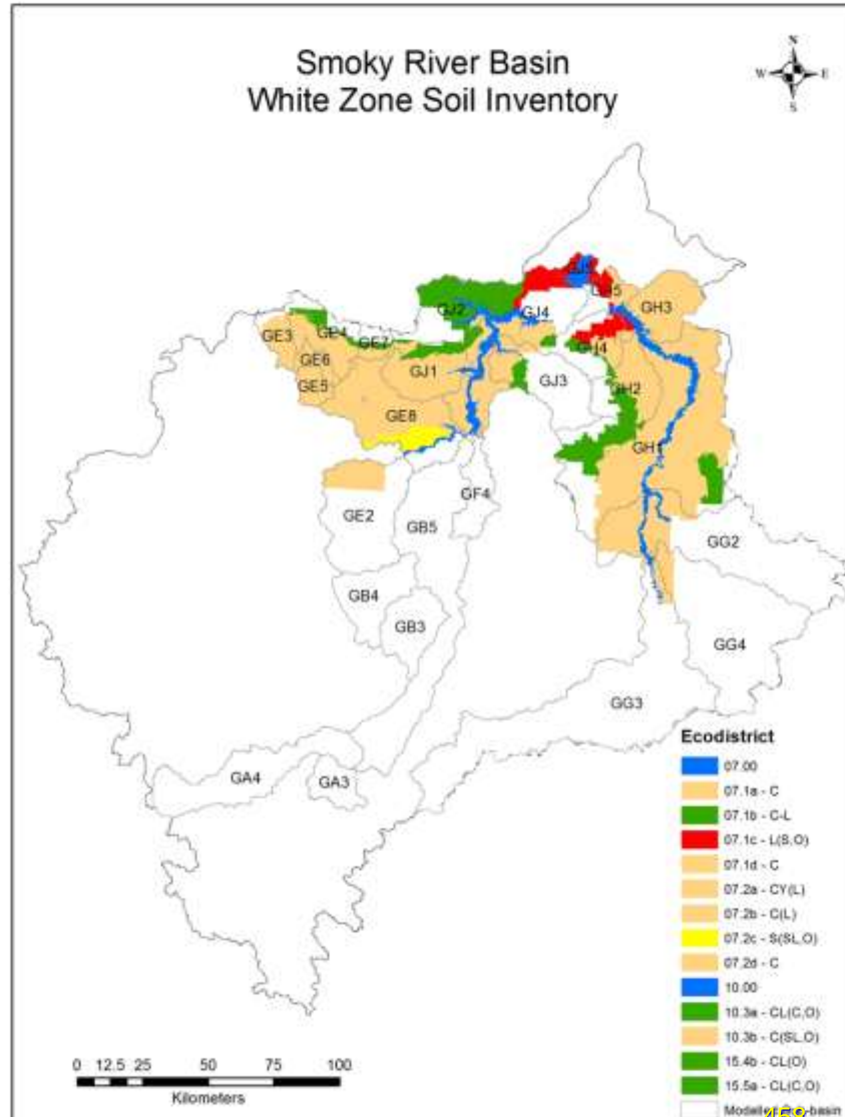
DEM and Derived Stream Network





Land Cover and Soils



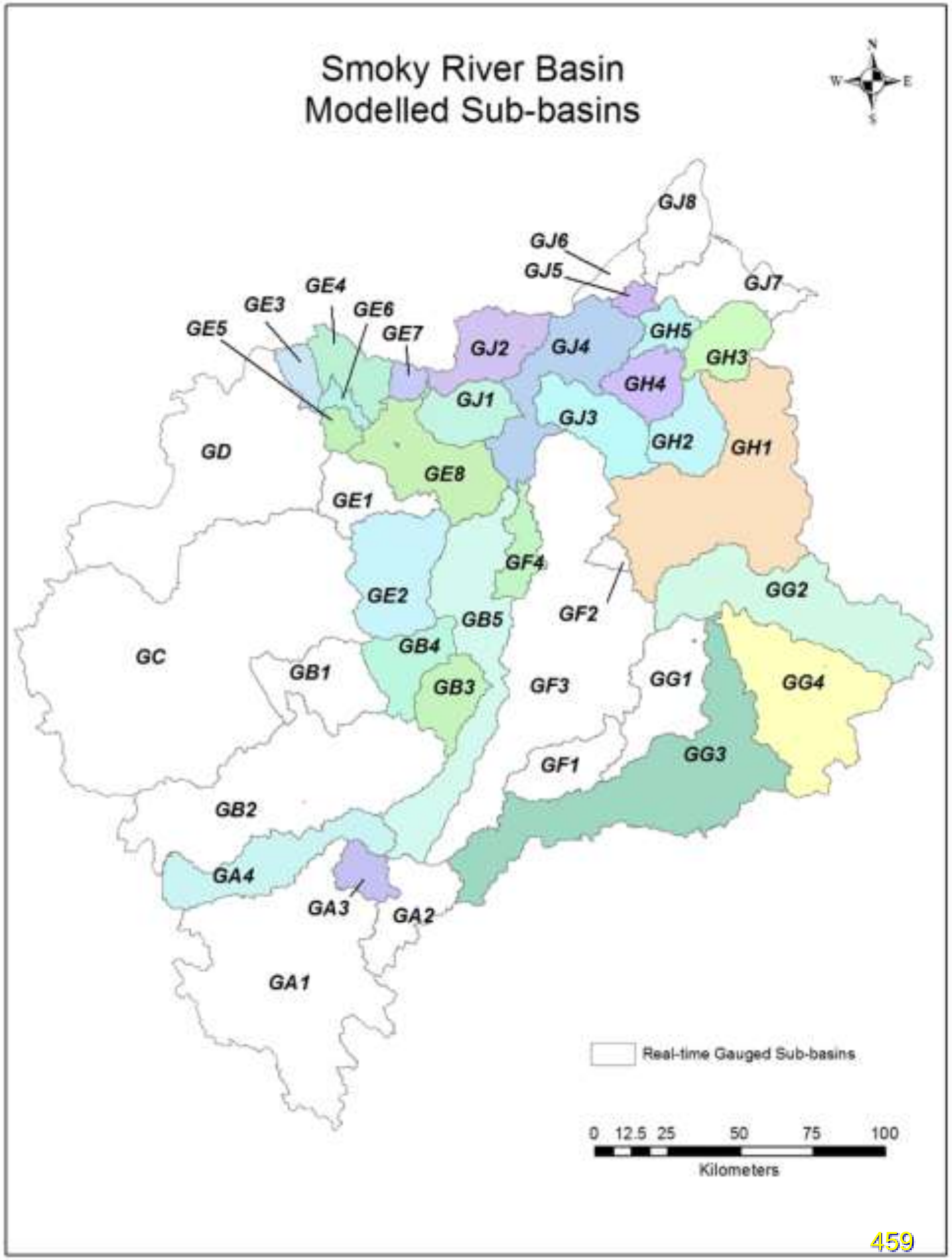


Sub-basins for Modelling

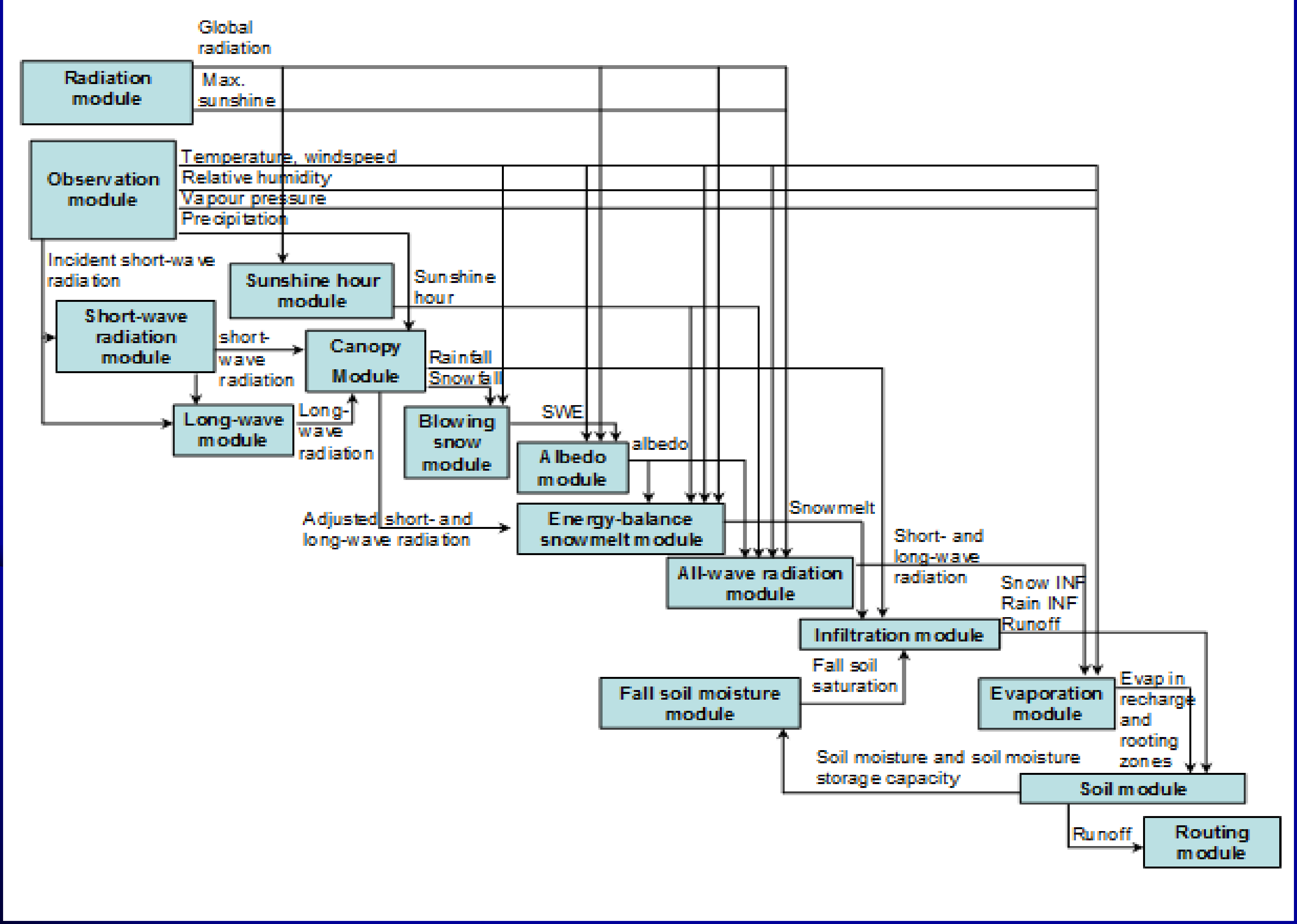
Modelled all ungauged and gauged basins without real time hydrometric stations

Sub-basins grouped into "types" based on ecoregion

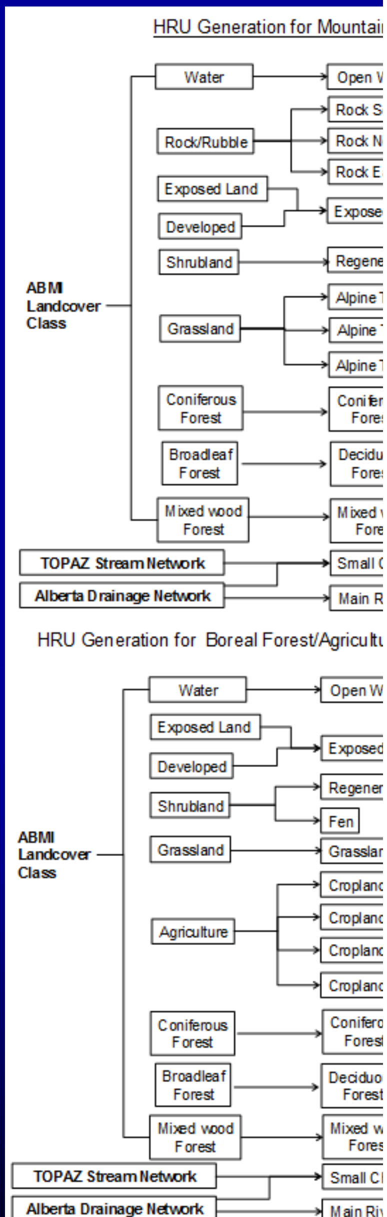
Real time gauged basins are estimated from gauge measurements and routed outside of CRHM using SSARR

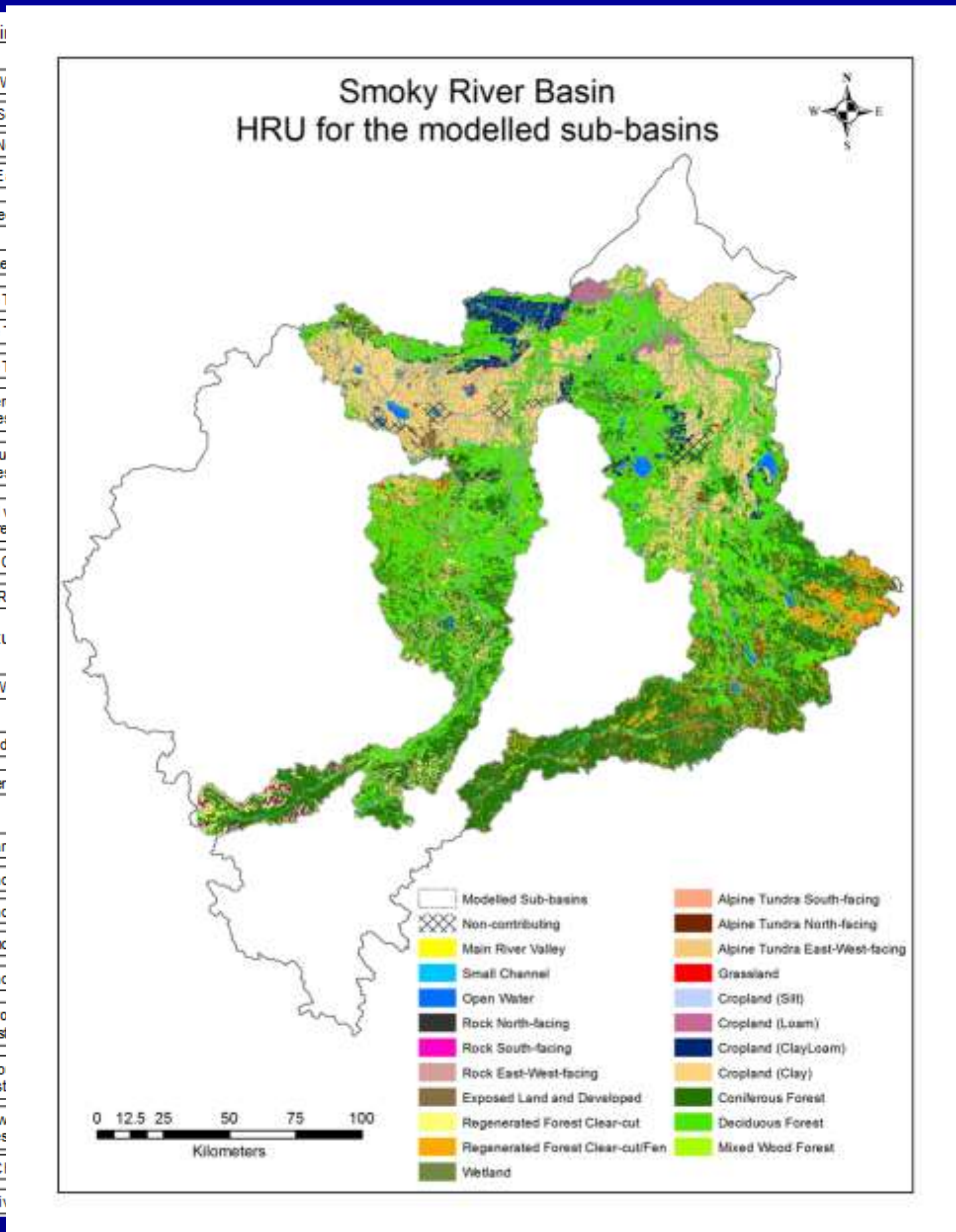


Module Structure within each HRU



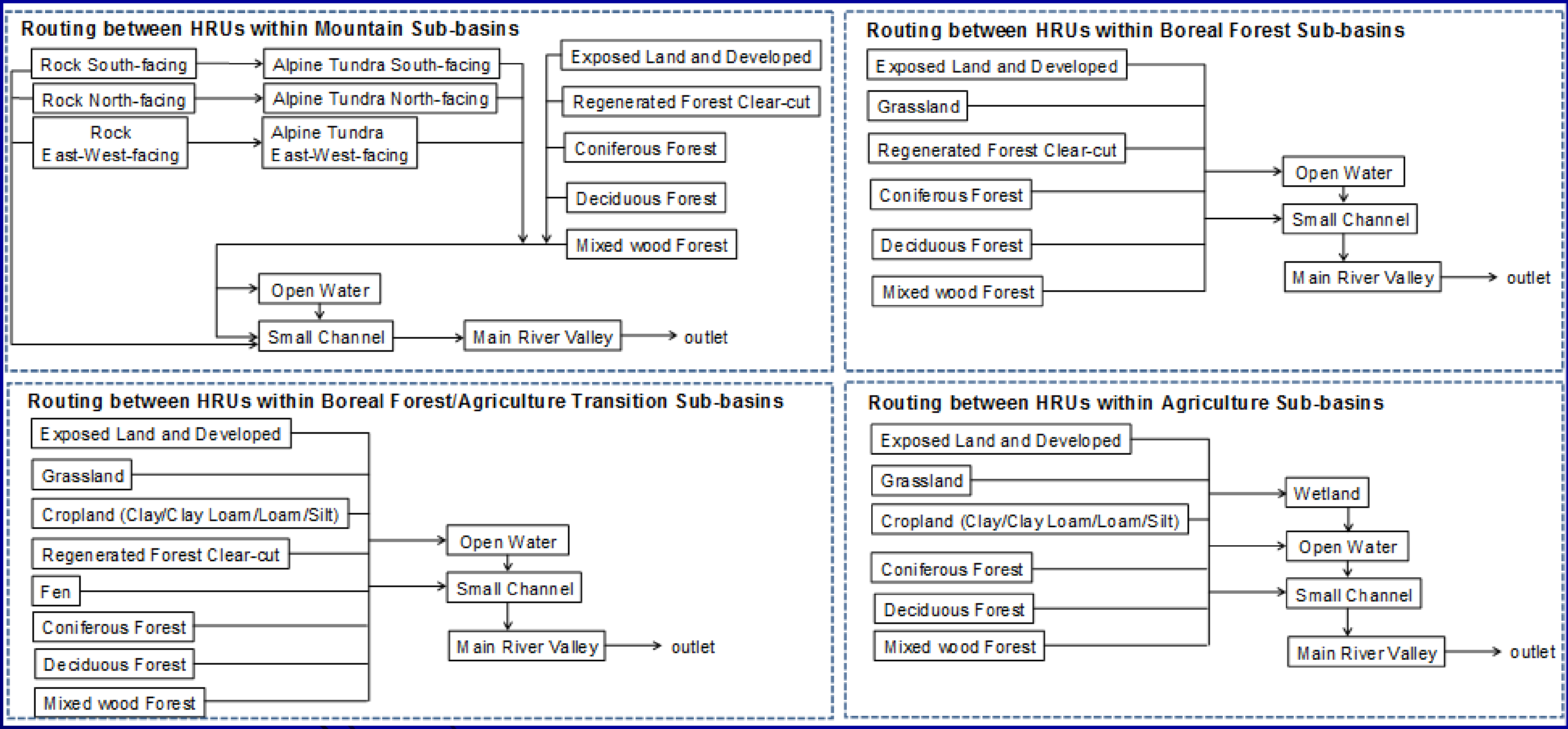
HRU Classification of Smoky Basin





HRU classification and interpretation of land cover, topography, drainage, soils to determine parameters was guided by sub-basin "type" which depended on ecoregion

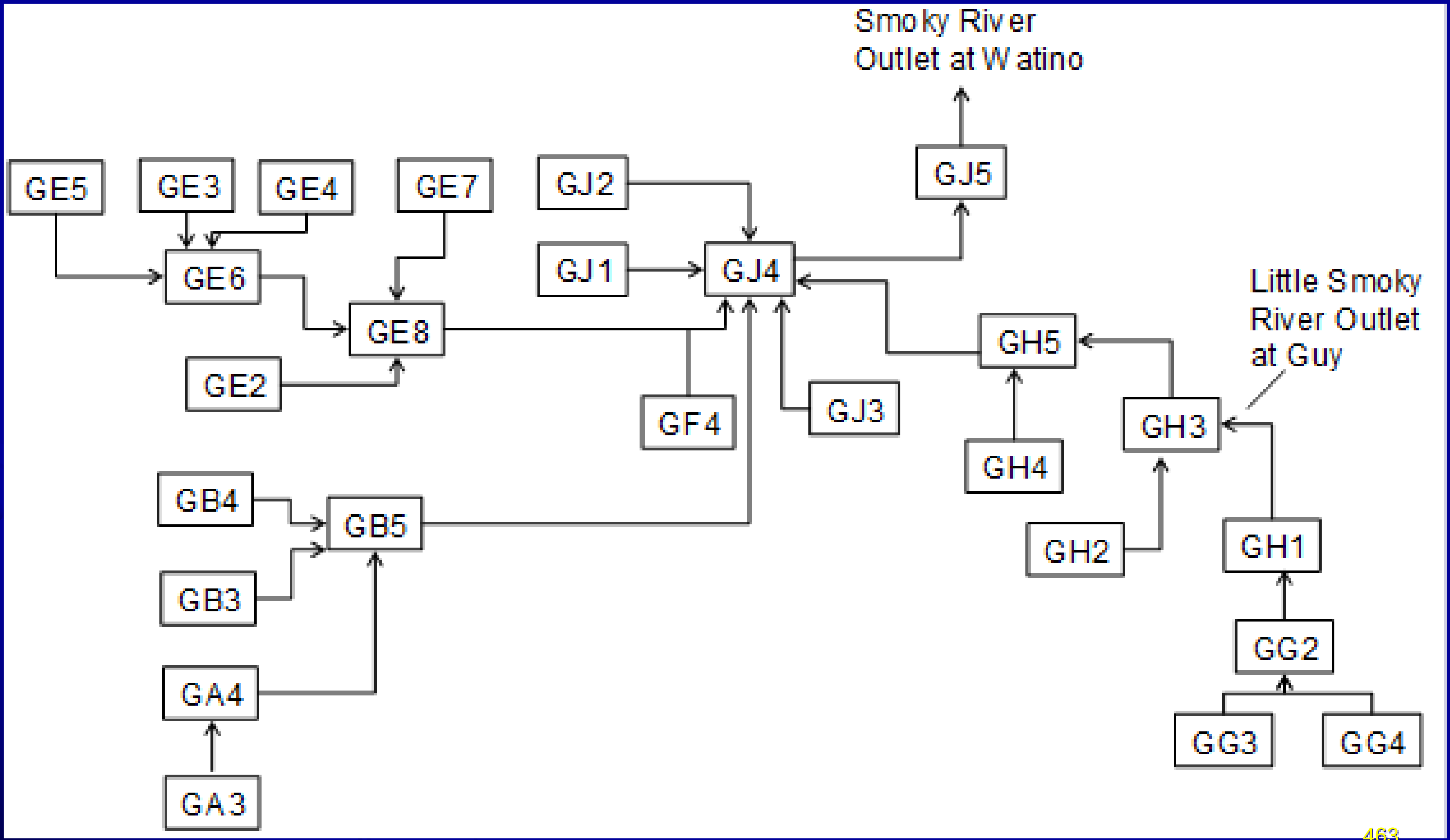
Routing between HRUs



Routing sequence depends on sub-basin type (ecoregion)

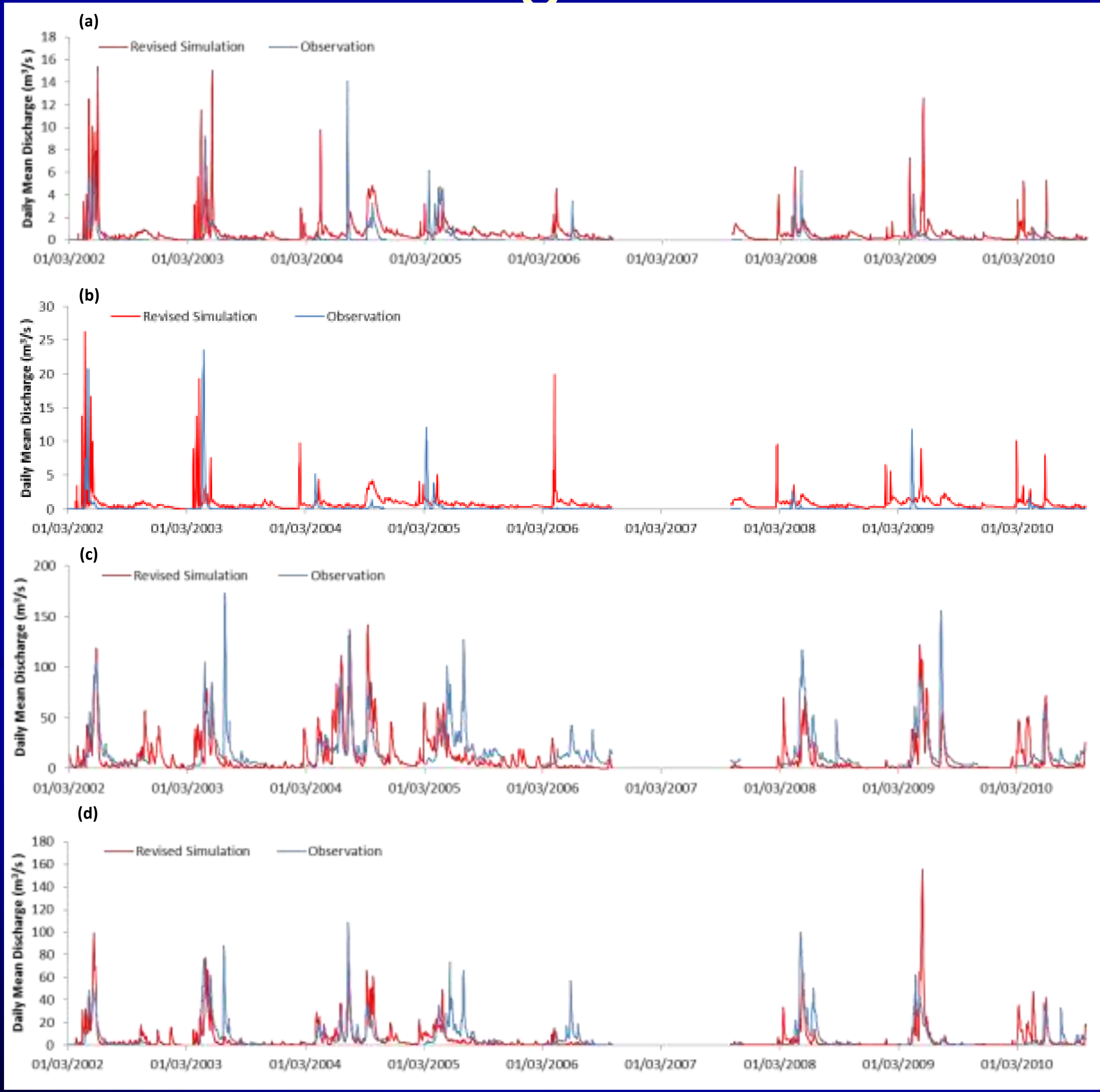
Routing between Sub-basins

Muskingum Routing used for river routing between sub-basins



Sub-basin Model Testing

Station Name	Station ID	Sub-basin
Grande Prairie Creek near Sexsmith	07GE003	GE7
Bear River near Valhalla Centre	07GE007	GE3
Little Smoky River at Little Smoky	07GG002	GG3
Iosegun River near Little Smoky	07GG003	GG4



Sub-basin

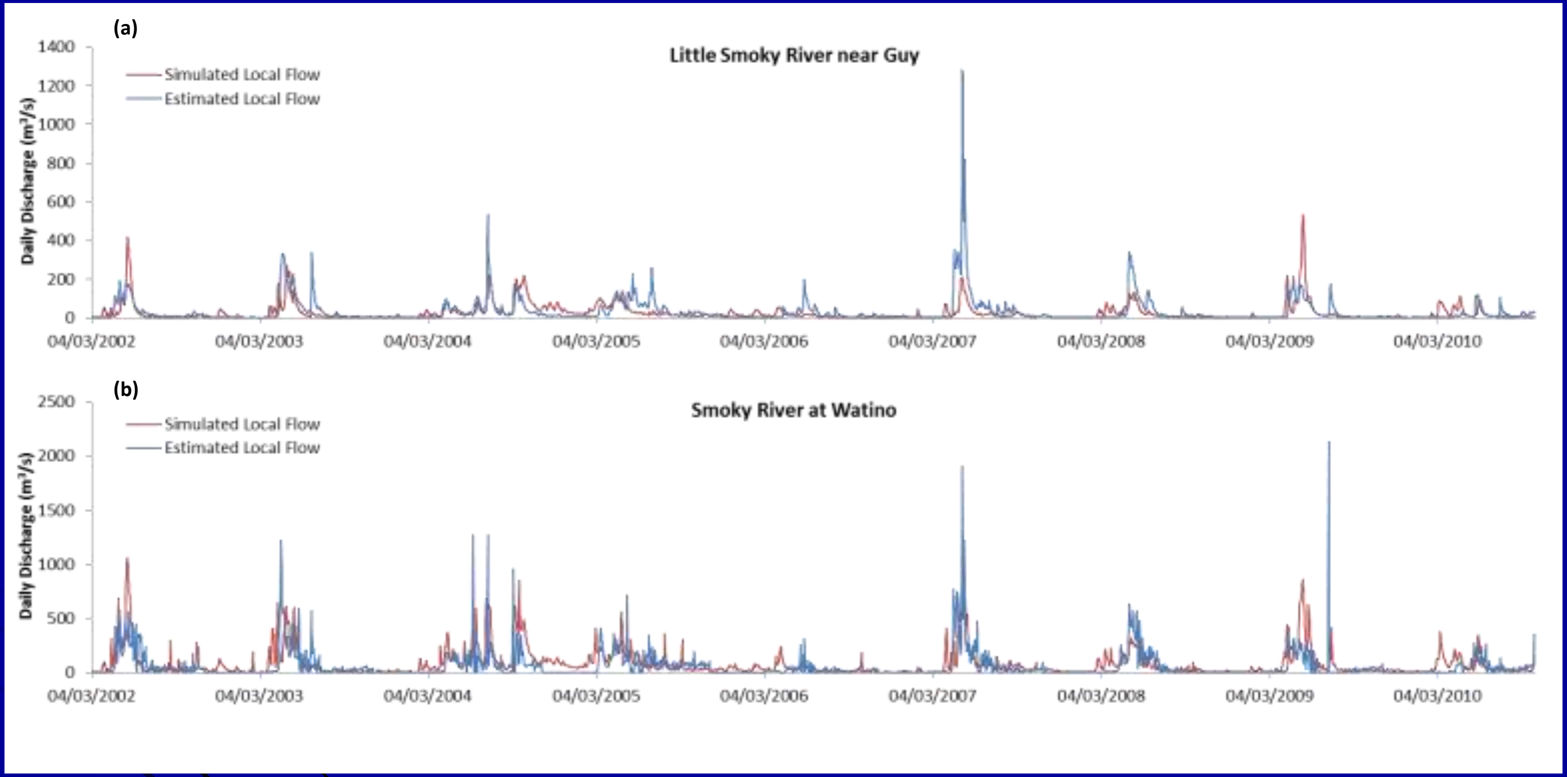
GE7

GE3

GG3

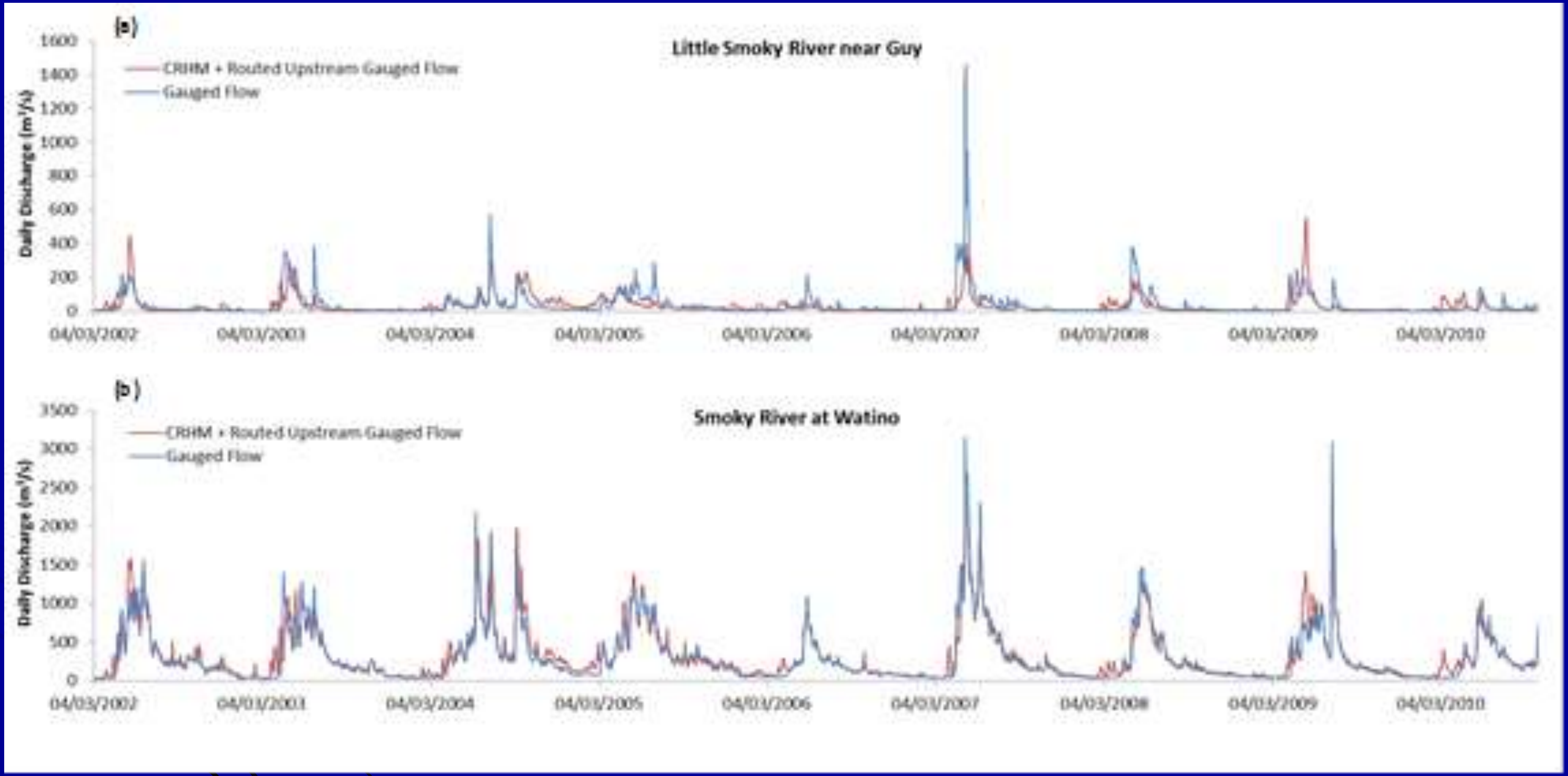
GG4

Basin Scale Local Inflow Evaluation



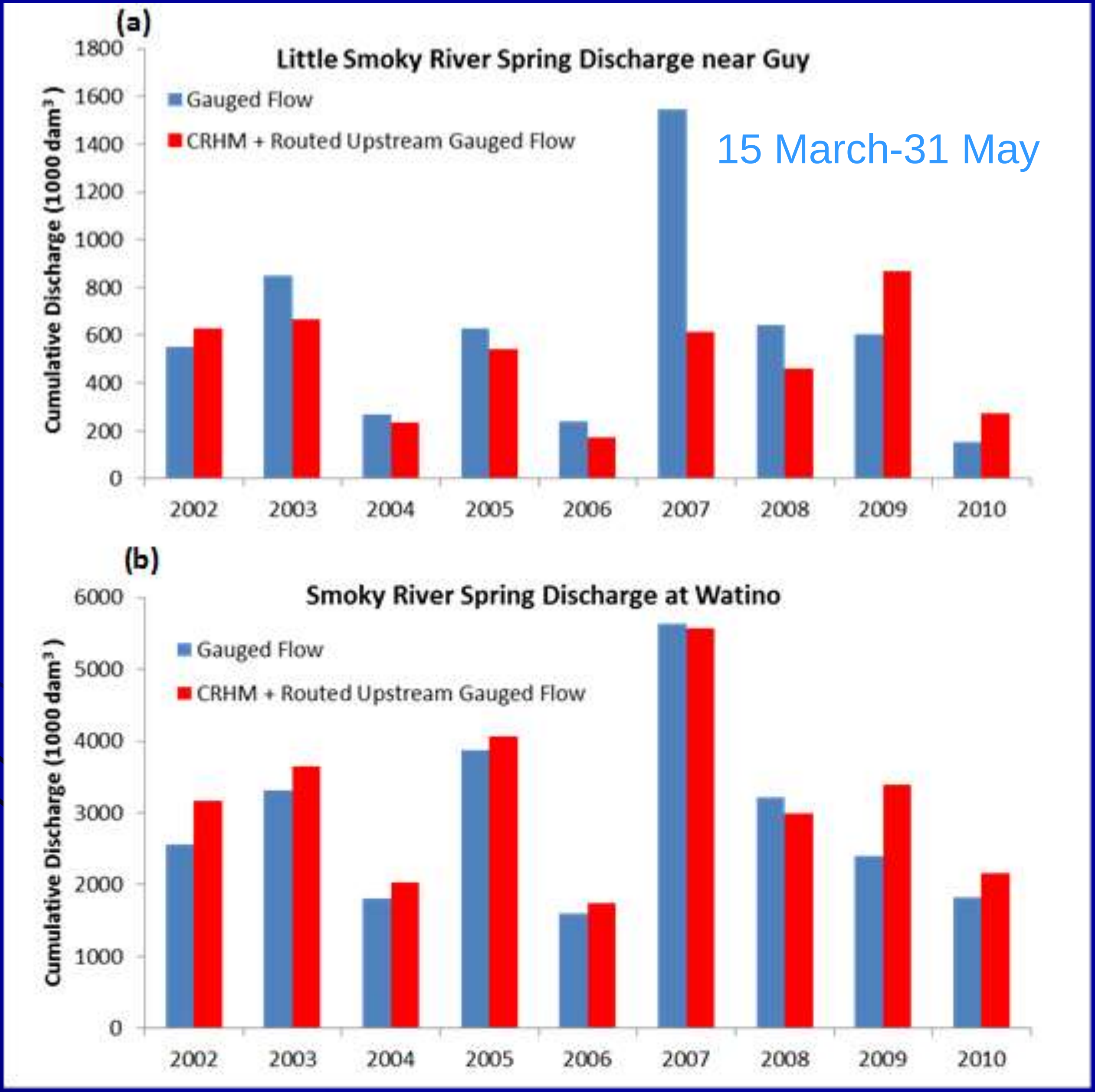
-Simulated local flows are only from CRHM hydrographs.
-Estimated local flows are gauged hydrographs minus routed upstream gauged hydrographs.

Basin-scale Prediction Evaluation

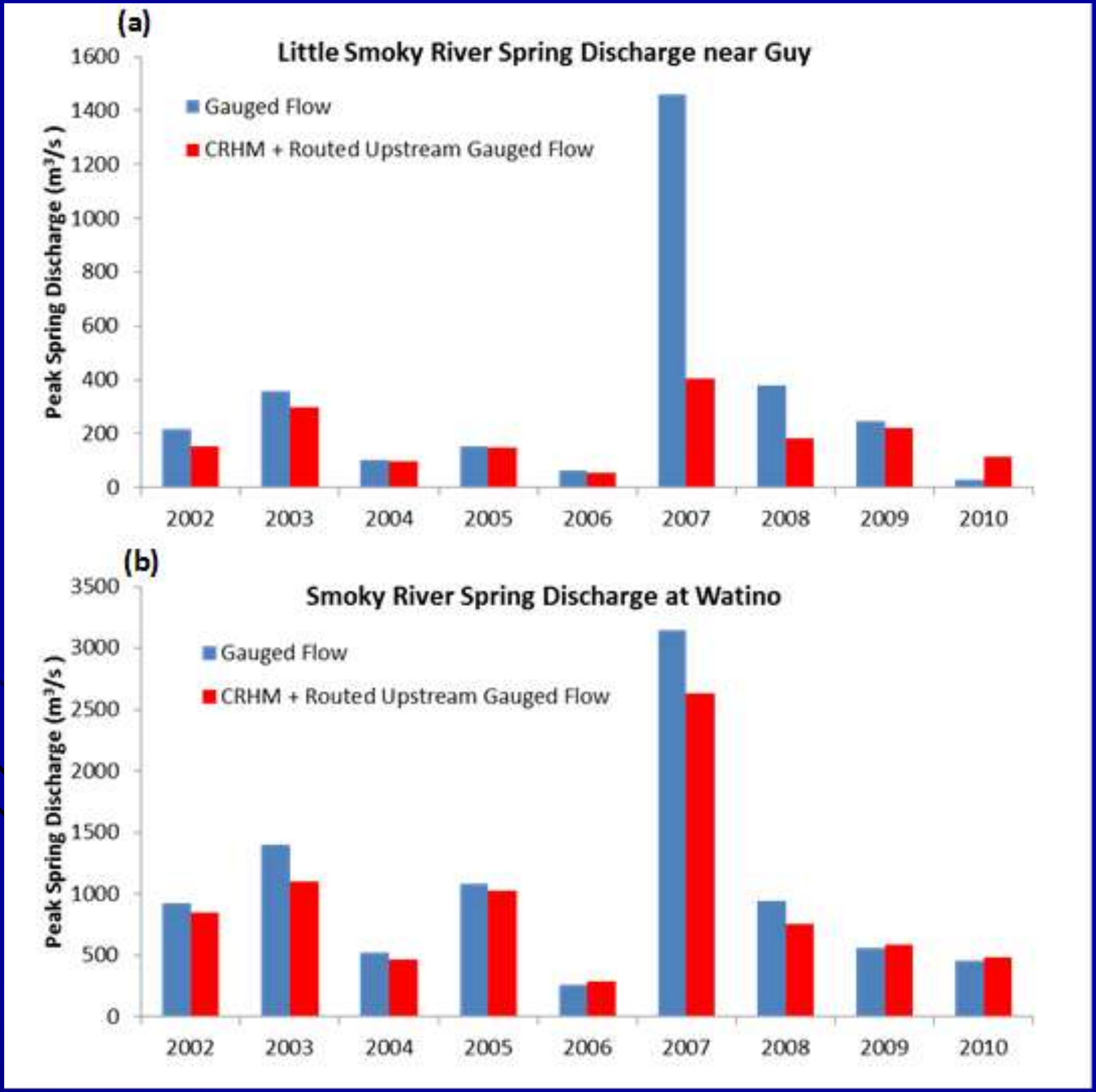


Predicted flows, Nash-Sutcliff Statistic: 0.41 (Little Smoky) and 0.87 (Smoky)

Predicted Spring Discharge



Predicted Spring Peak Discharge



Conclusions

- Better understanding of processes by intensive field study and detailed distributed modelling in research basins can be the basis for more realistic models and confident parameterisation.
- Using the results and understanding from research basins It is possible to simulate multiple hydrological states and fluxes in Alberta’s mountains and prairies without extensive calibration from streamflow observations.
- These models can be used to reliably show the sensitivity of Alberta’s river basins to climate change, drainage and land use change and provide new insights because of their strong physical basis.