Water Management Implications of CRHM: Mountains to Prairies to Arctic

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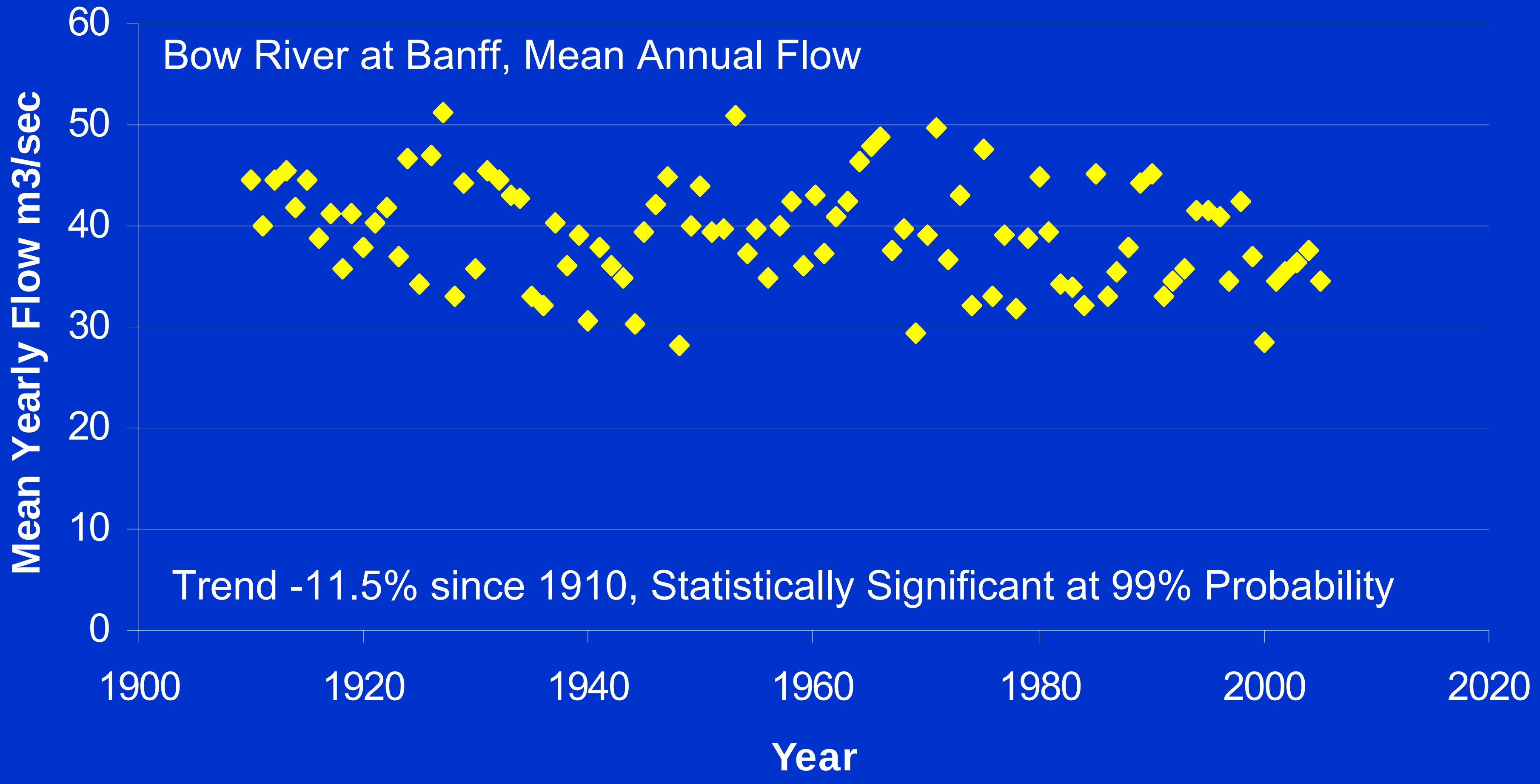
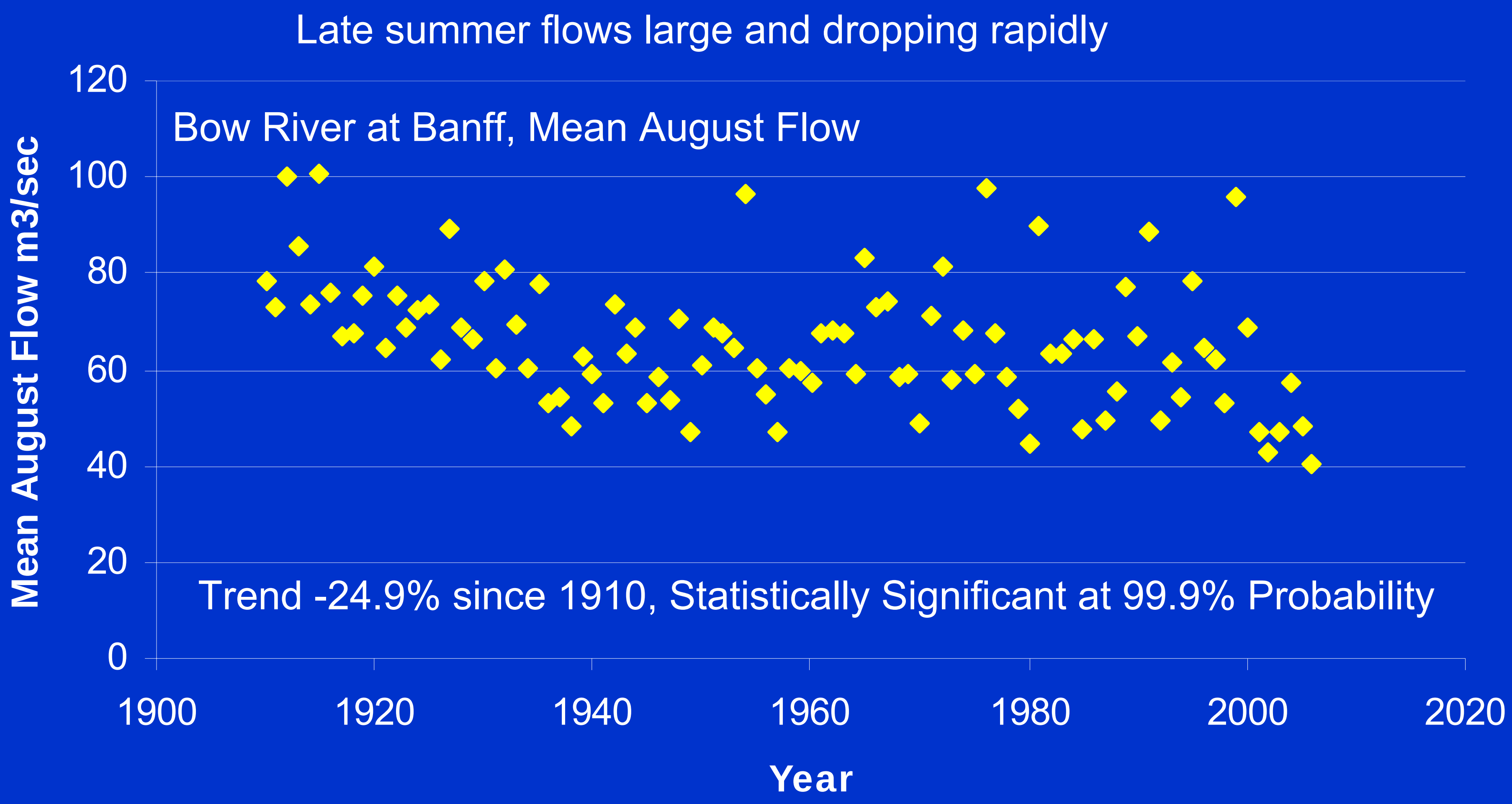
Problem
Rocky Mountain Water Resources are Declining
WHY?

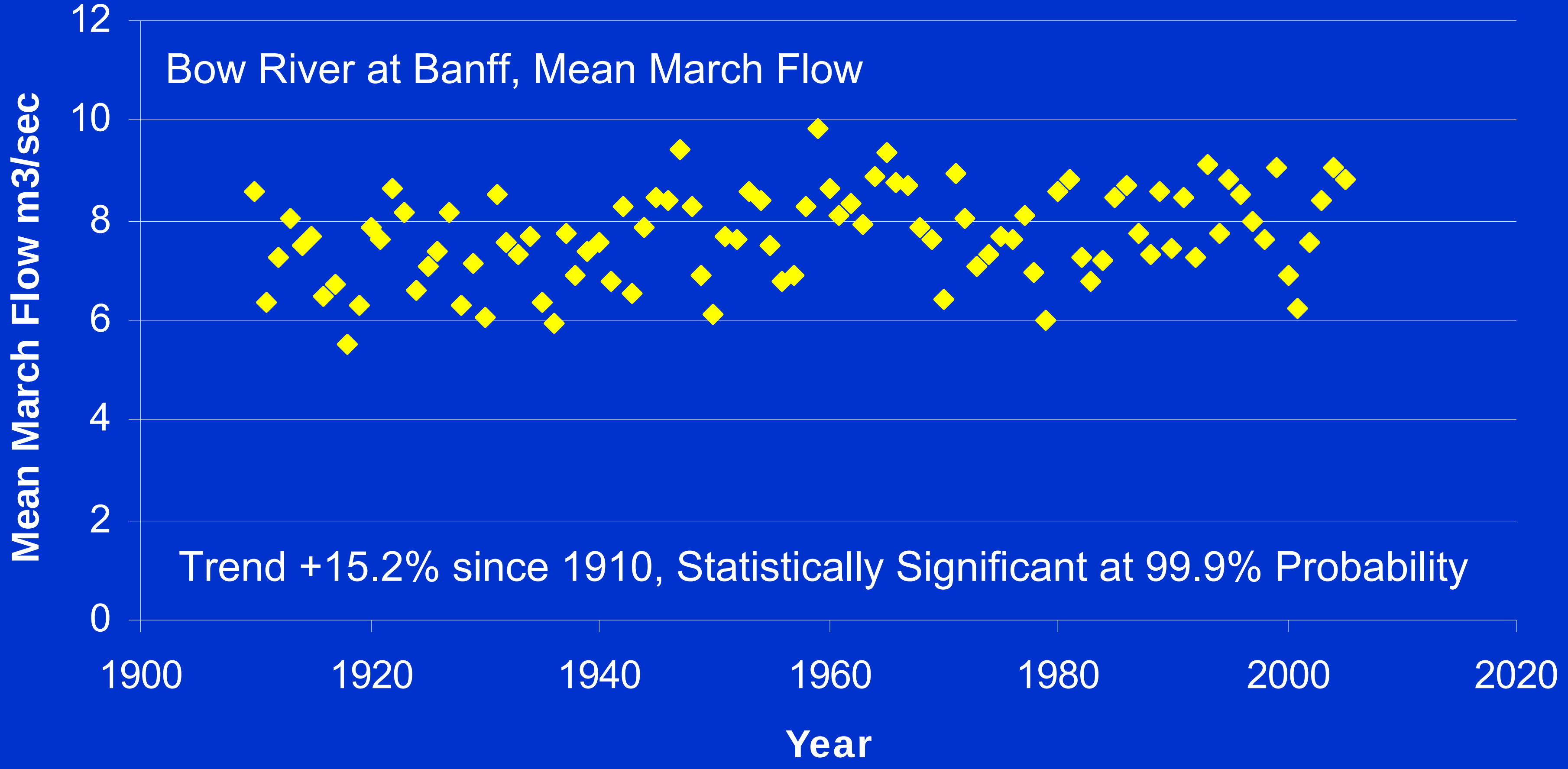


Flows in Late Summer



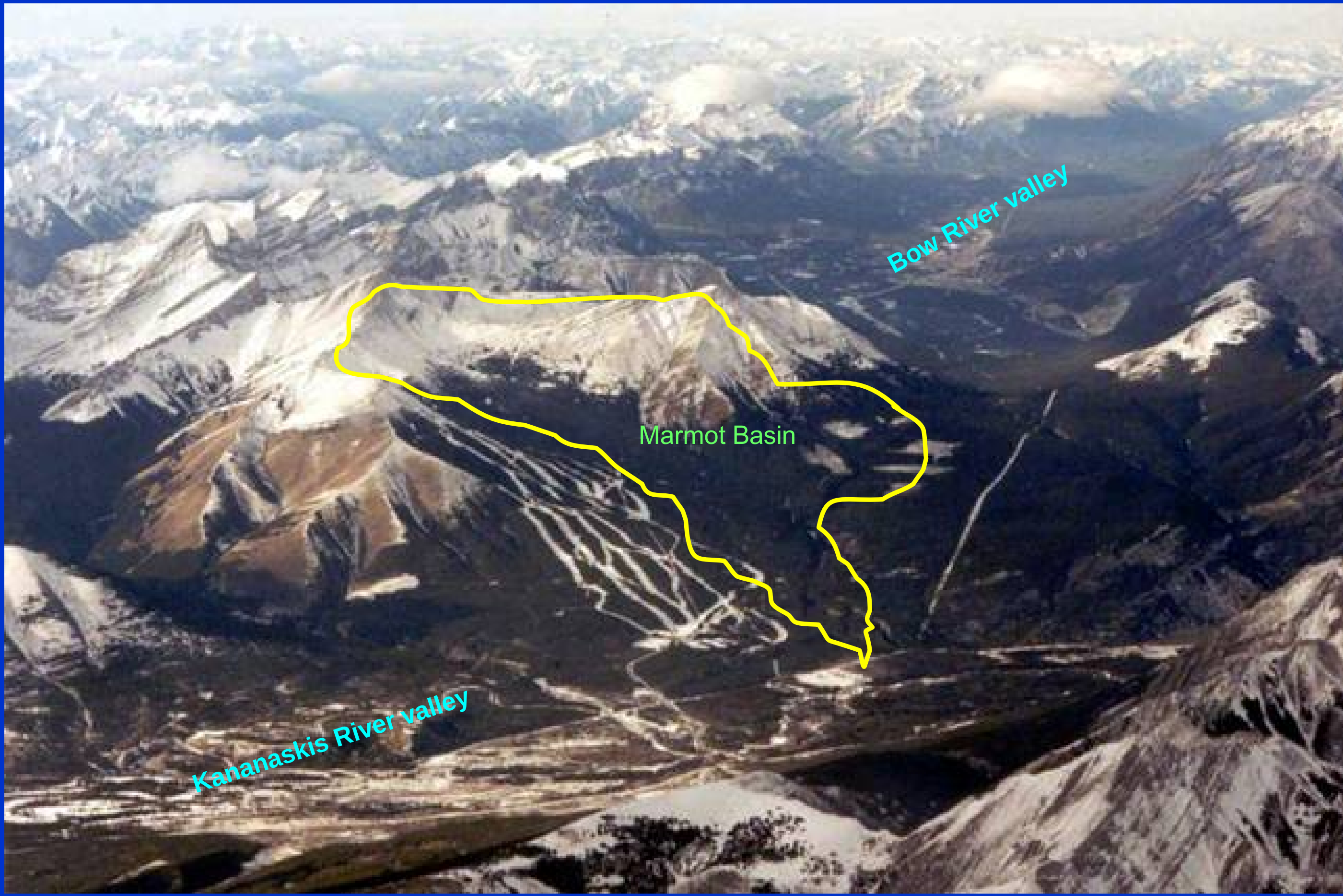
Early Spring Flow Increasing

Winter flows small and rising somewhat

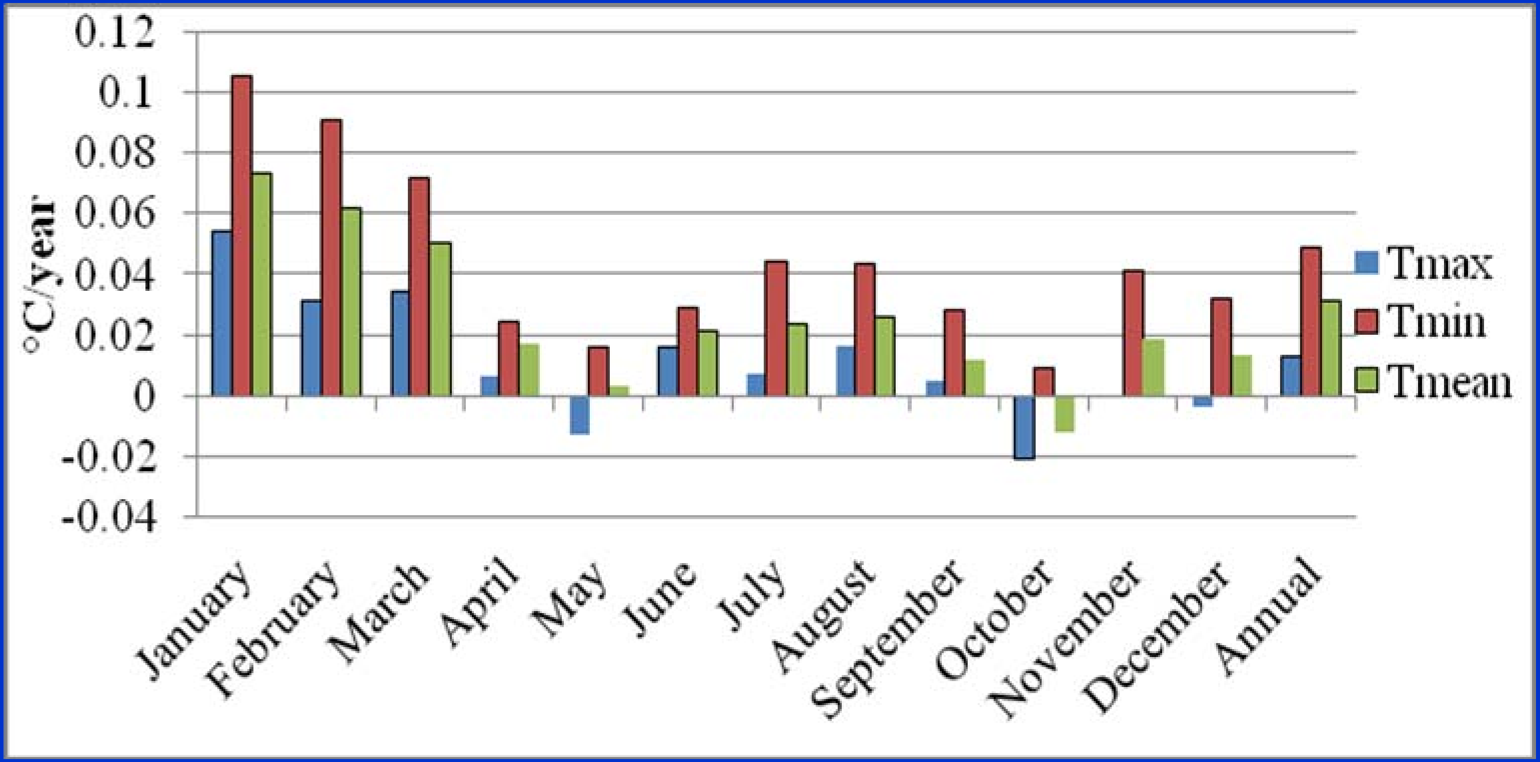


Marmot Creek Research Basin

- 1450-2886 m.a.s.l. Kananaskis Valley, Bow River
- Alpine
- Subalpine
- Montane
- Clearcut
- Meadow
- 900 mm precipitation
- 70% snowfall
- ~50% runoff



Temperature Trends at High Elevation in Marmot Creek, Rocky Mountains

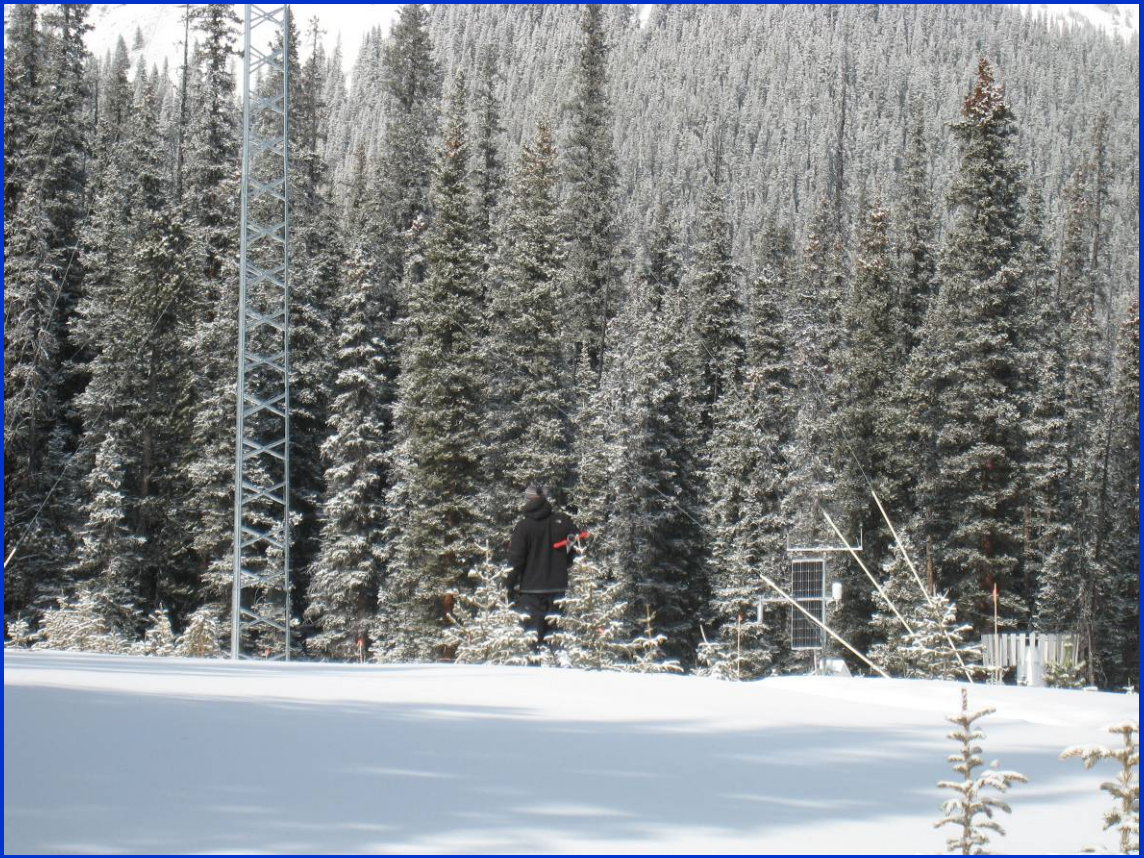


Winters are warmer by 3 to 4 °C since 1962

Harder & Pomeroy

Upper Clearing

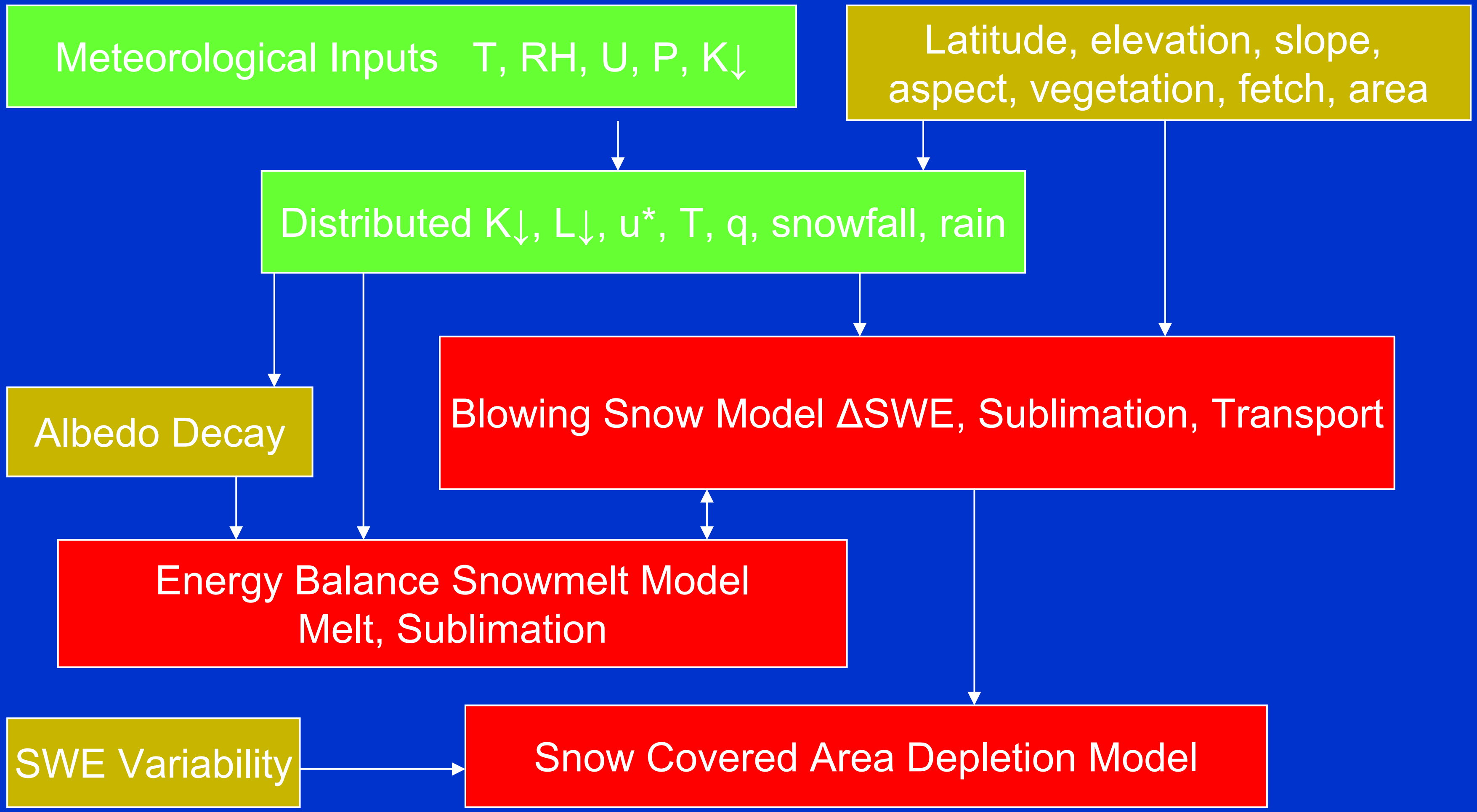
- 1844 m
- Small forest clearing
- Sheltered by fir and spruce forest



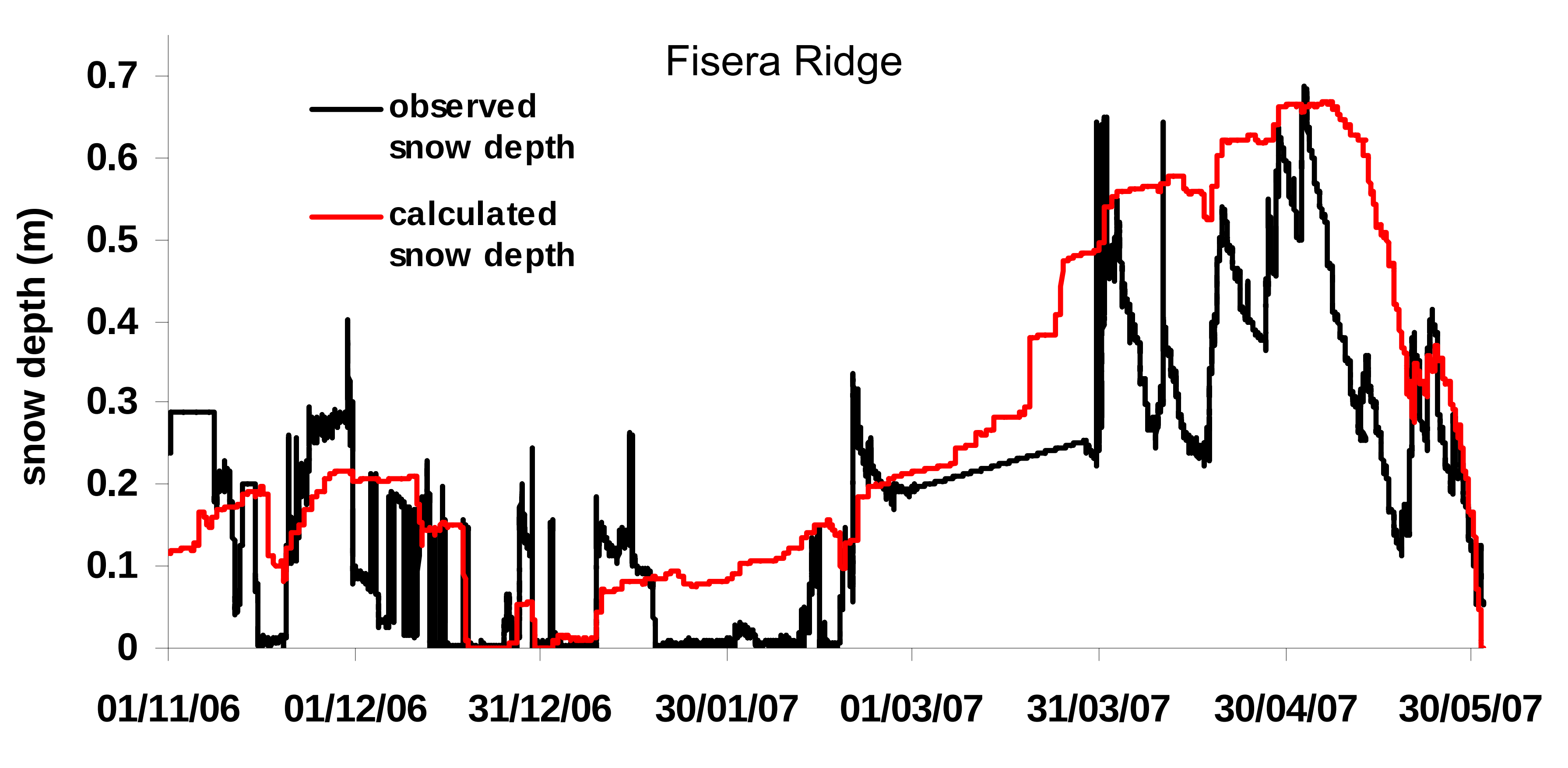
Fisera Ridge, Mt Allan Cirque

- 2318 m
- Alpine Ridge
- Windblown

CRHM for Alpine Terrain



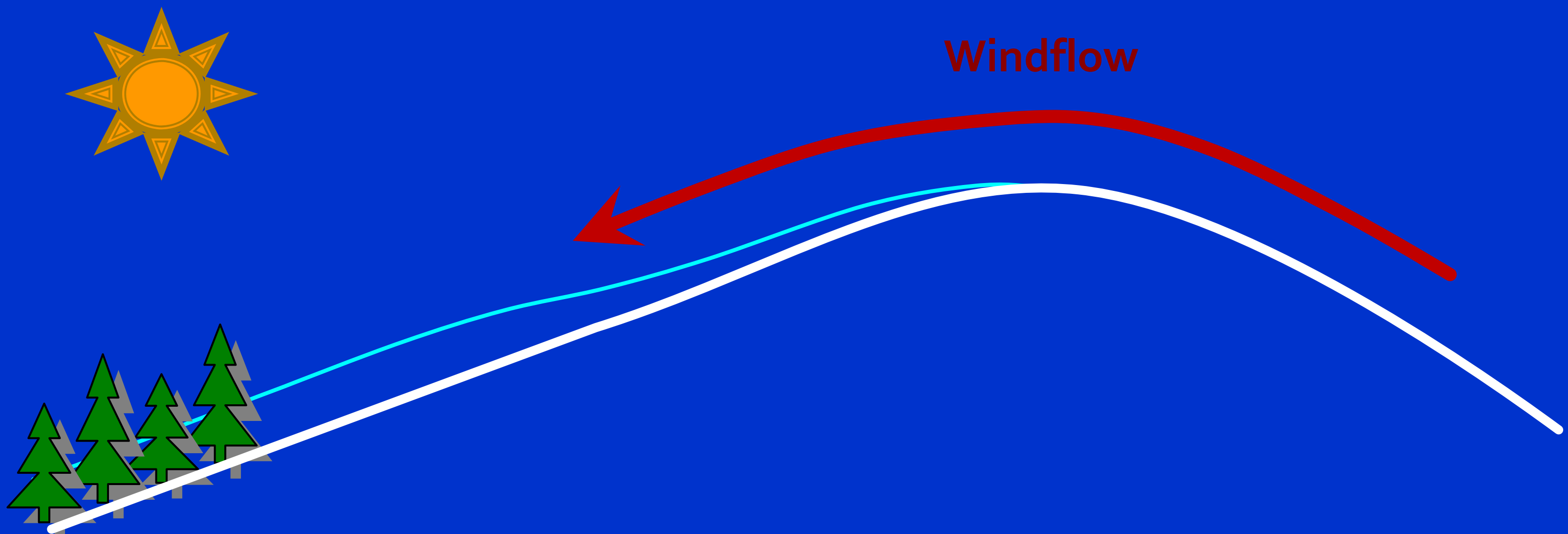
Alpine Ridge Snow Modelling

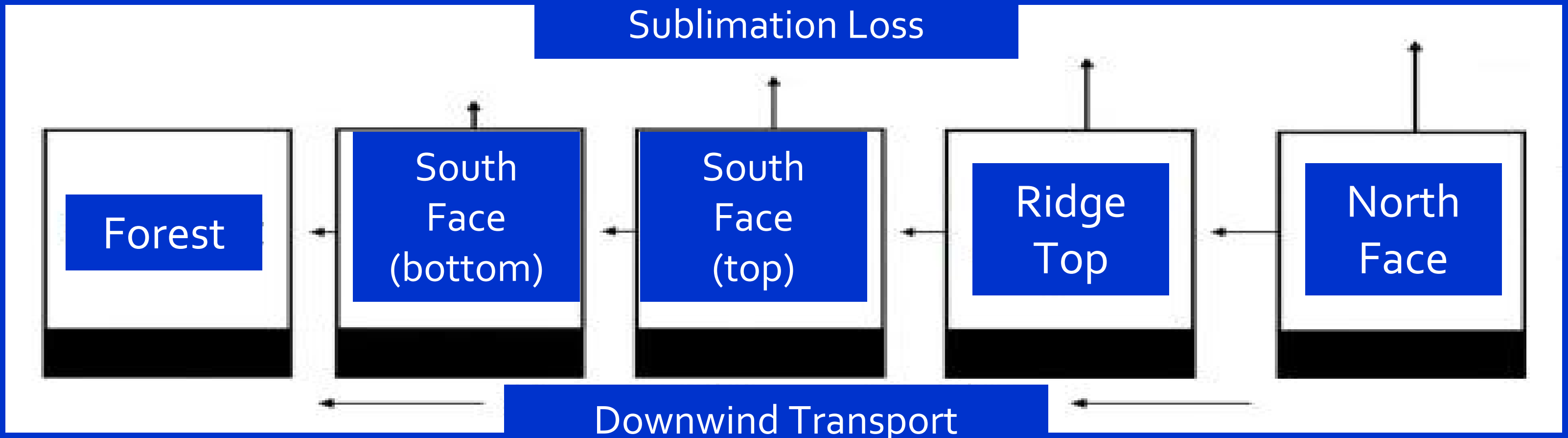


rms error = 0.134 m, mean error = 0.074 m

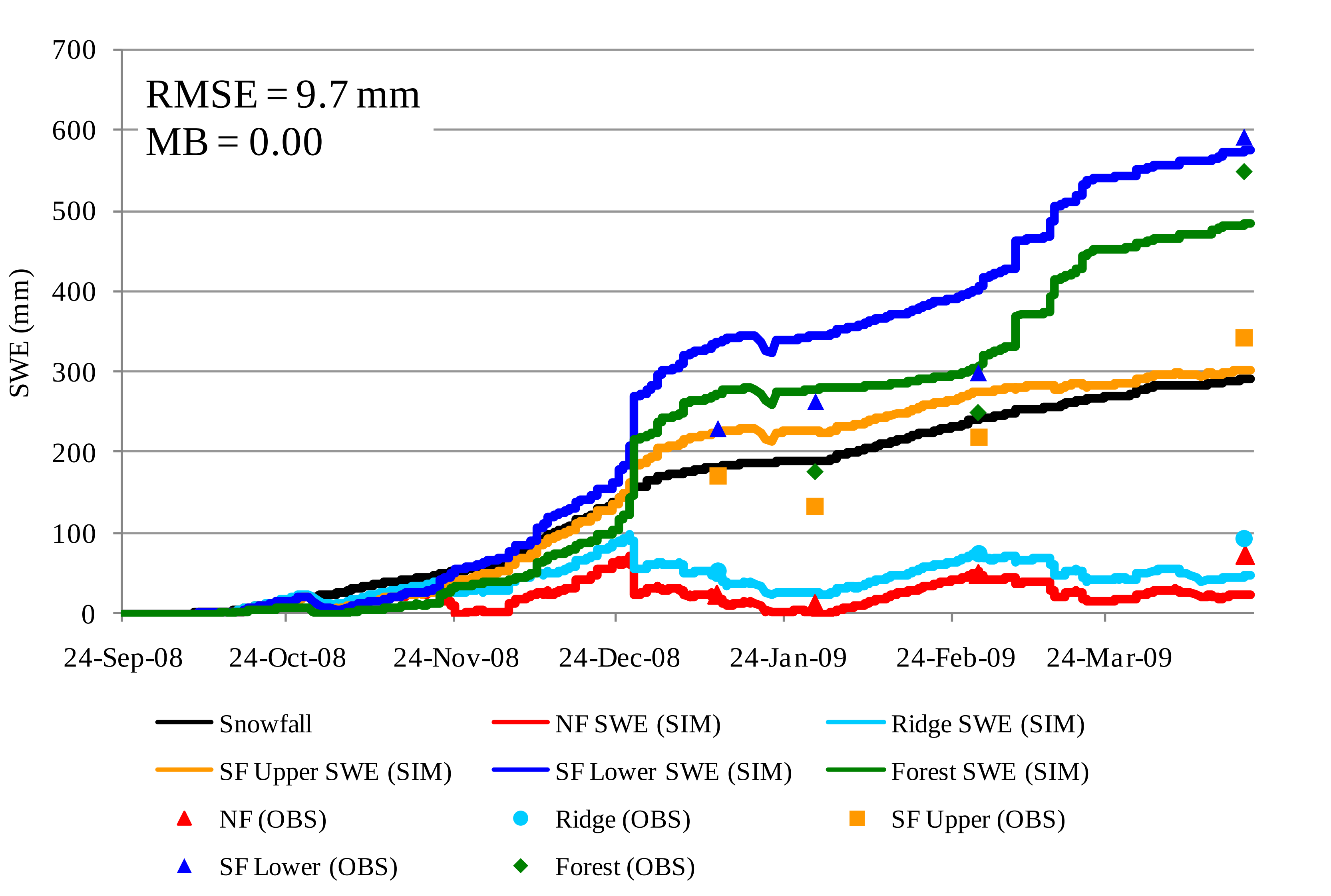
Blowing snow flow parameterisation

- Dominant windflow: north to south
- Flow over ridgetop and into forest

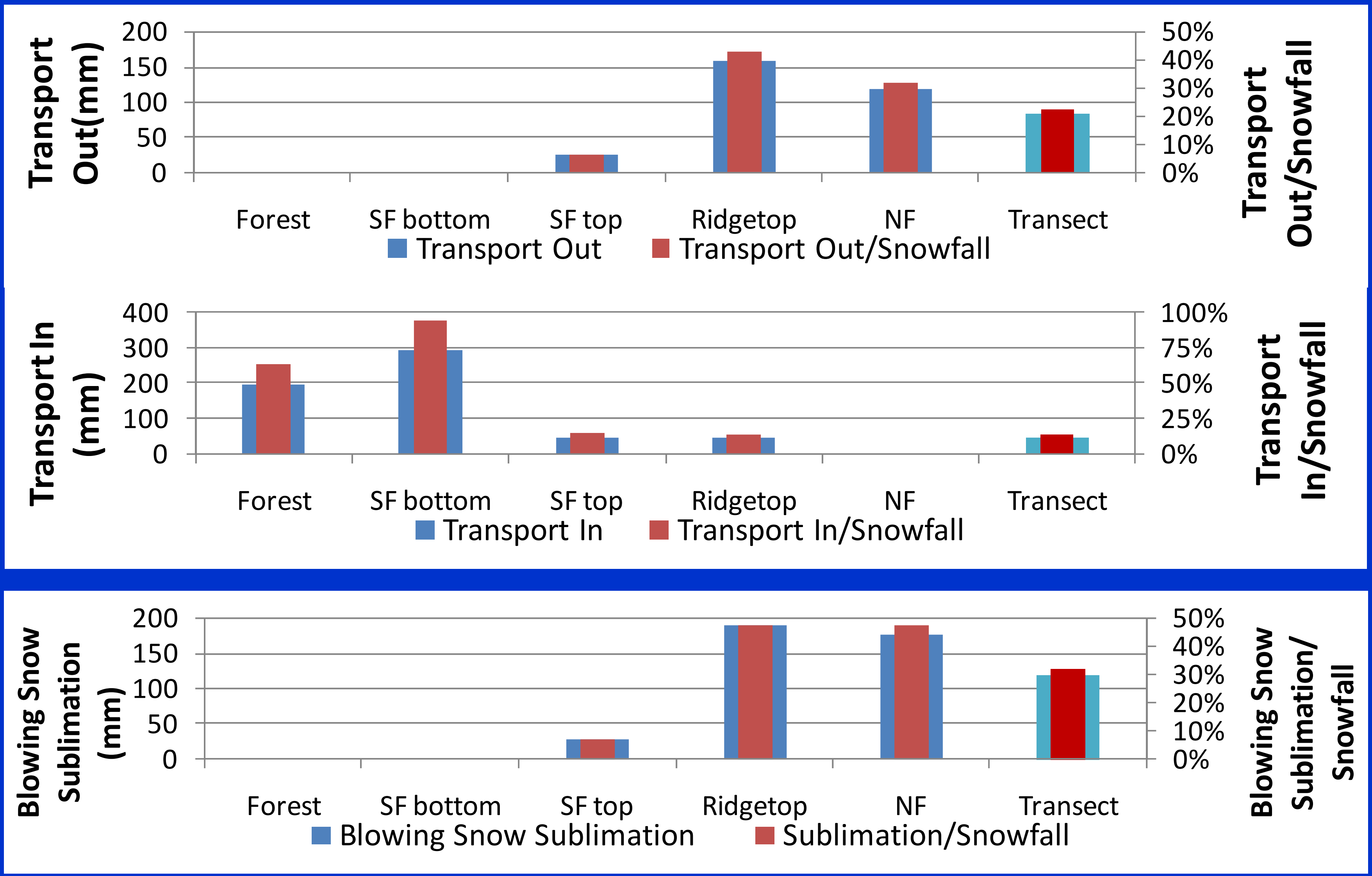




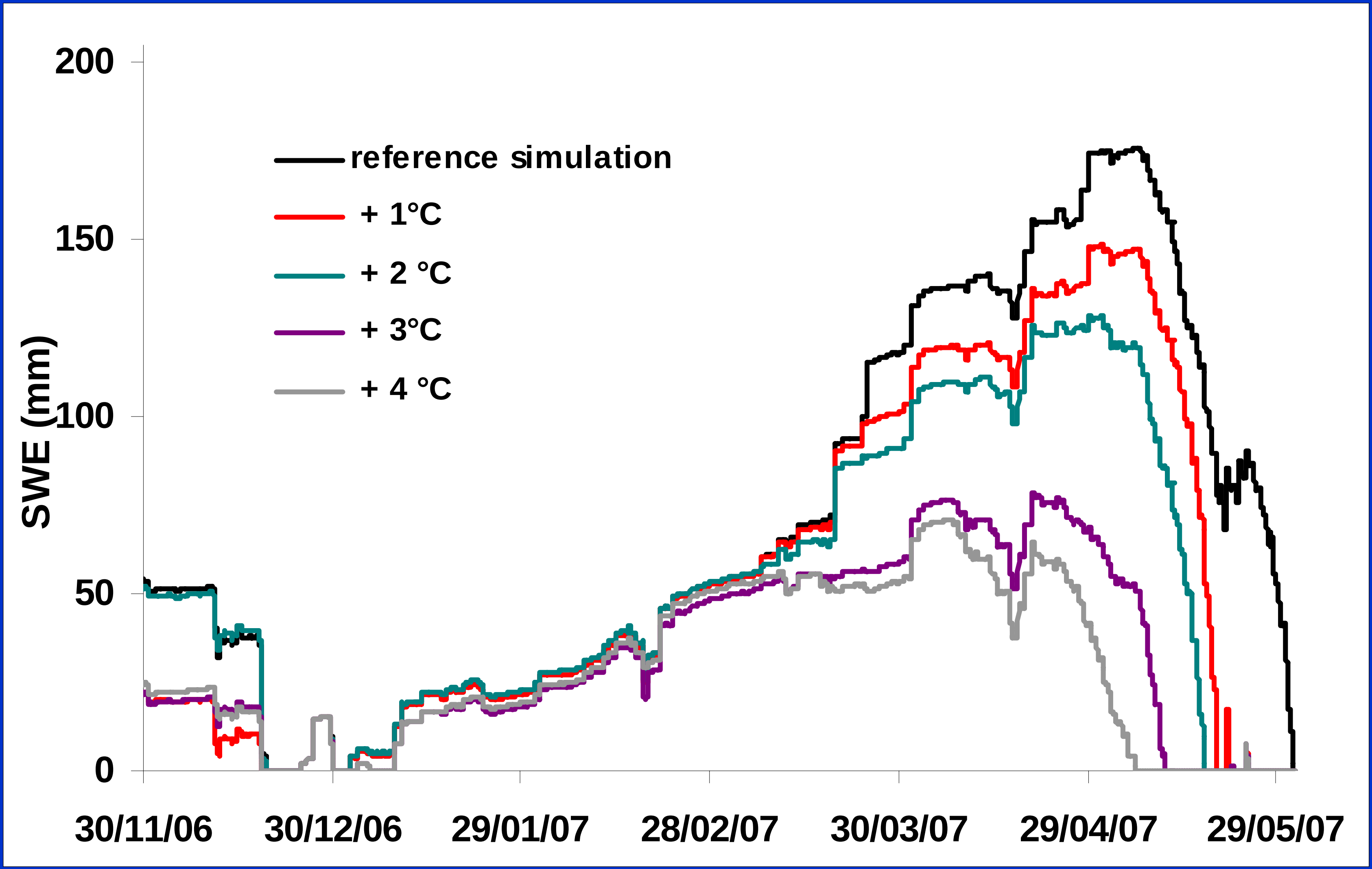
Landscape Units: 2008-2009



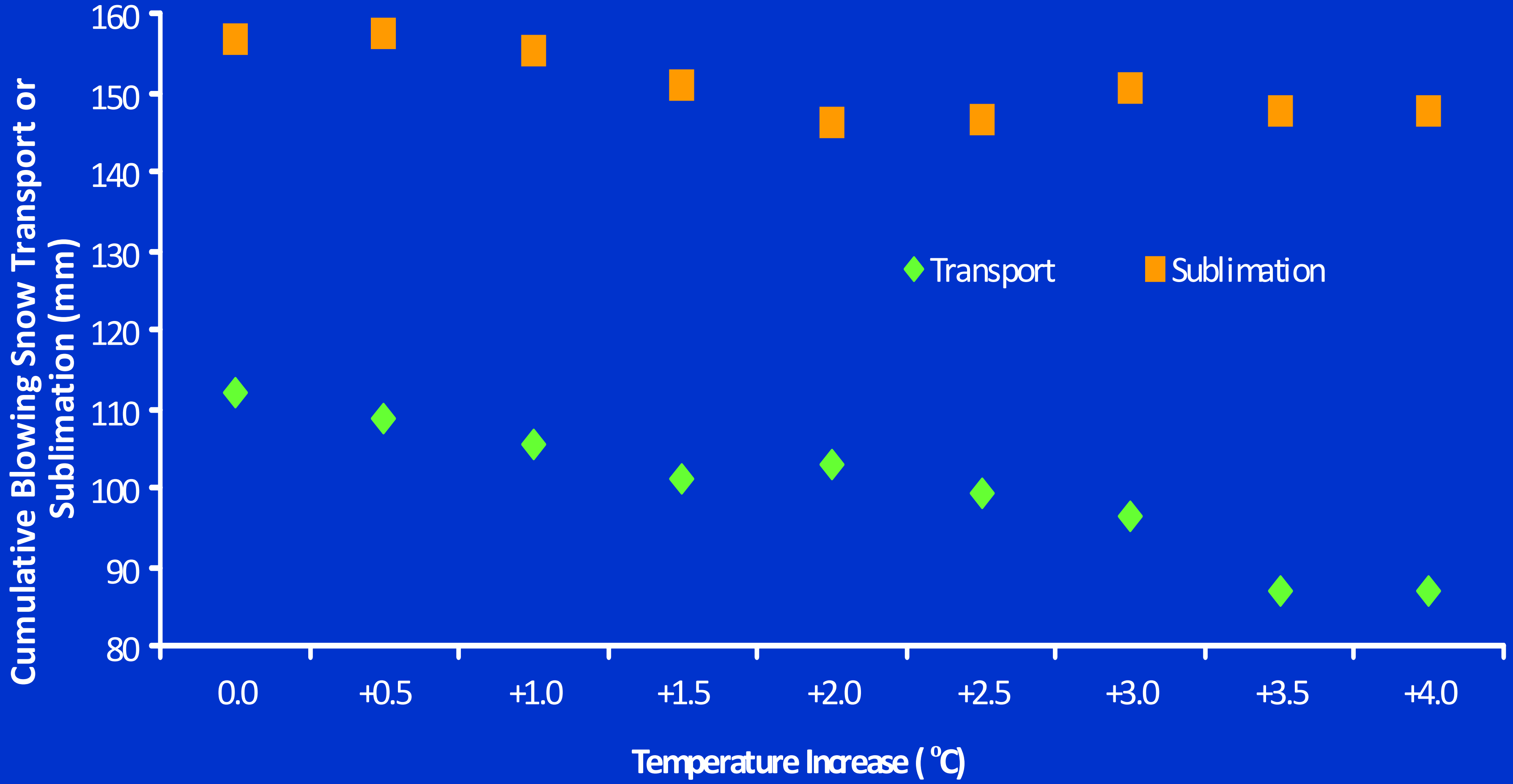
Simulation Summary: 2008/2009



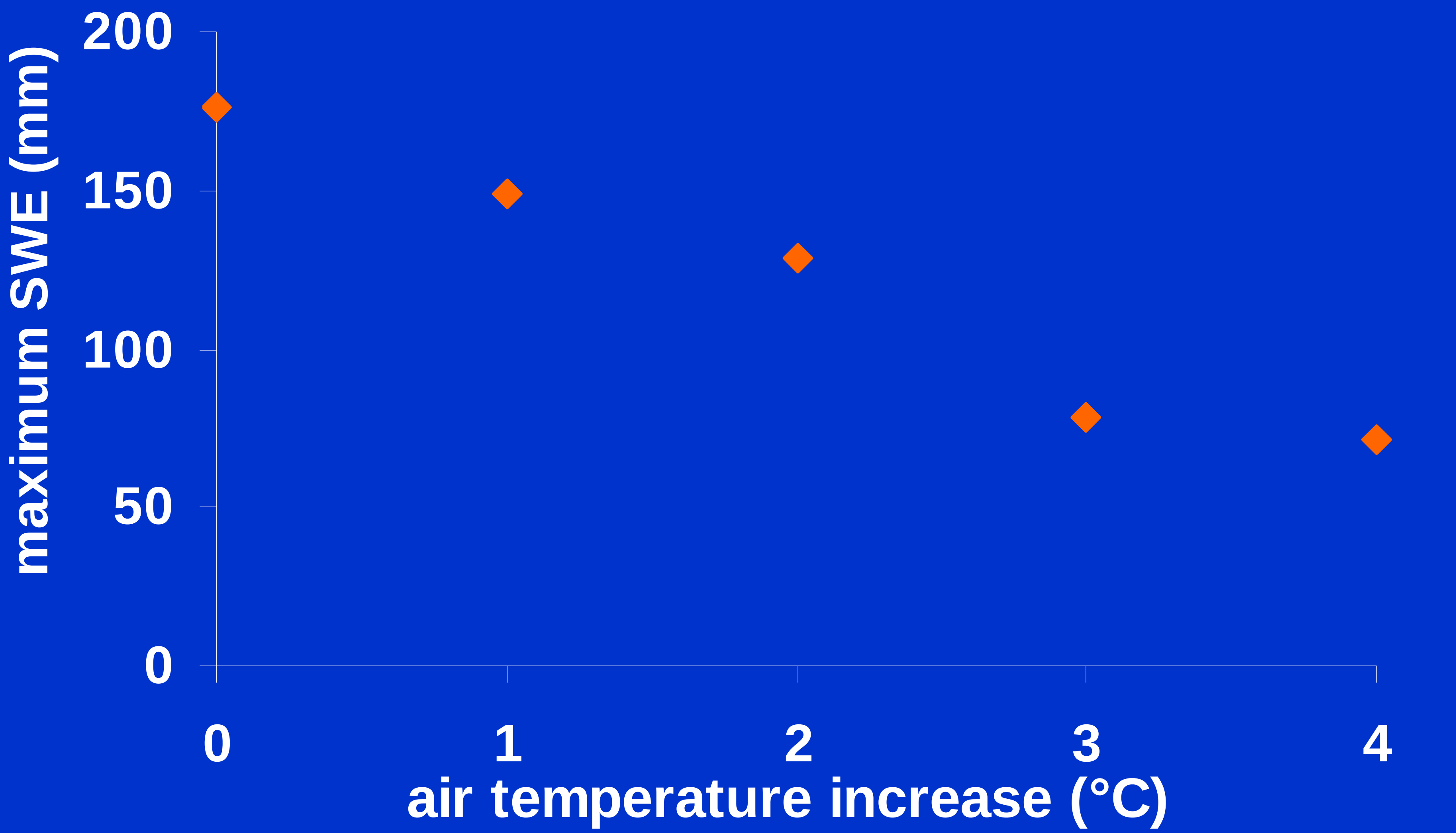
Winter Warming Impact on Alpine Ridge Snow Accumulation



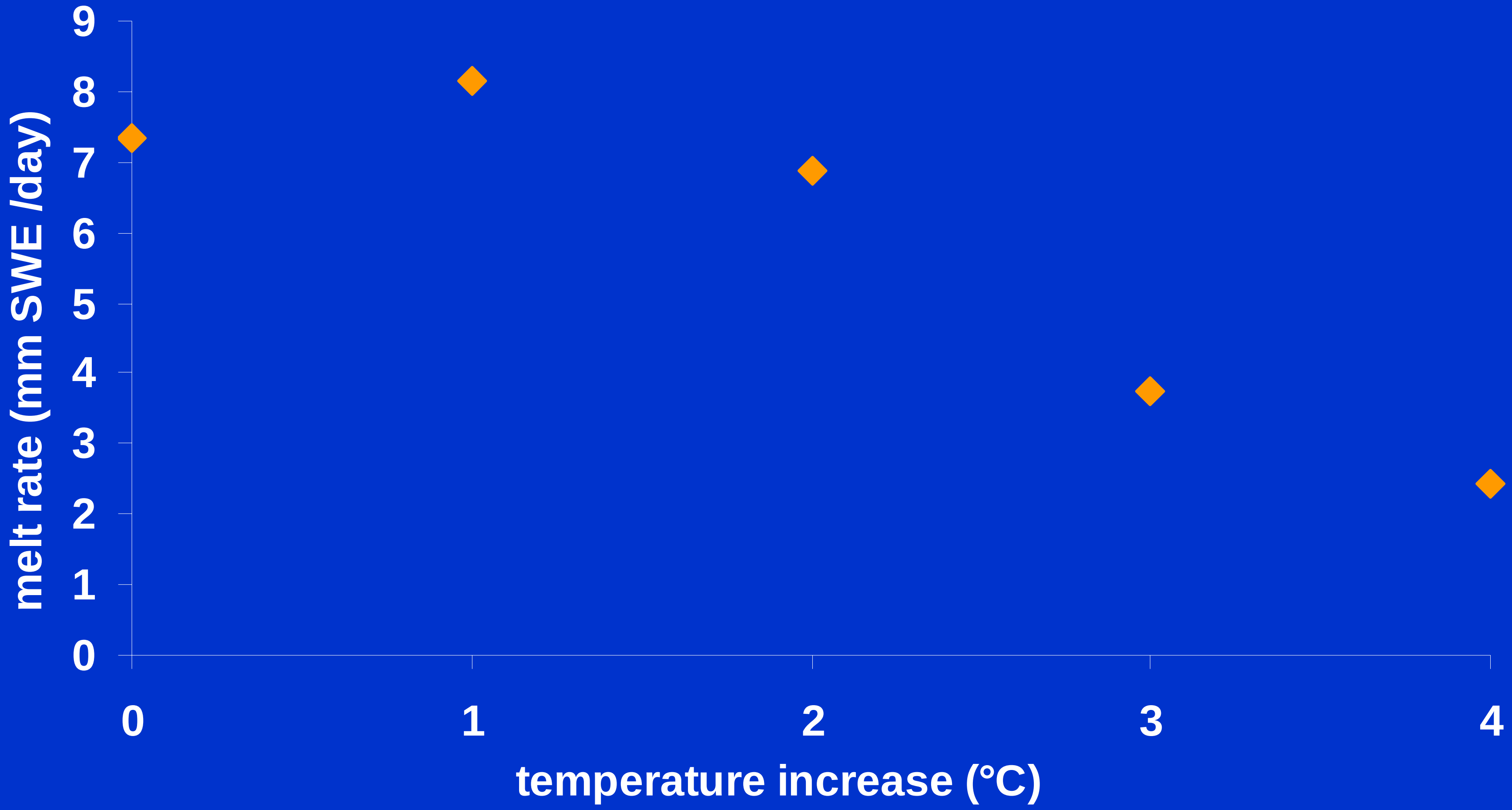
Impact of Warming on Blowing Snow Fluxes



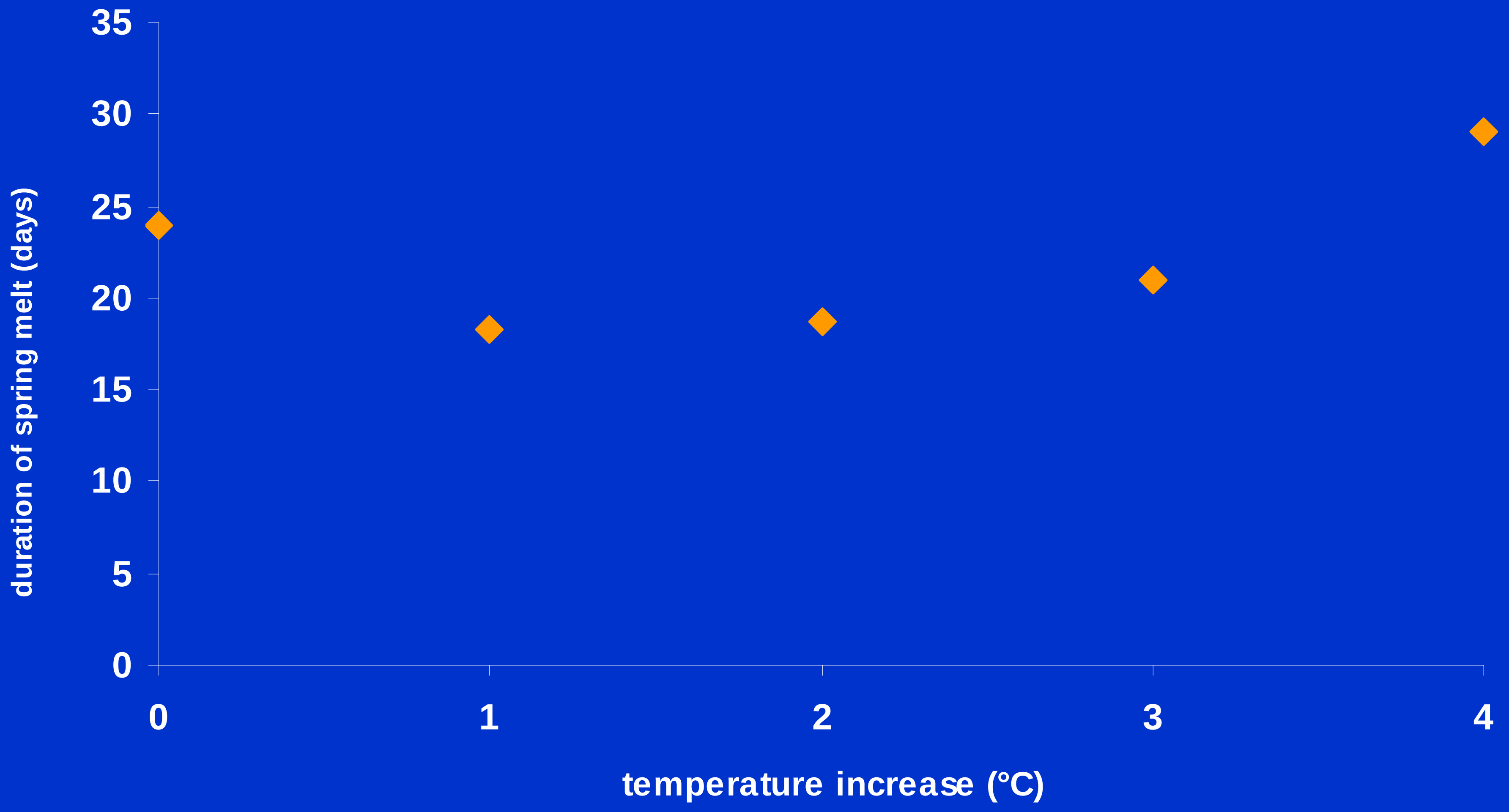
Impact of Winter Warming on Maximum Snow Accumulation



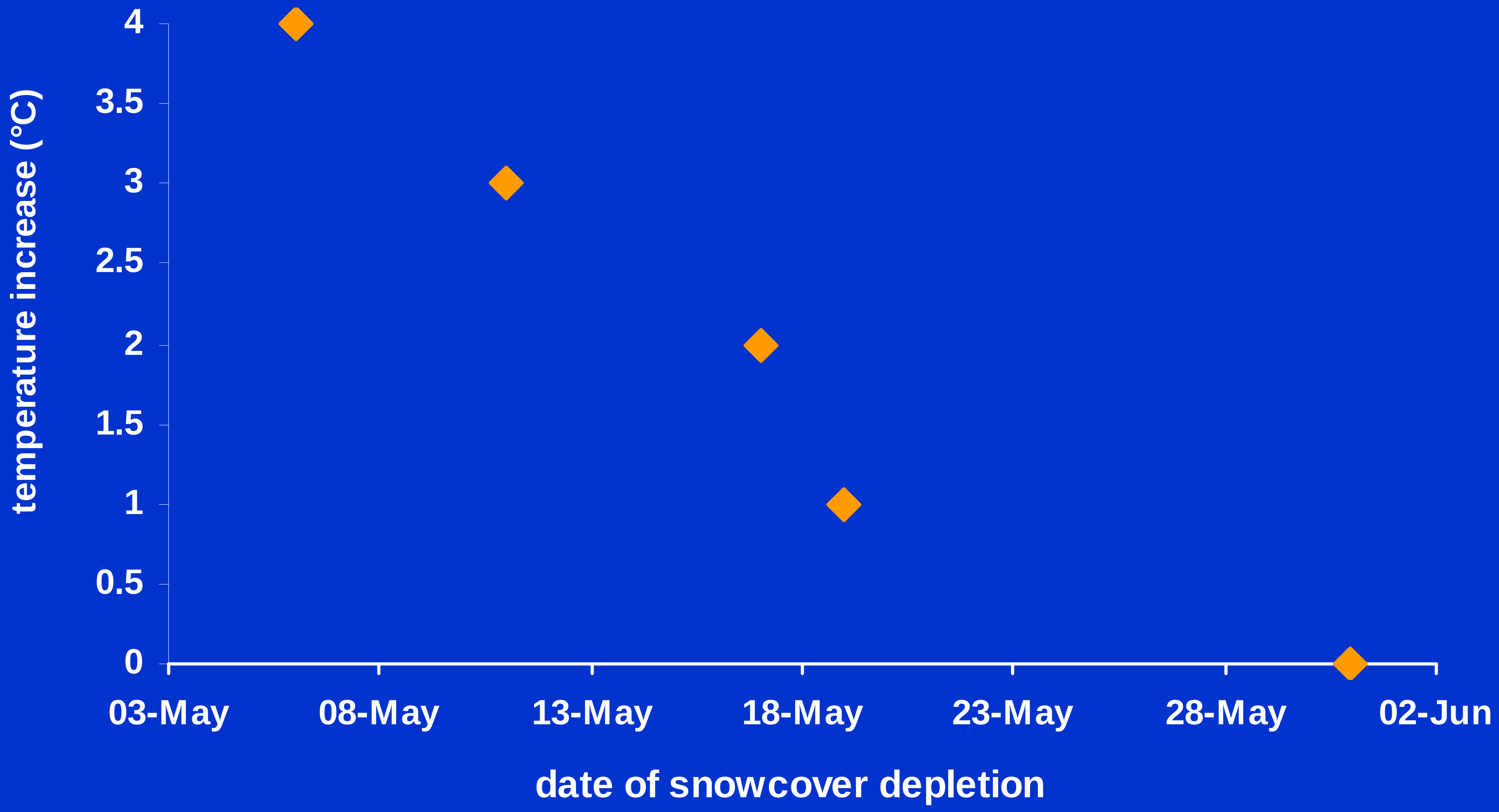
Impact of Winter Warming on Snowmelt Rate



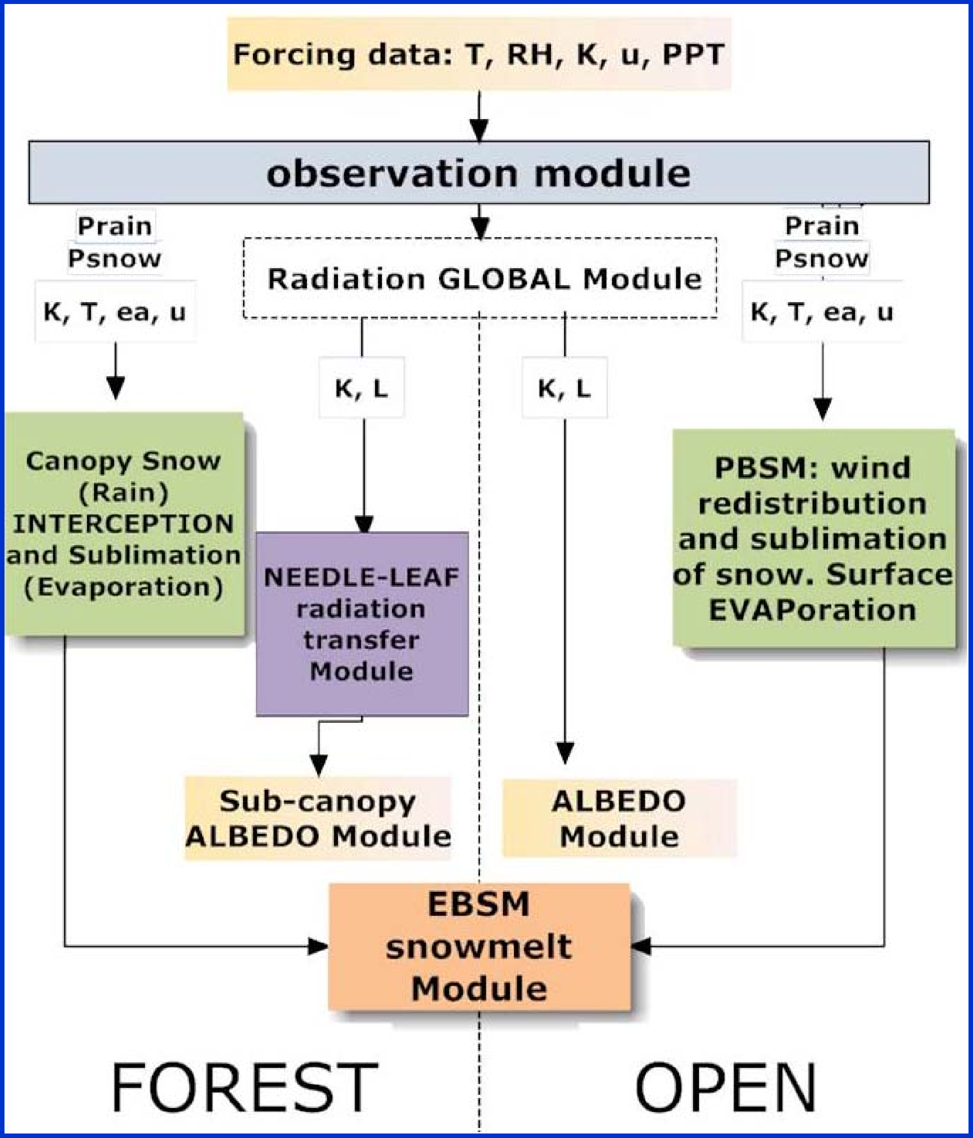
Impact of Winter Warming on Spring Snowmelt Duration



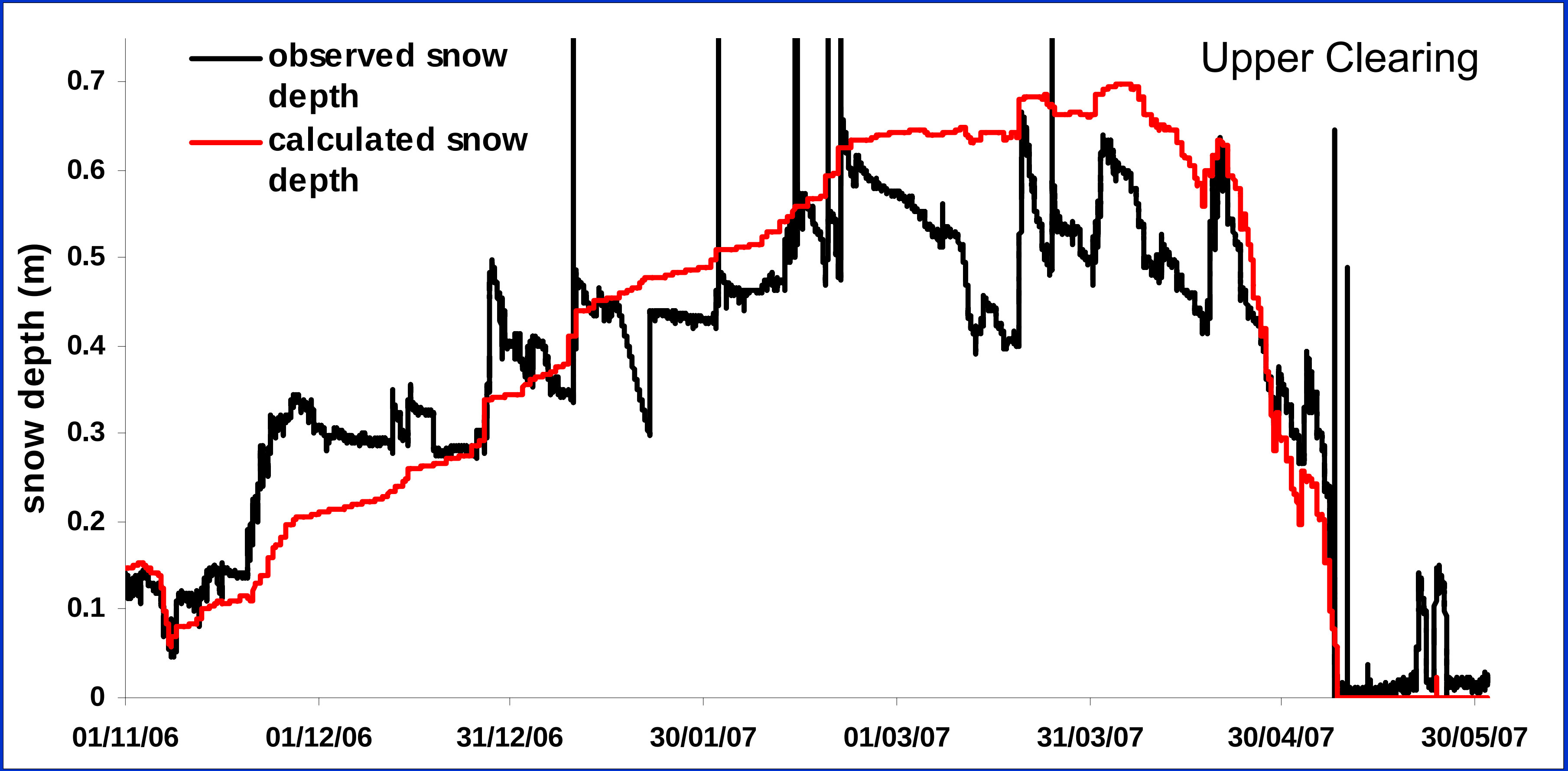
Impact of Winter Warming on Date of Snowpack Depletion



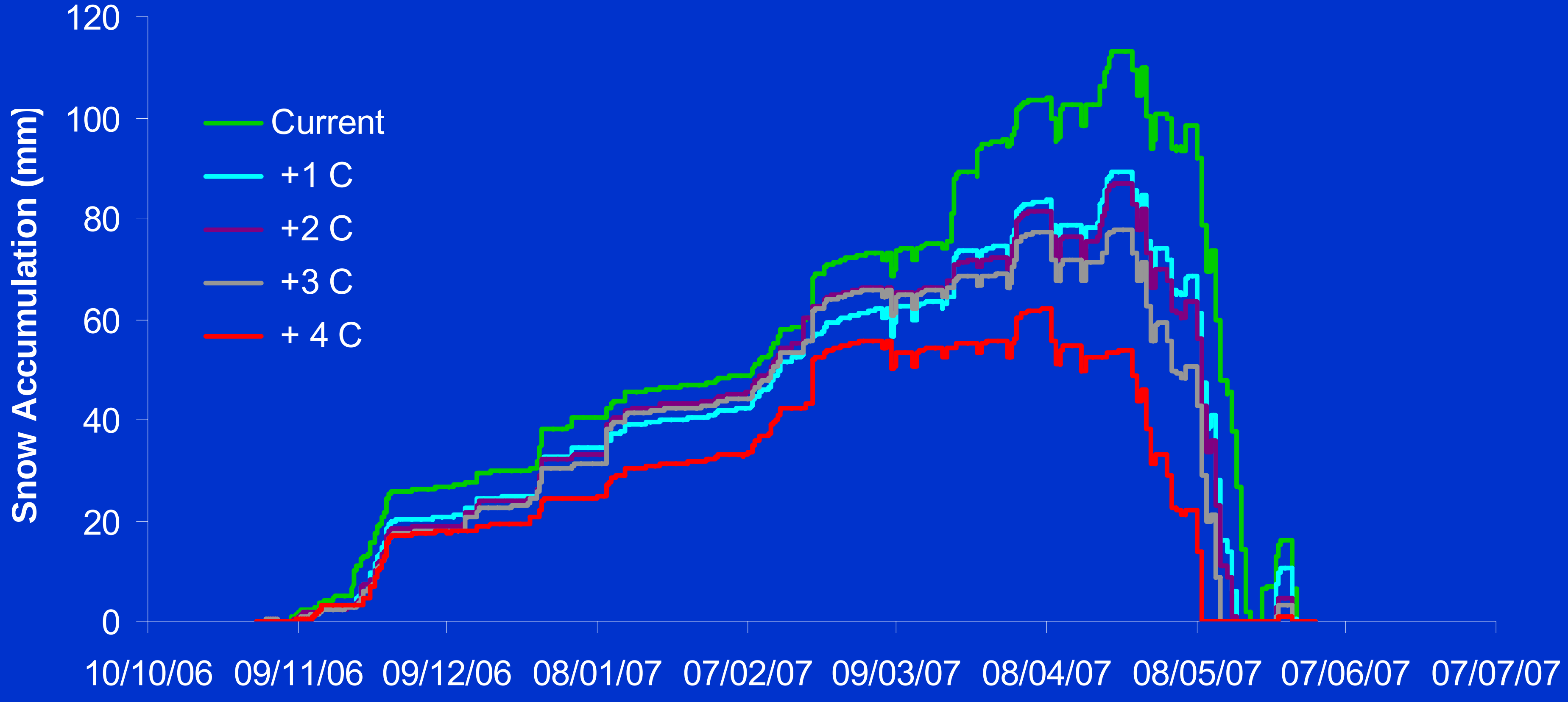
CRHM for Mountain Forests



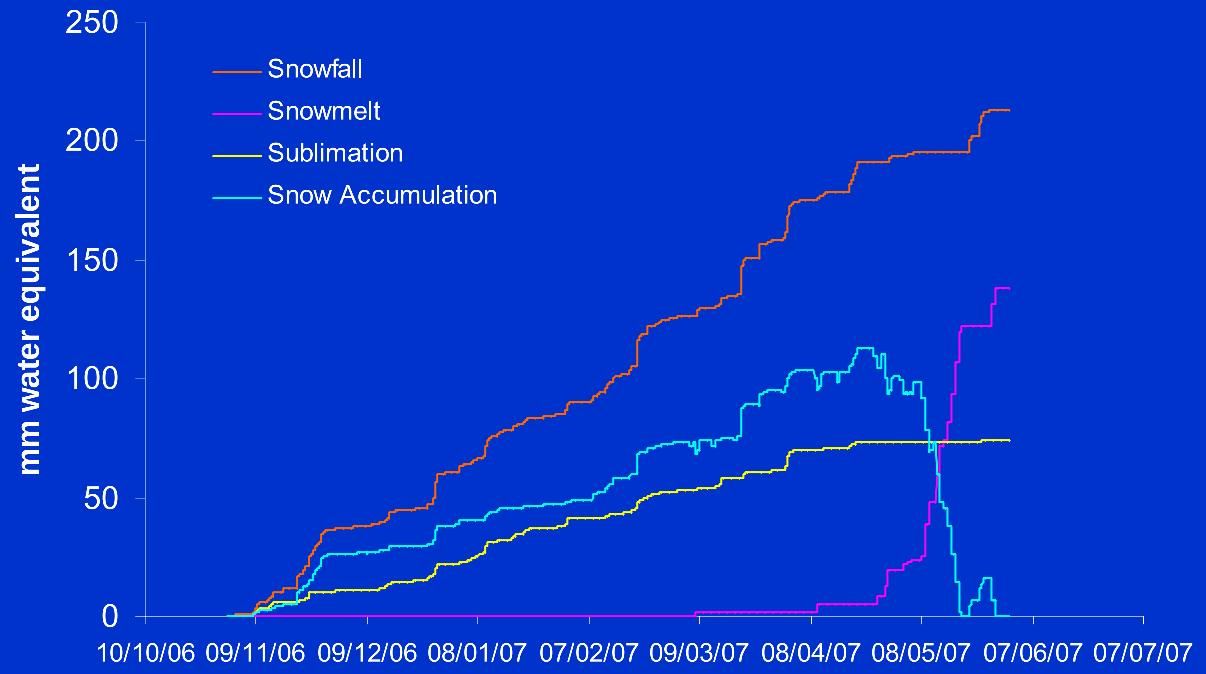
Forest Snow Modelling



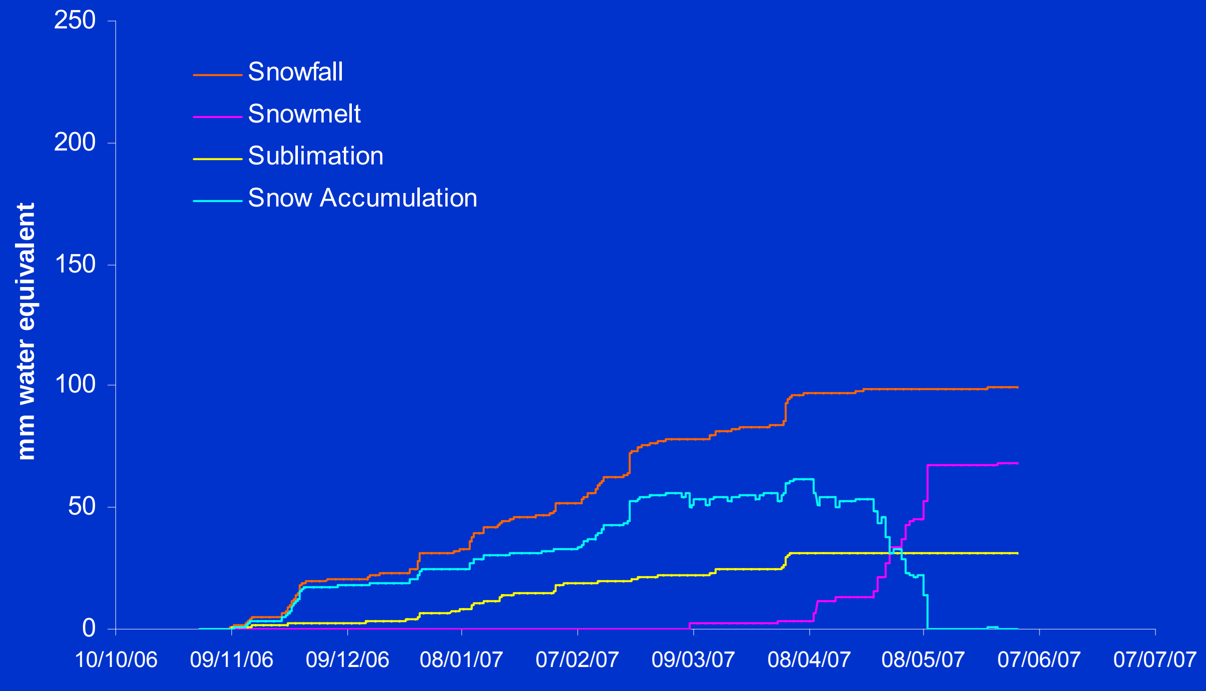
Winter Warming Impact on Mountain Forest Snow Regime



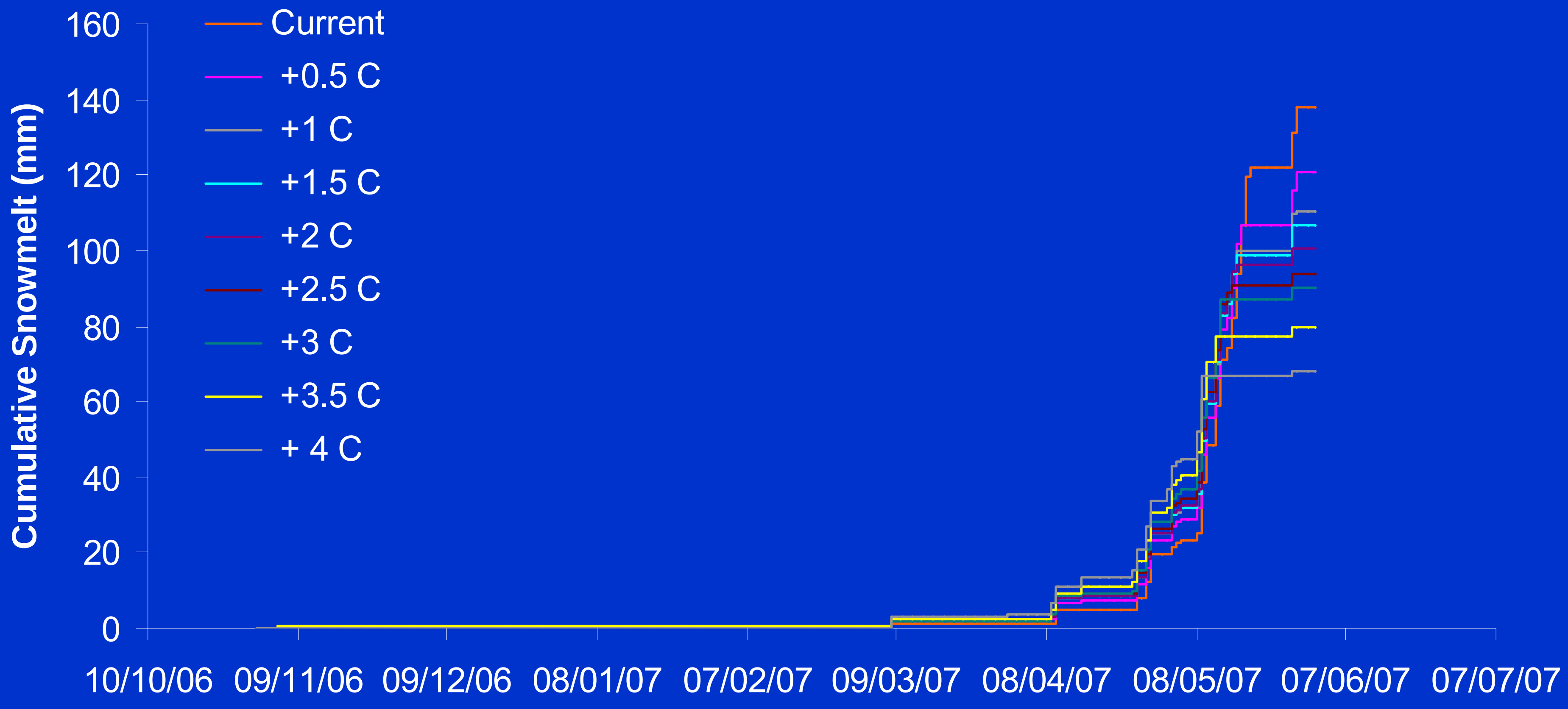
Current Climate
Forest Snow Processes



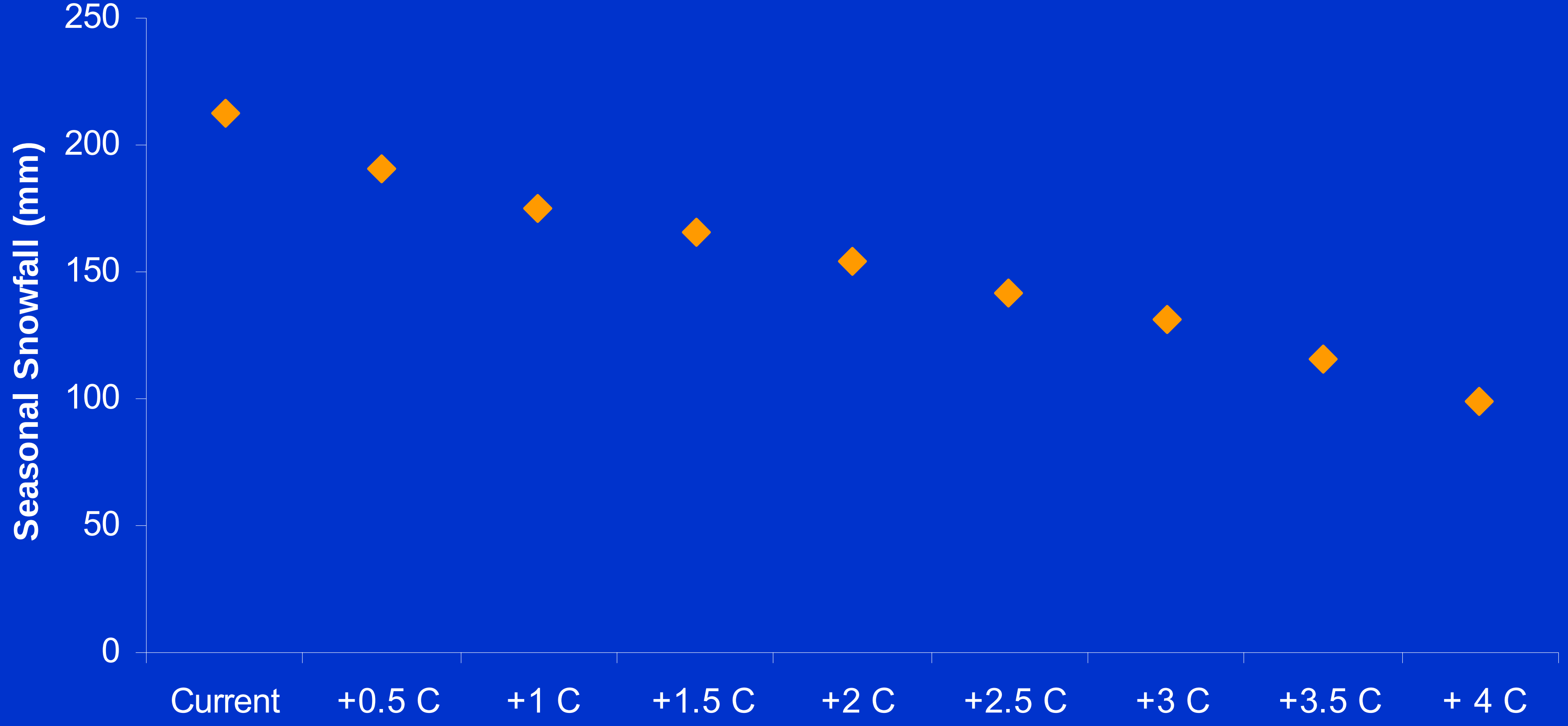
+4 C Climate
Forest Snow Processes



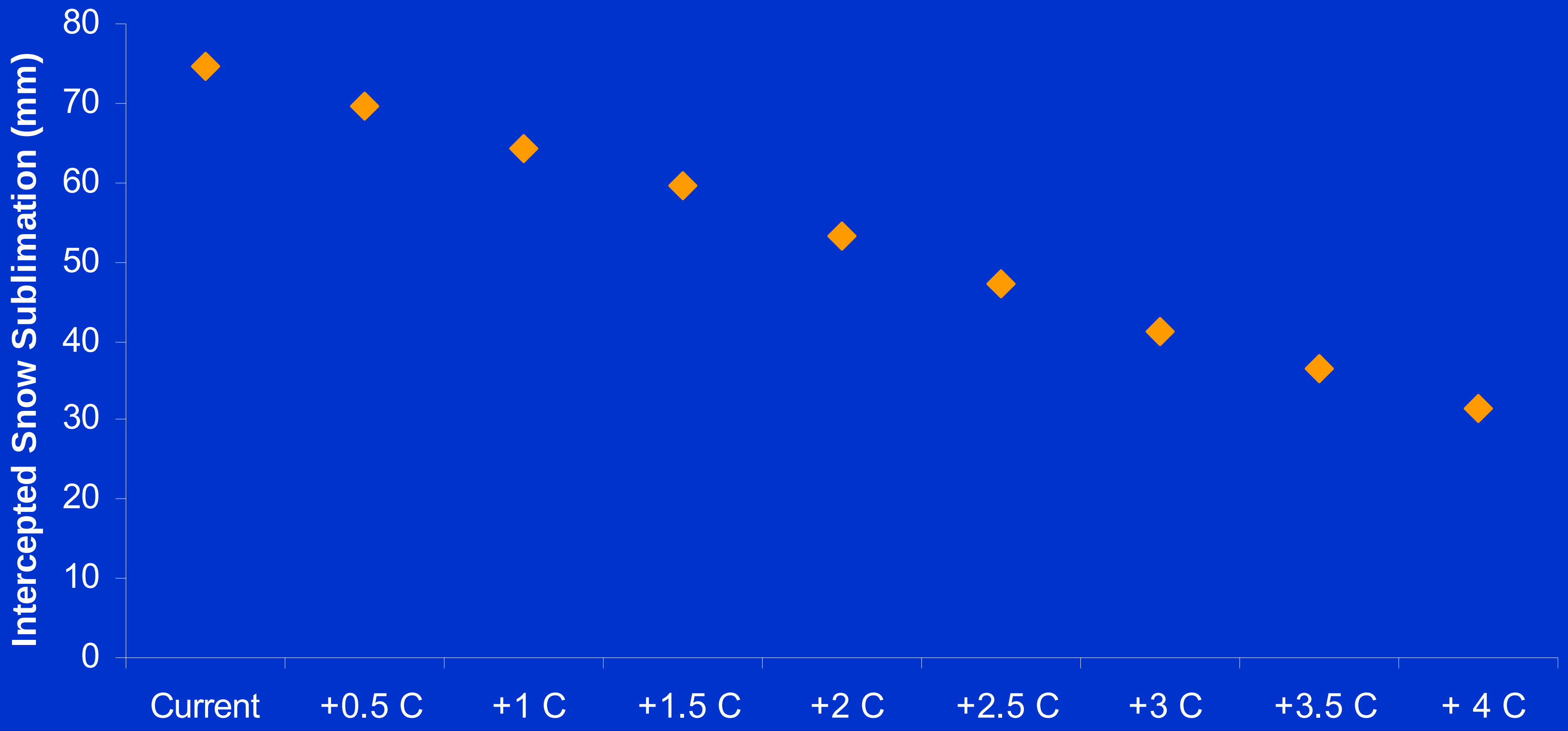
Change in Melt with Temperature



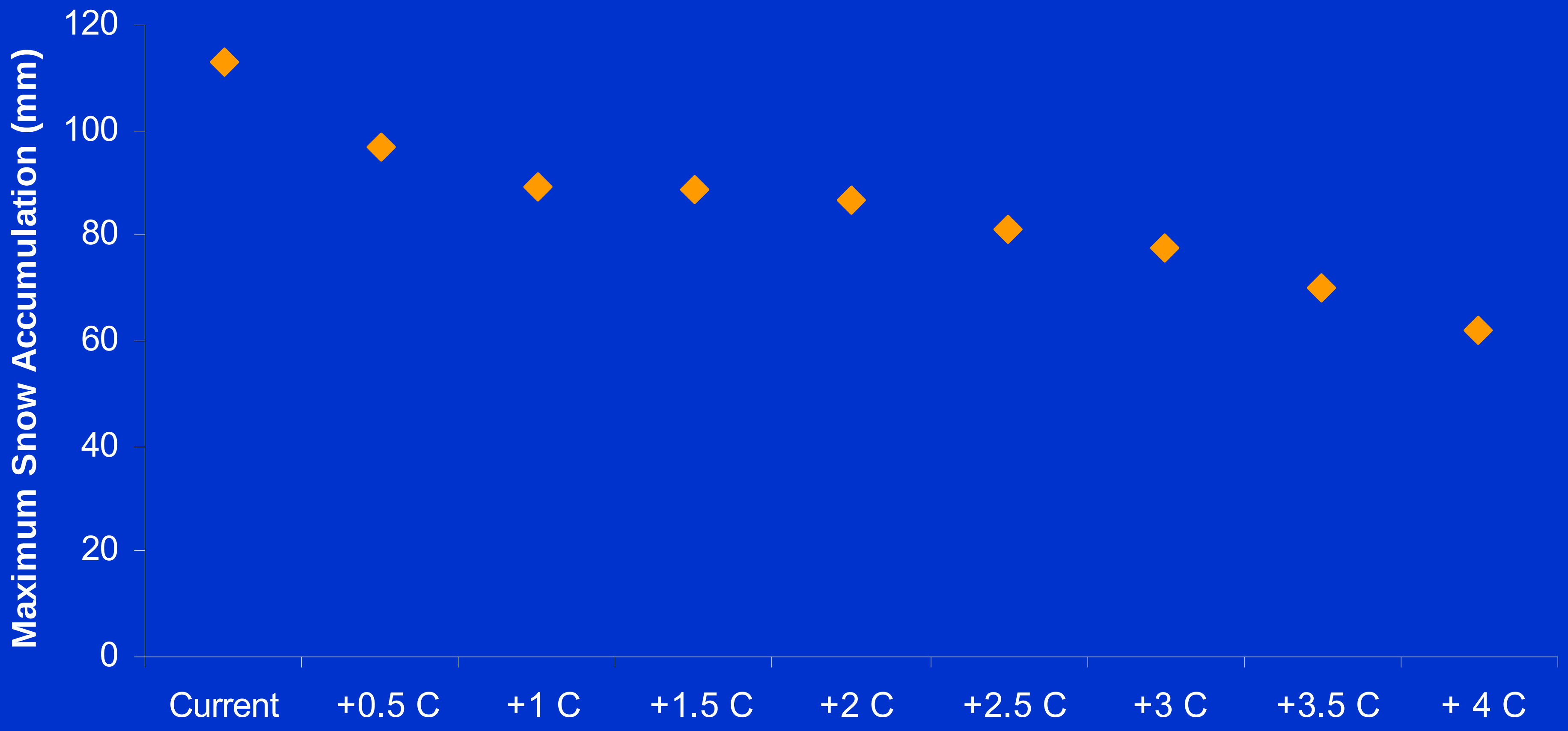
Change in Snowfall with Temperature



Change in Sublimation with Temperature



Change in Maximum Accumulation with Temperature



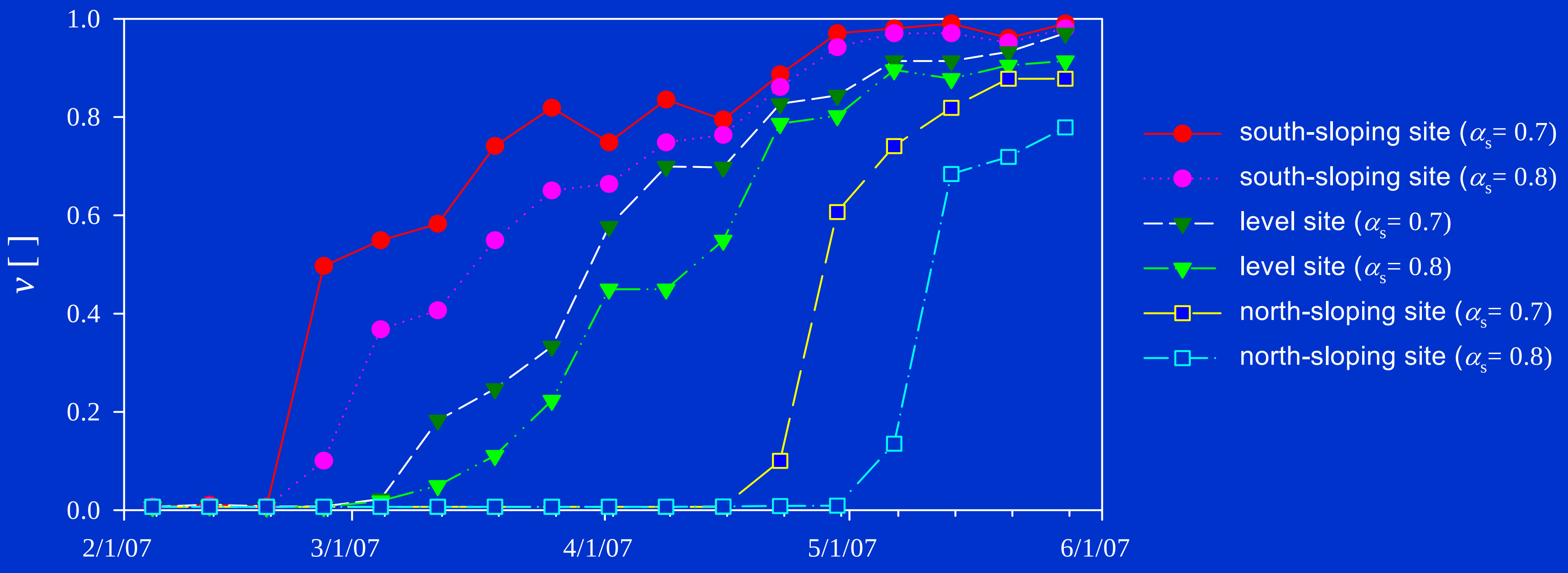
Water Management Implications

- These results show that intact mountain forests have a mitigating effect on some aspects of climate variability and that wind-swept open environments are highly sensitive to climate warming.
- Full consideration of blowing and intercepted snow processes along with energy balance snowmelt calculations must be given for credible climate change impact studies of mountain snow hydrology.

Effects of Forest Cover Change

- Evergreen forest canopy is associated with two primary hydrological effects
  - Snow and rainfall interception and subsequent sublimation and evaporation resulting in reduced sub-canopy snowfall or rainfall,
  - Alteration of sub-canopy radiation and turbulent transfer affecting the snowmelt rate.

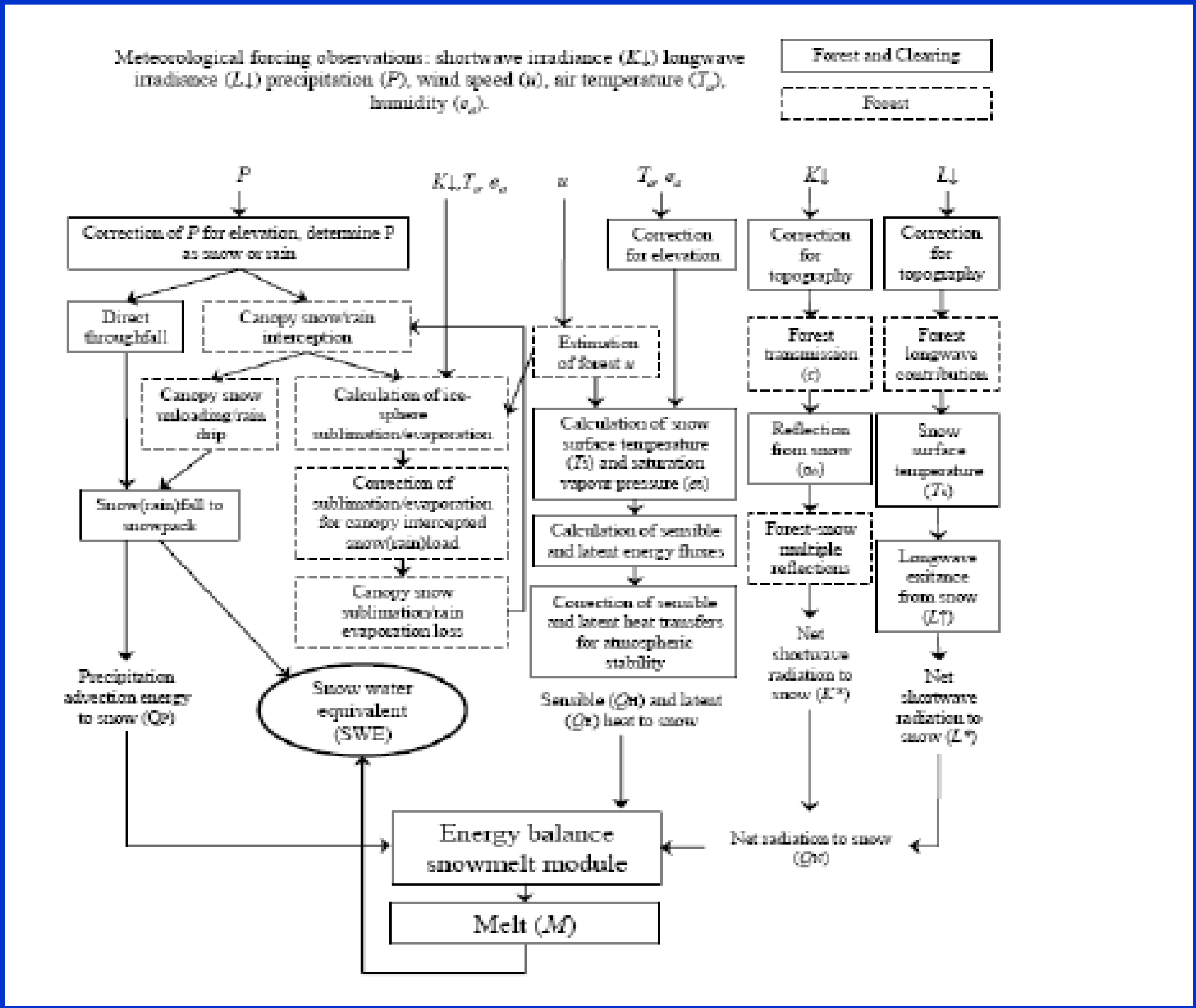
Forest Sky View for Maximum Melt Energy from Net Radiation



There is no simple relationship between forest density and melt rate.
Influence of slope, aspect, solar elevation, weather and albedo are overwhelming.

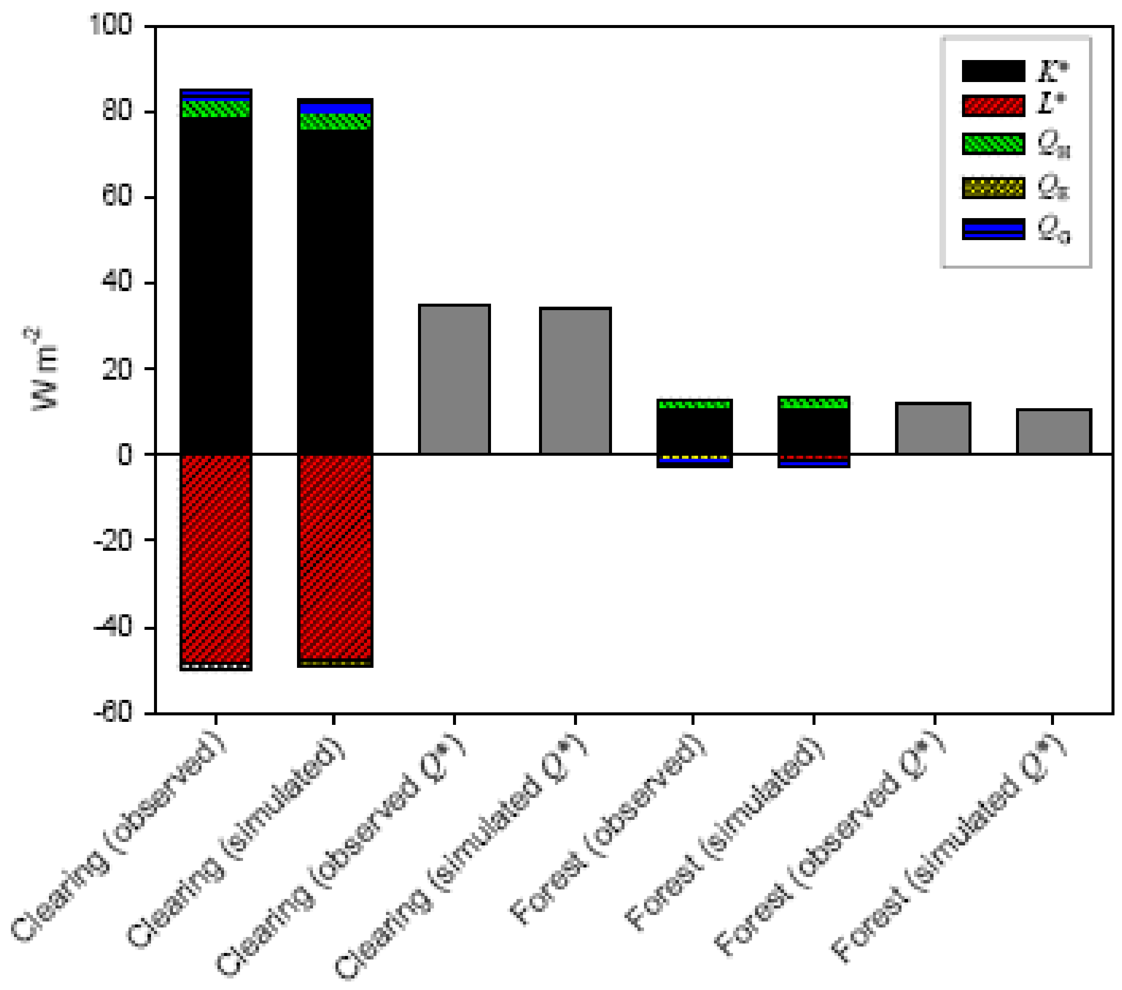
Ellis and Pomeroy, in preparation

CRHM Forest

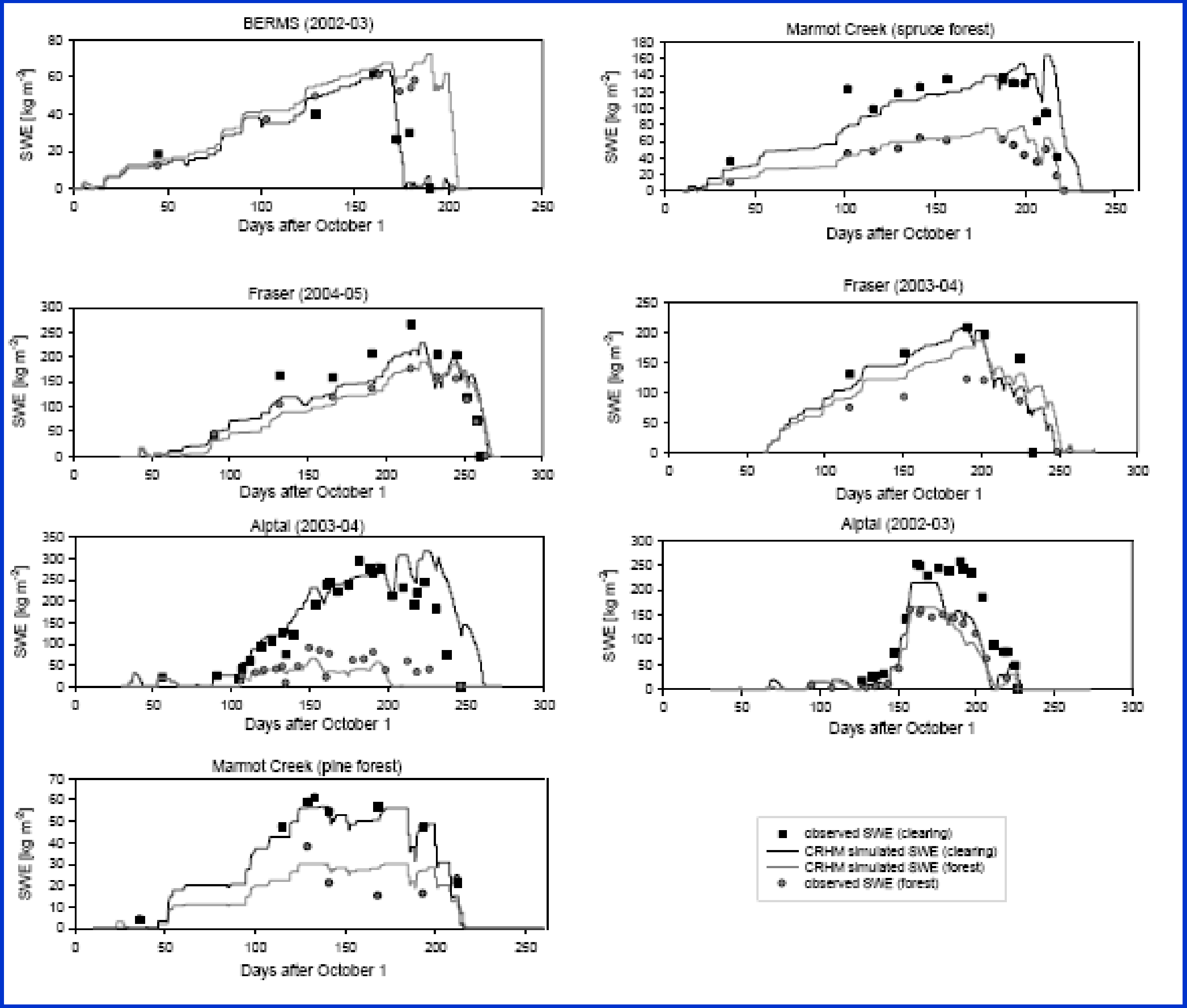


Meteorological forcing observations: shortwave irradiance (K↓) longwave irradiance (L↓) precipitation (P), wind speed (u), air temperature (Ta), humidity (ea).
Forest and Clearing
Forest
P
K↓, Ta, ea
u
Ta, ea
K↓
L↓
Correction of P for elevation, determine P as snow or rain
Correction for elevation
Correction for topography
Correction for topography
Direct throughfall
Canopy snow/rain interception
Estimation of forest u
Forest transmission (τ)
Forest longwave contribution
Canopy snow unloading/rain drip
Calculation of ice-sphere sublimation/evaporation
Calculation of snow surface temperature (Ts) and saturation vapour pressure (es)
Reflection from snow (αs)
Snow surface temperature (Ts)
Snow(rain)fall to snowpack
Correction of sublimation/evaporation for canopy intercepted snow(rain)load
Calculation of sensible and latent energy fluxes
Forest-snow multiple reflections
Longwave exitance from snow (L↑)
Canopy snow sublimation/rain evaporation loss
Correction of sensible and latent heat transfers for atmospheric stability
Net shortwave radiation to snow (K*)
Net shortwave radiation to snow (L*)
Precipitation advection energy to snow (QP)
Snow water equivalent (SWE)
Sensible (QH) and latent (QE) heat to snow
Energy balance snowmelt module
Net radiation to snow (QN)
Melt (M)

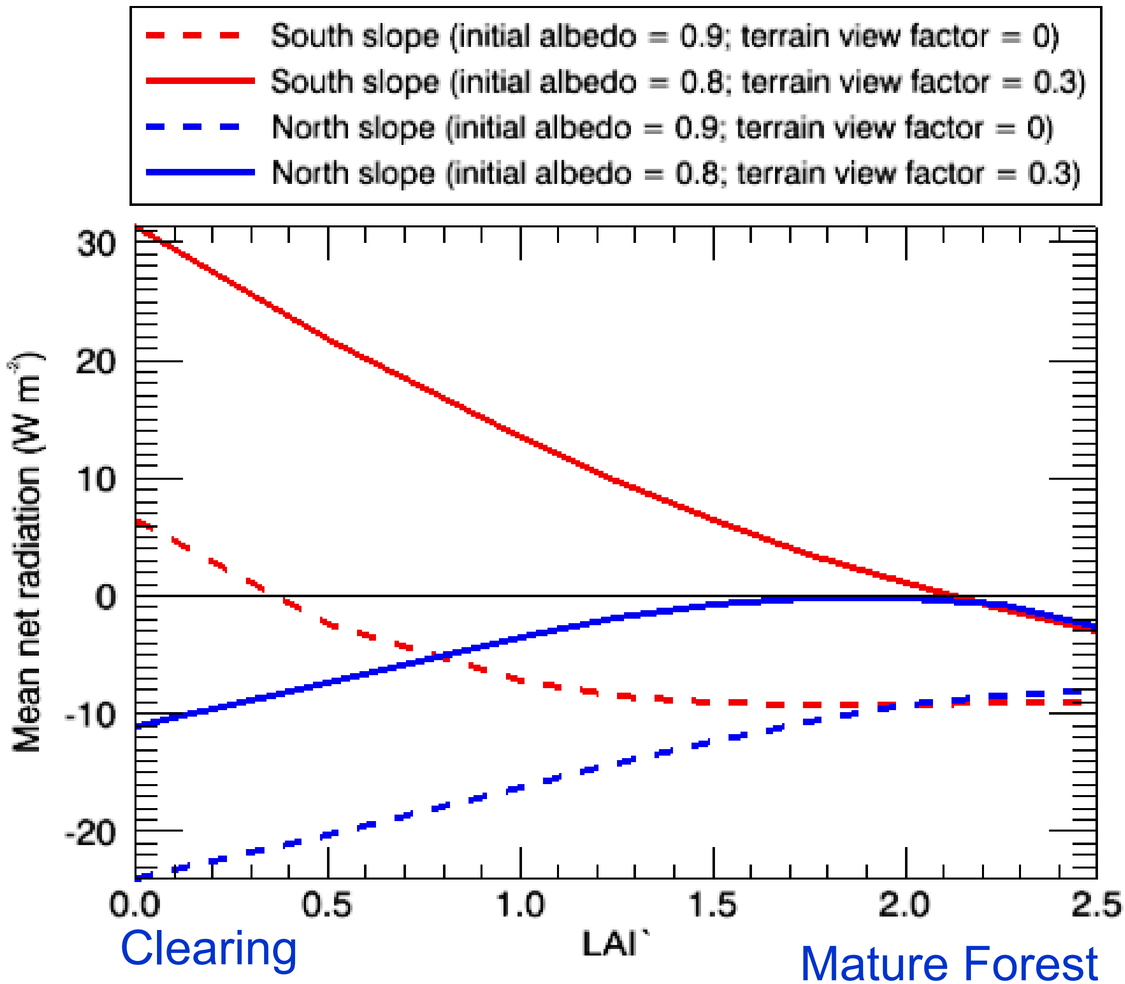
Observed and Modelled Forest Energetics – Marmot Creek



CRHM Forest Tests – Colorado, Switzerland, Alberta



Slope and Forest Density Effect on Net Radiation for Snowmelt - Rockies



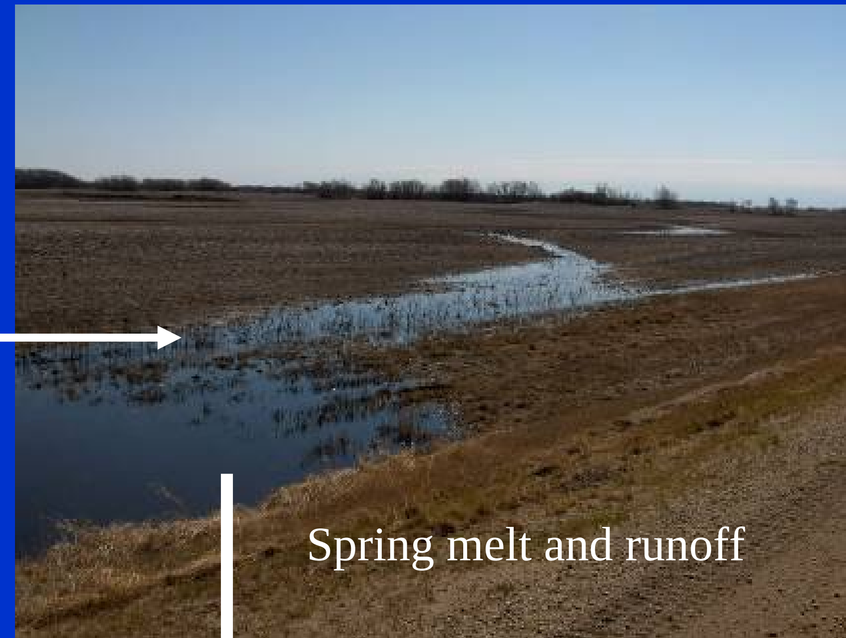
Net radiation = solar + thermal radiation

Ellis & Pomeroy, in preparation

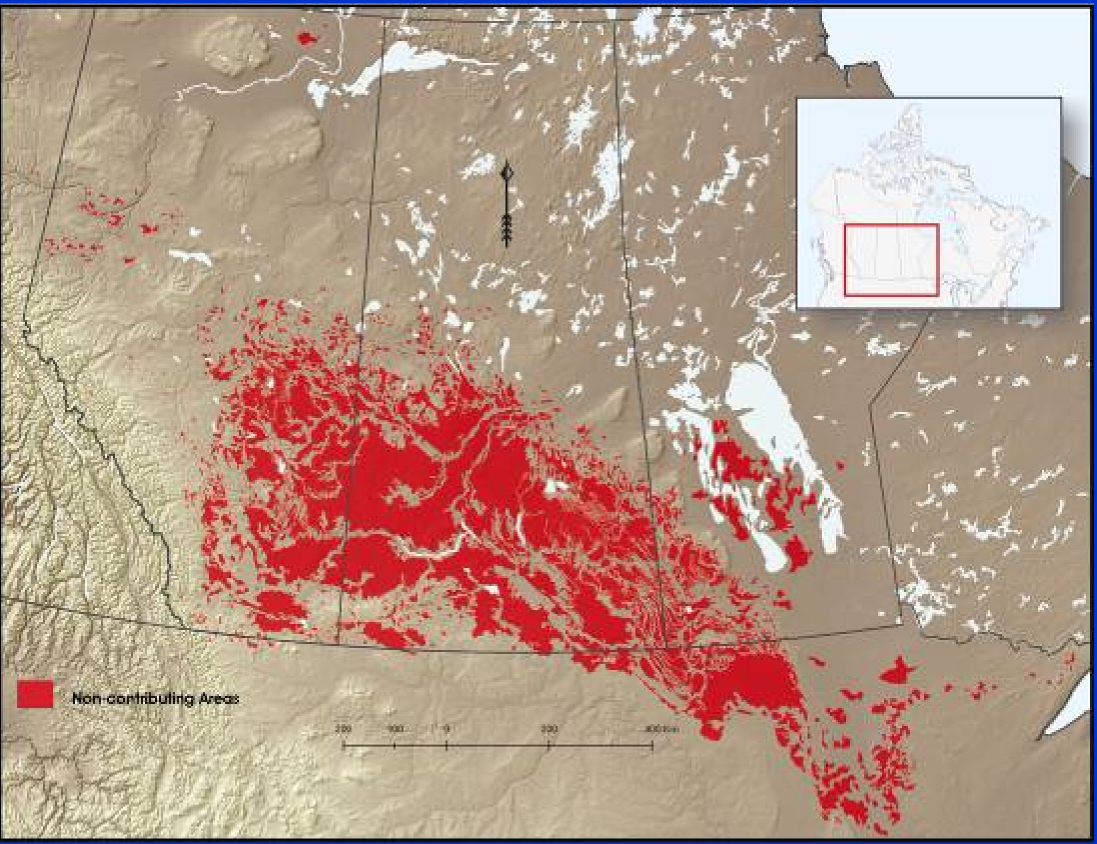
Water Management Implications

- Forest clearing increases snow accumulation
- Forest clearing accelerates snowmelt rates on south facing slopes and level sites, BUT
- Forest clearing reduces snowmelt rates on north facing slopes

Prairie Runoff Generation



PRAIRIE HYDROLOGY – Limited Contributing Areas for Streamflow



Non-contributing areas for streamflow extensive in Canadian Prairies

Localized hydrology affected by poor drainage, storage in small depressions

Modelling Prairie Hydrology

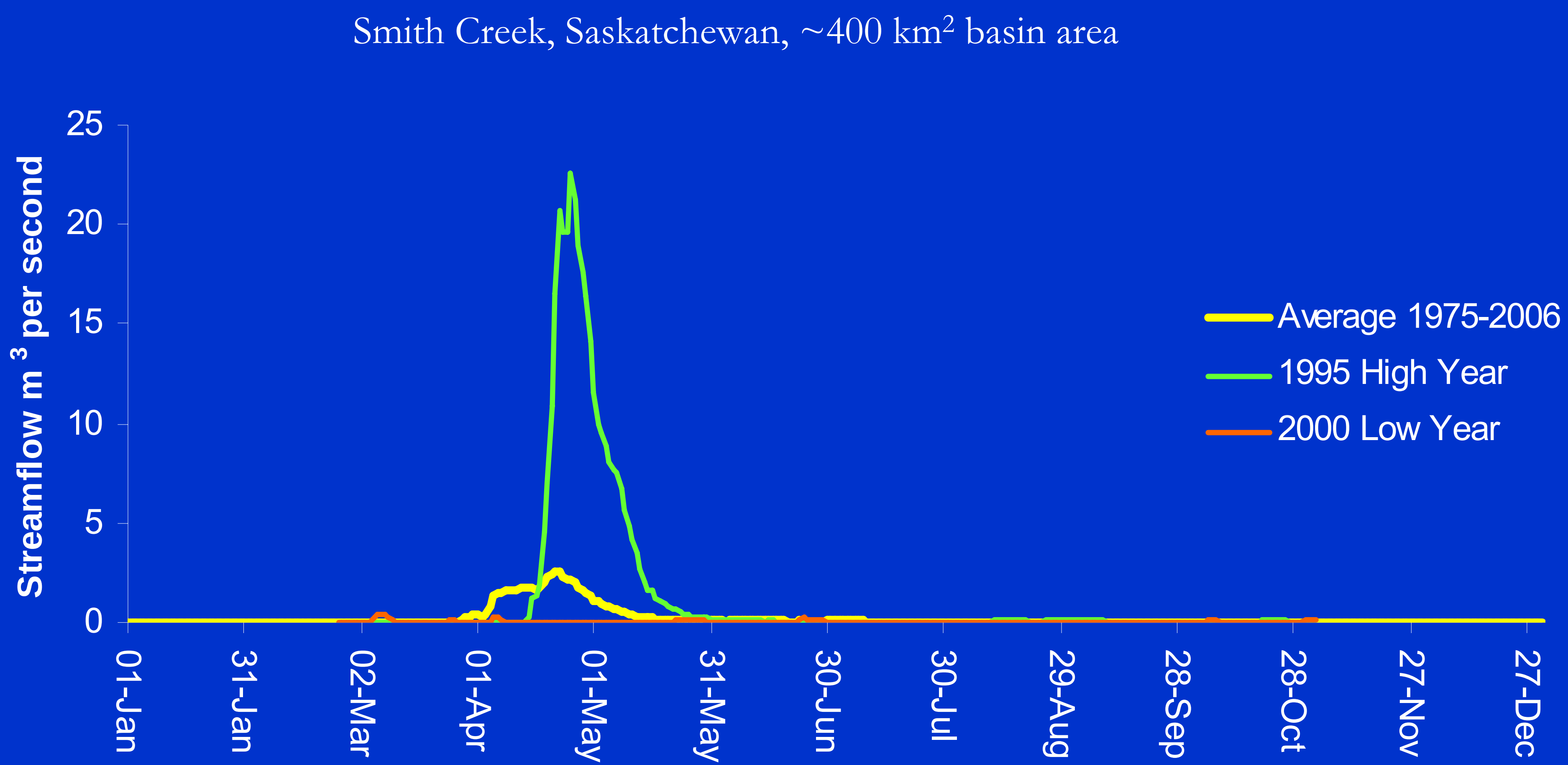
- Need a physical basis to calculate the effects of changing climate, land use, wetland drainage
- Need to incorporate key prairie hydrology processes: snow redistribution, frozen soils, spring runoff, wetland fill and spill, non-contributing areas
- Frustration that hydrological models developed elsewhere do not have these features and fail in this environment
- Streamflow calibration does not provide information on basin non-contributing areas and is not suitable for change analysis

Smith Creek Hydrology Study

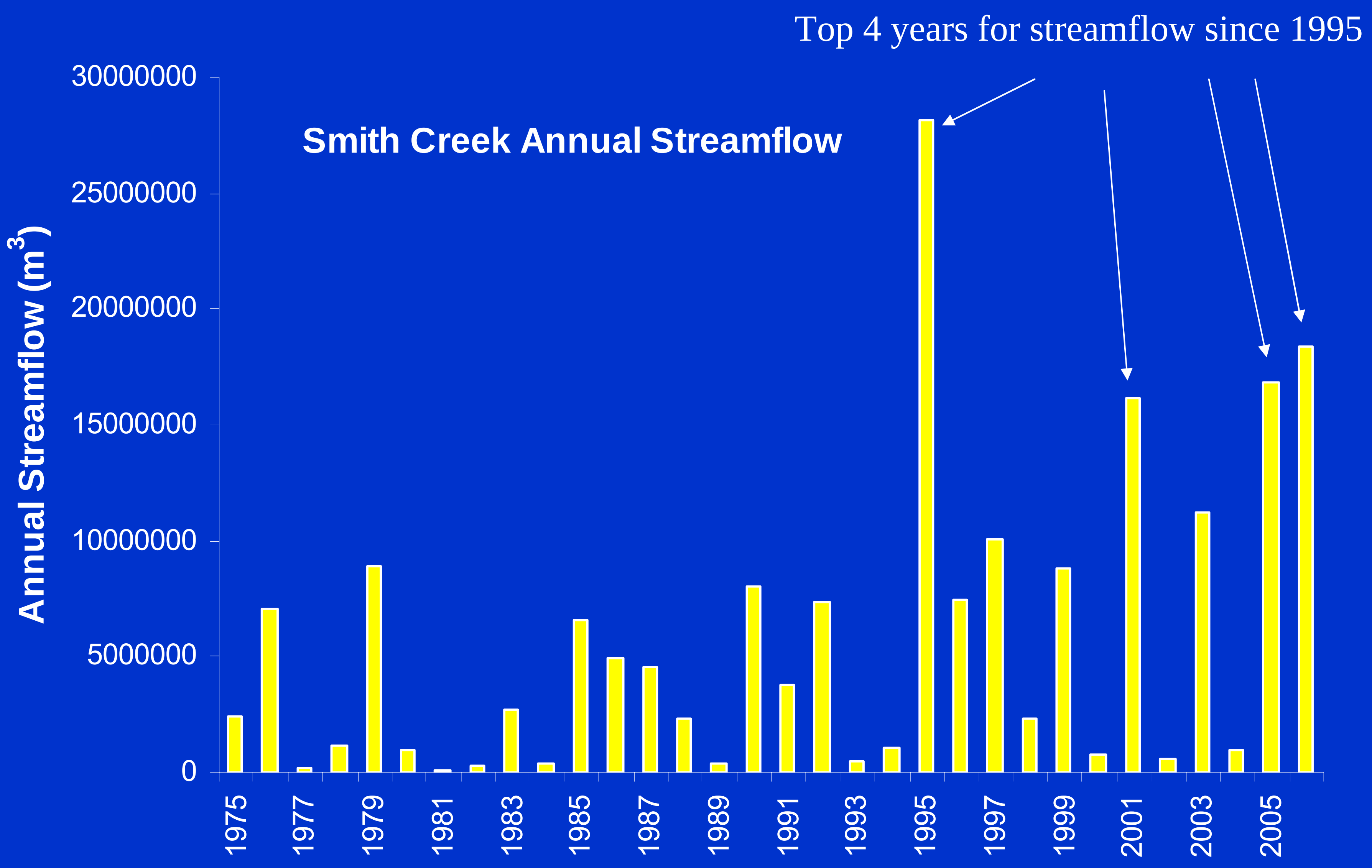
- Problem: Inability to reliably model the basins of the Upper Assiniboine River and other prairie basins where variable contributing area, wetlands, nonsaturated evapotranspiration, frozen soils, snow redistribution and snowmelt play a major role in hydrology.

- Objectives
  - Develop a Prairie Hydrological Model computer program that can simulate the response of streams, wetlands, and soil moisture to weather inputs for various basin types.
  - Evaluate the model performance in Smith Creek by comparing to observations of streamflow, wetland extent, and snowpack.
  - Use the Prairie Hydrological Model to estimate the sensitivity of streamflow, wetland water storage, and soil moisture to changes in drainage and land use.

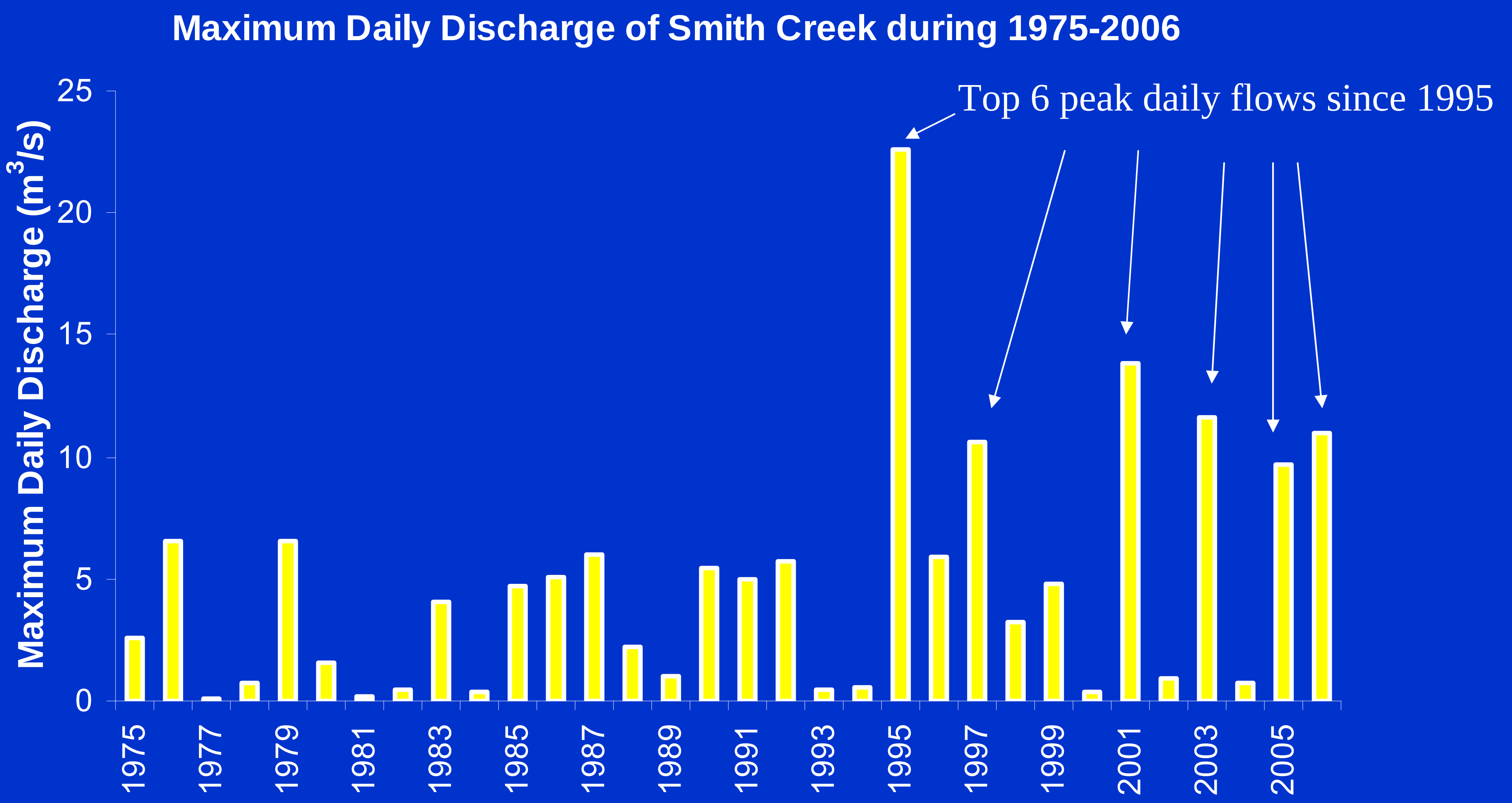
Smith Creek – extreme interannual and seasonal variability



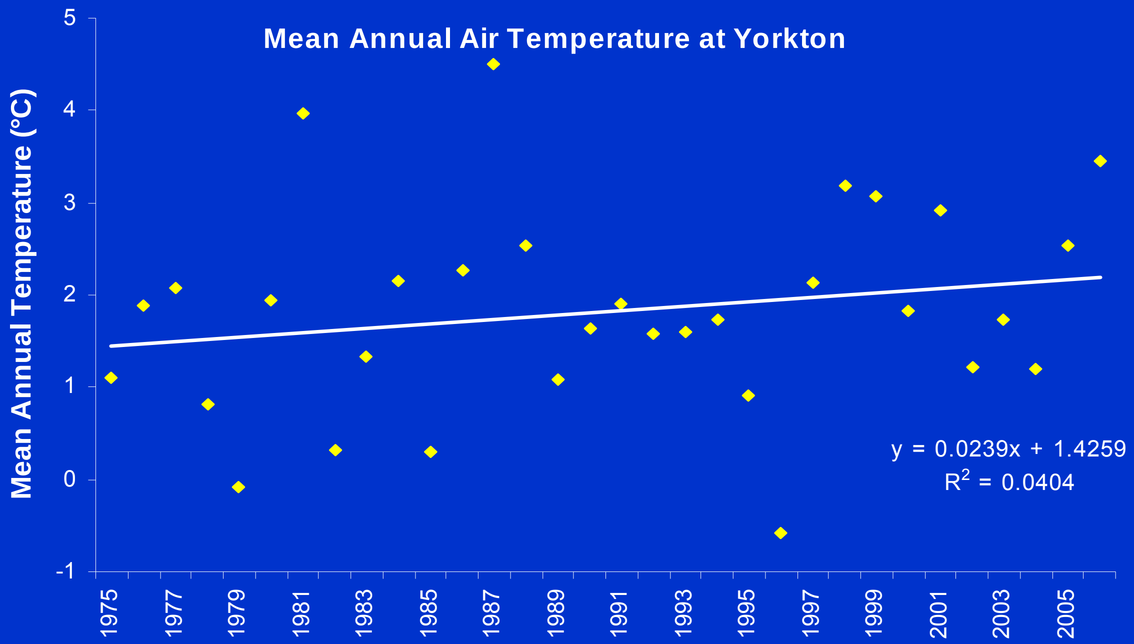
Streamflow over Time



Peak Flow over Time

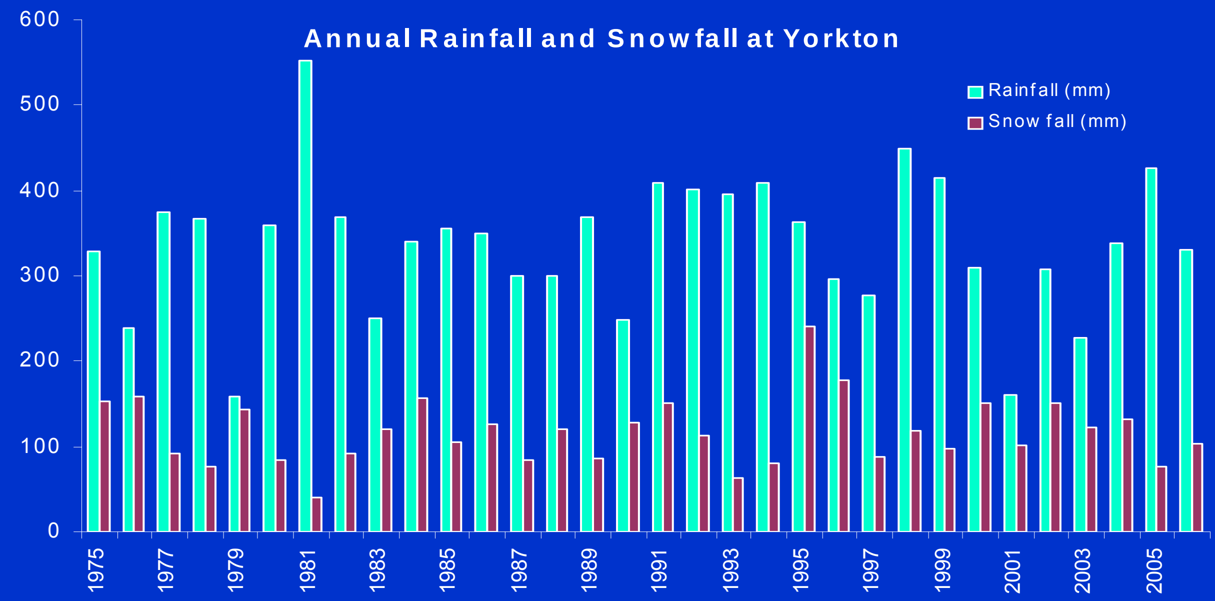


Changing Climate?

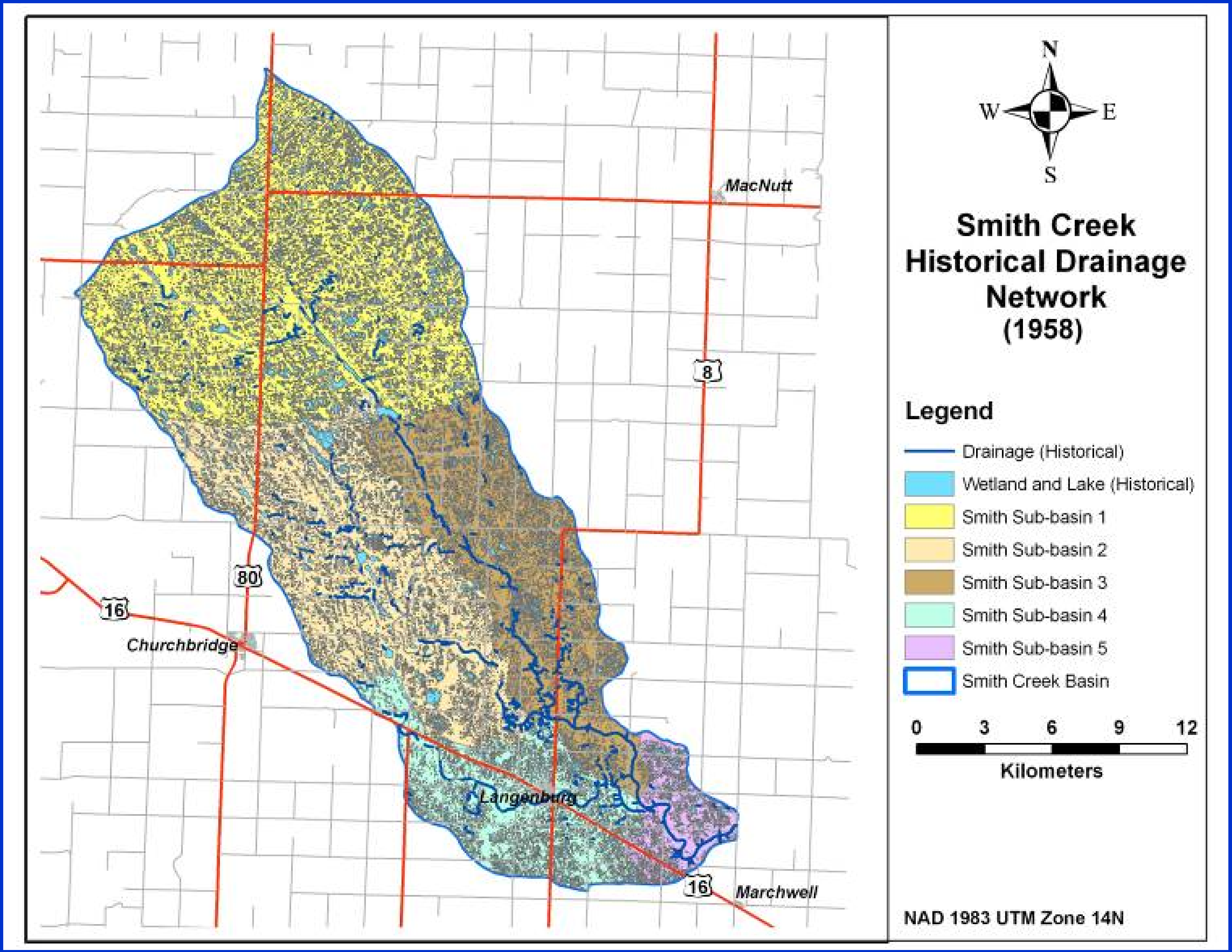


Warming but high variability

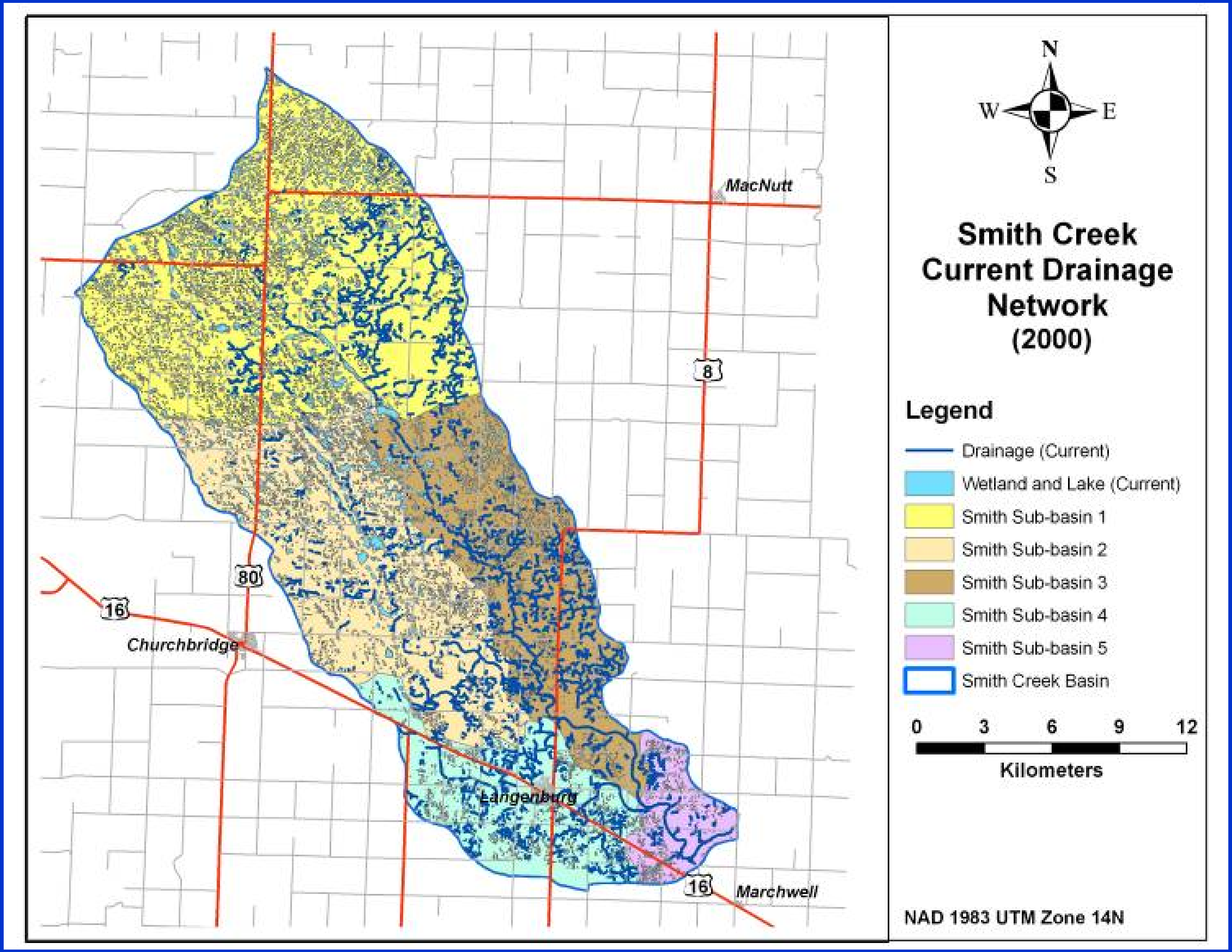
No trend in rainfall and snowfall



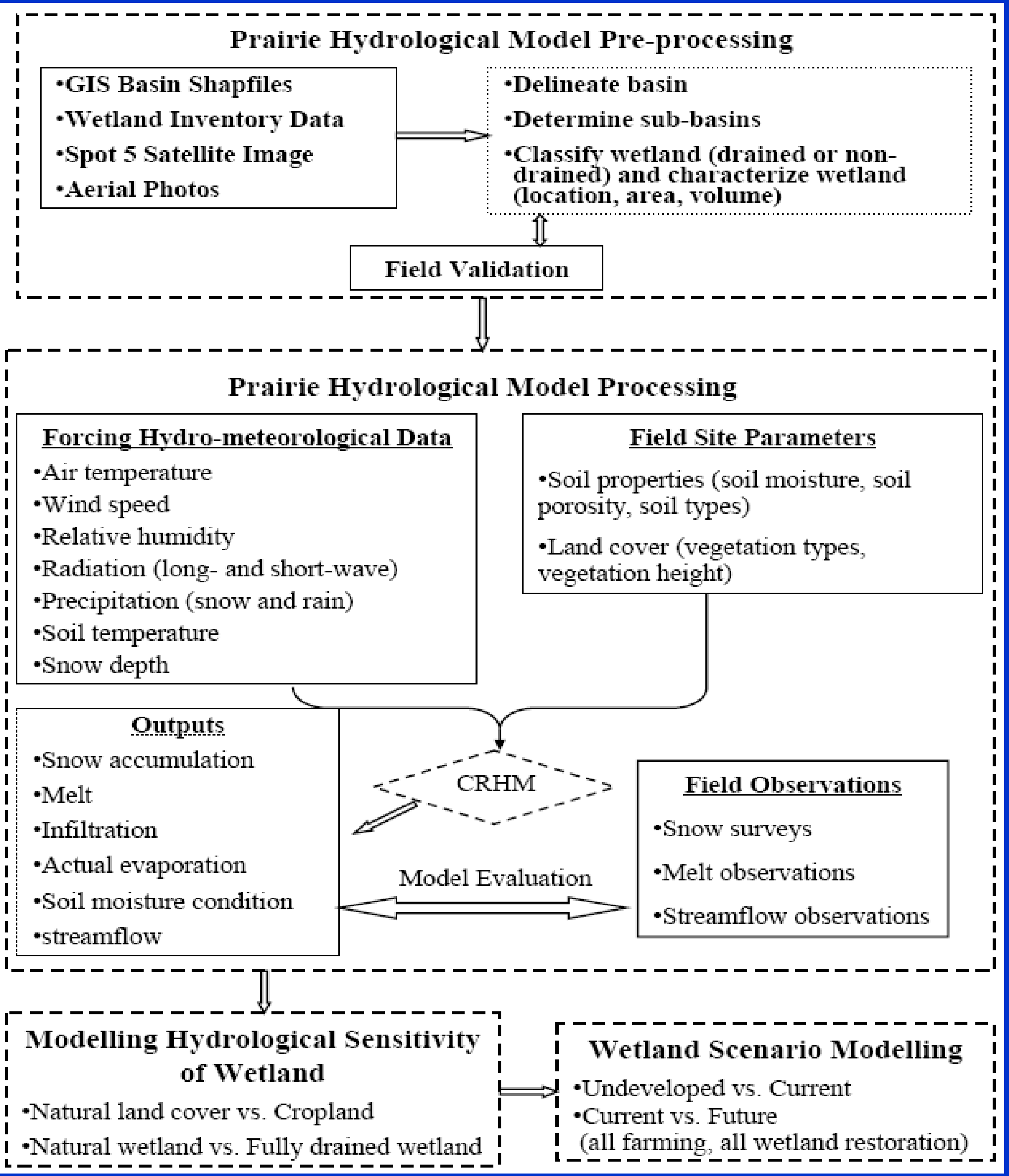
Drainage of Wetlands?



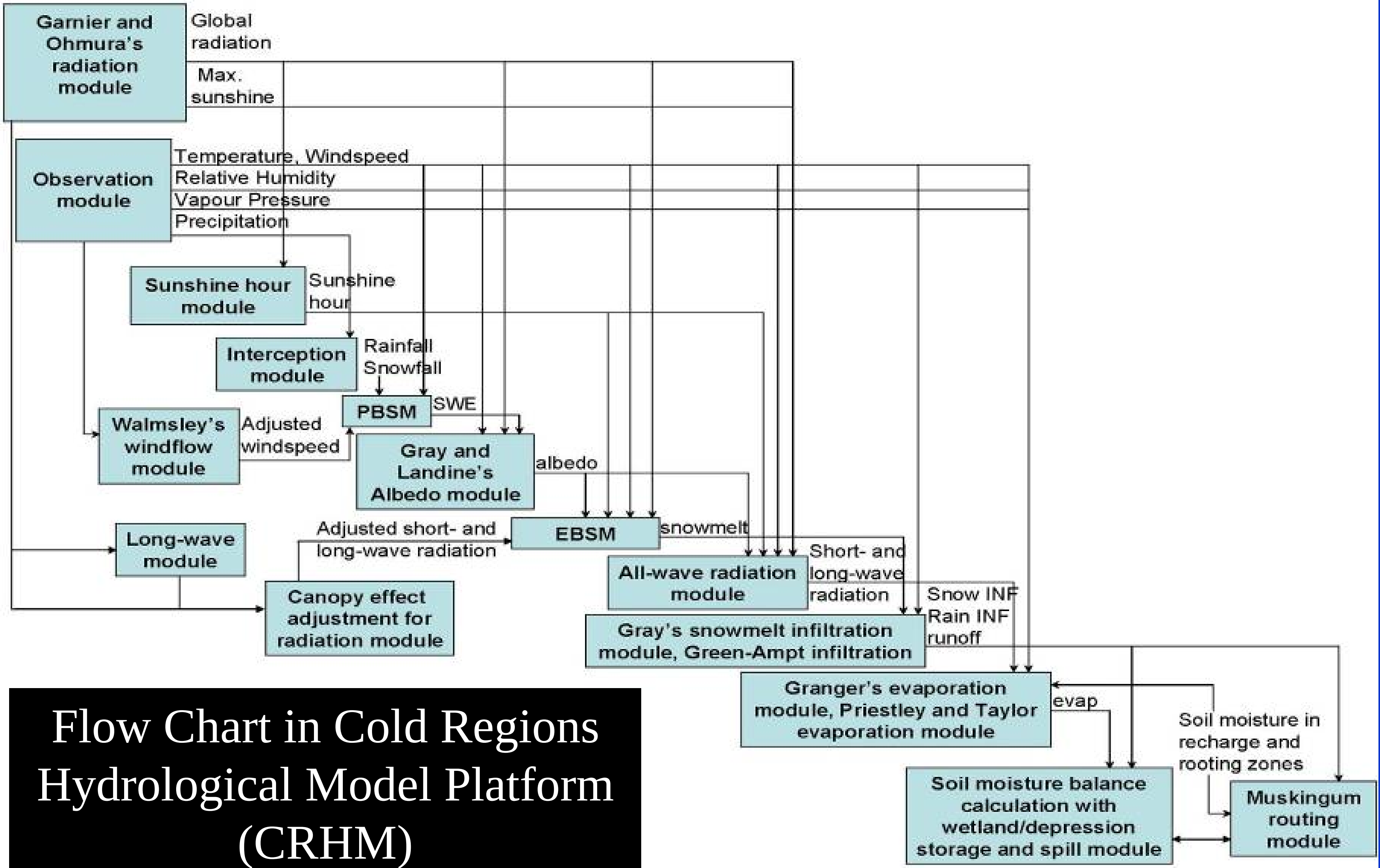
Drainage of Wetlands?



Modelling Approach

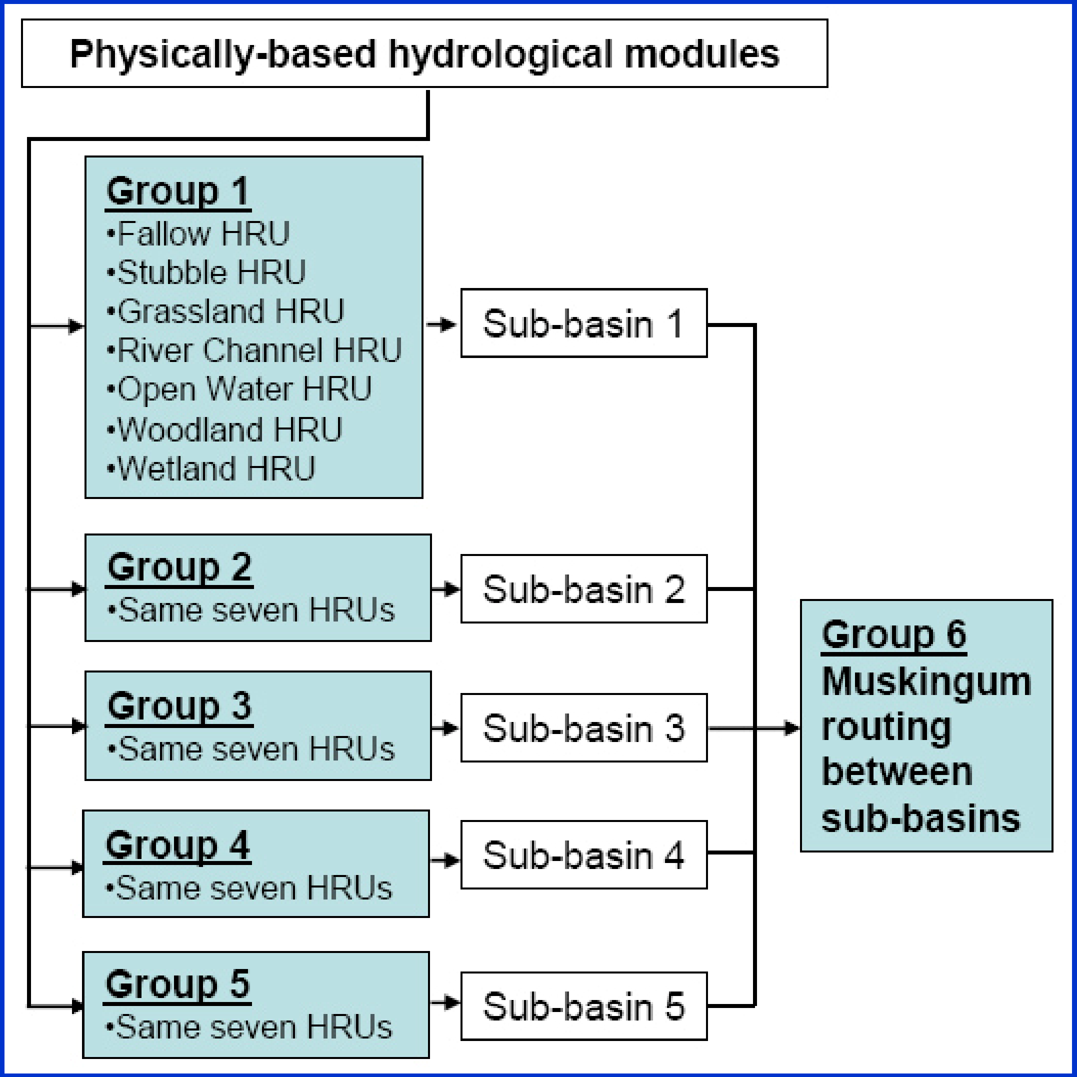


CRHM – Prairie Hydrological Model Configuration



Flow Chart in Cold Regions Hydrological Model Platform (CRHM)

HRU Configuration for Smith Creek

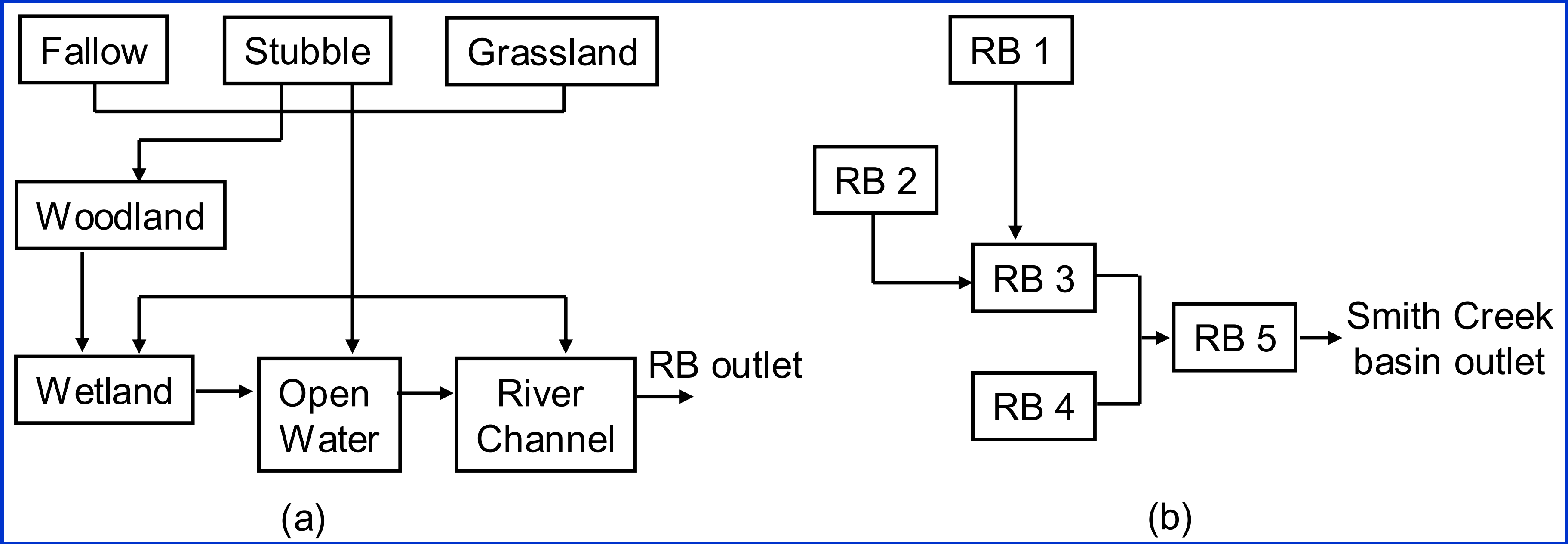


HRUs “grouped” into “representative basins”, RBs, that are repeated for sub-basins but with individual parameter sets. Routing between RBs permits large scale process estimation.

Small scale Processes

Large Scale Processes

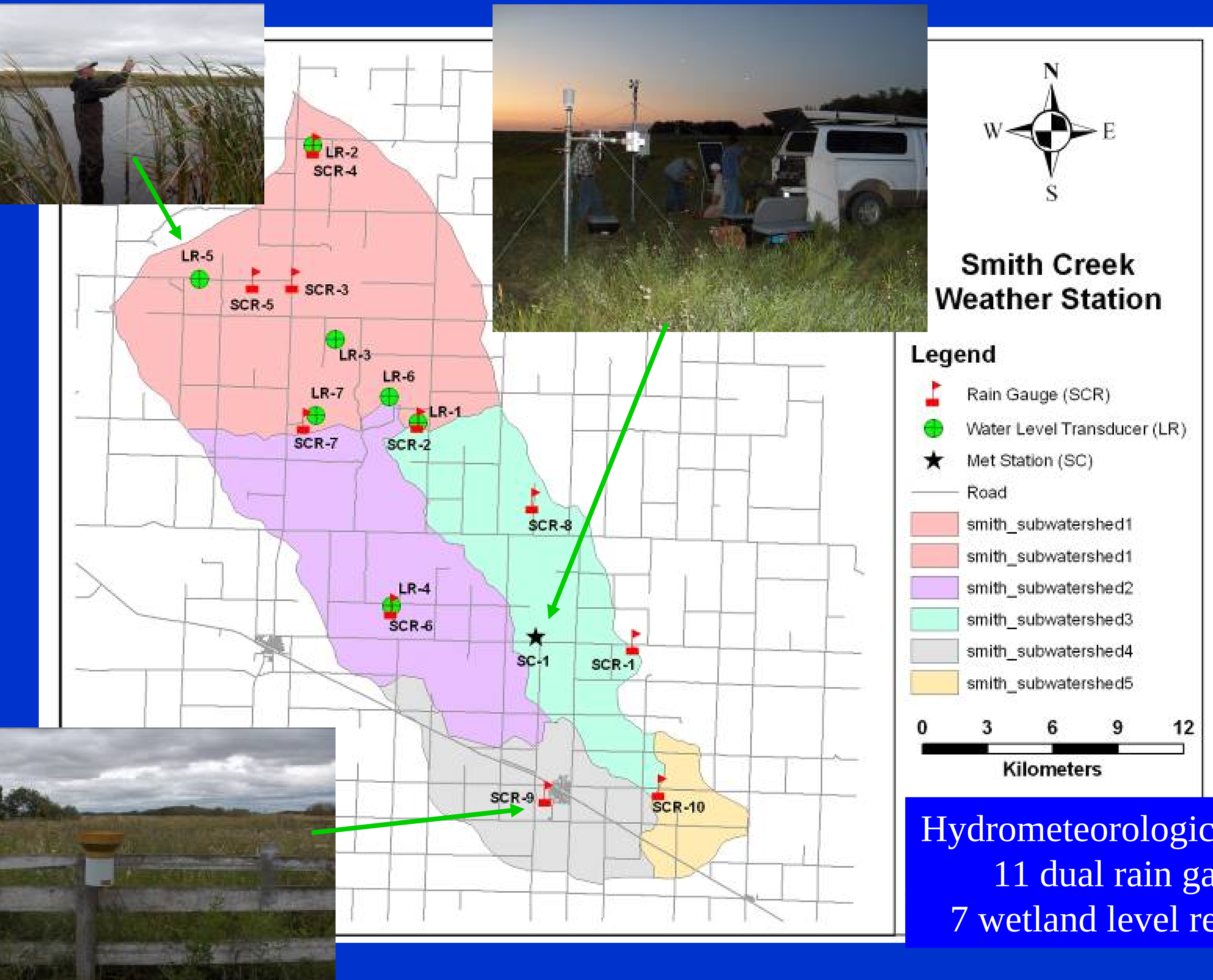
Routing



Amongst HRU in a Representative Basin

Amongst Representative Basins

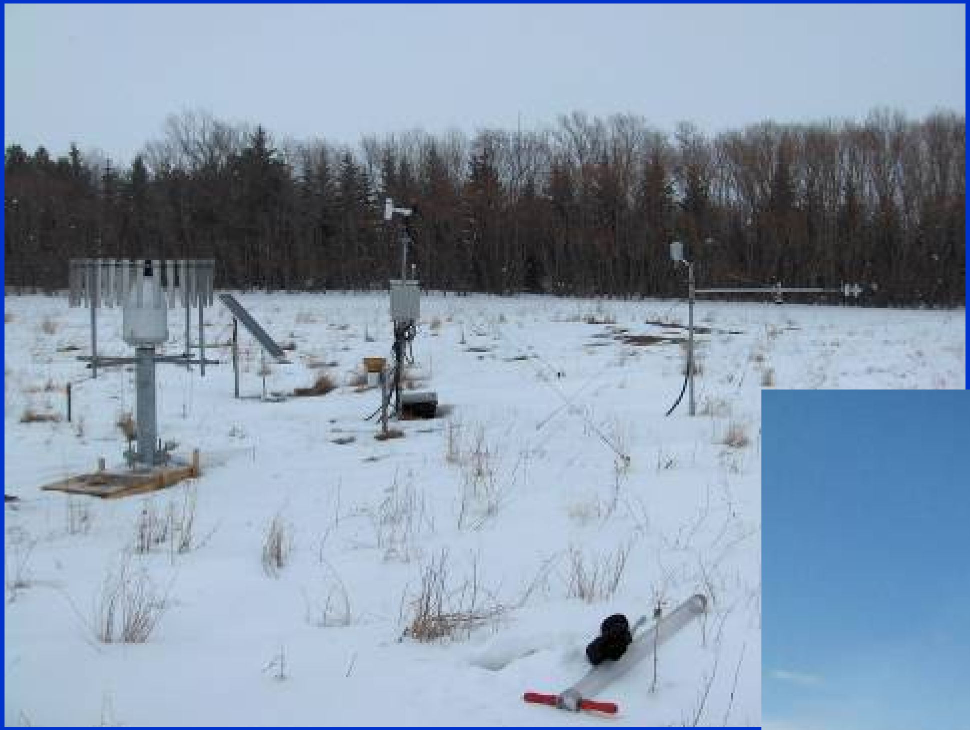
Instrumentation of Smith Creek



Completed
Summer 2007

Hydrometeorological Station
11 dual rain gauges
7 wetland level recorders

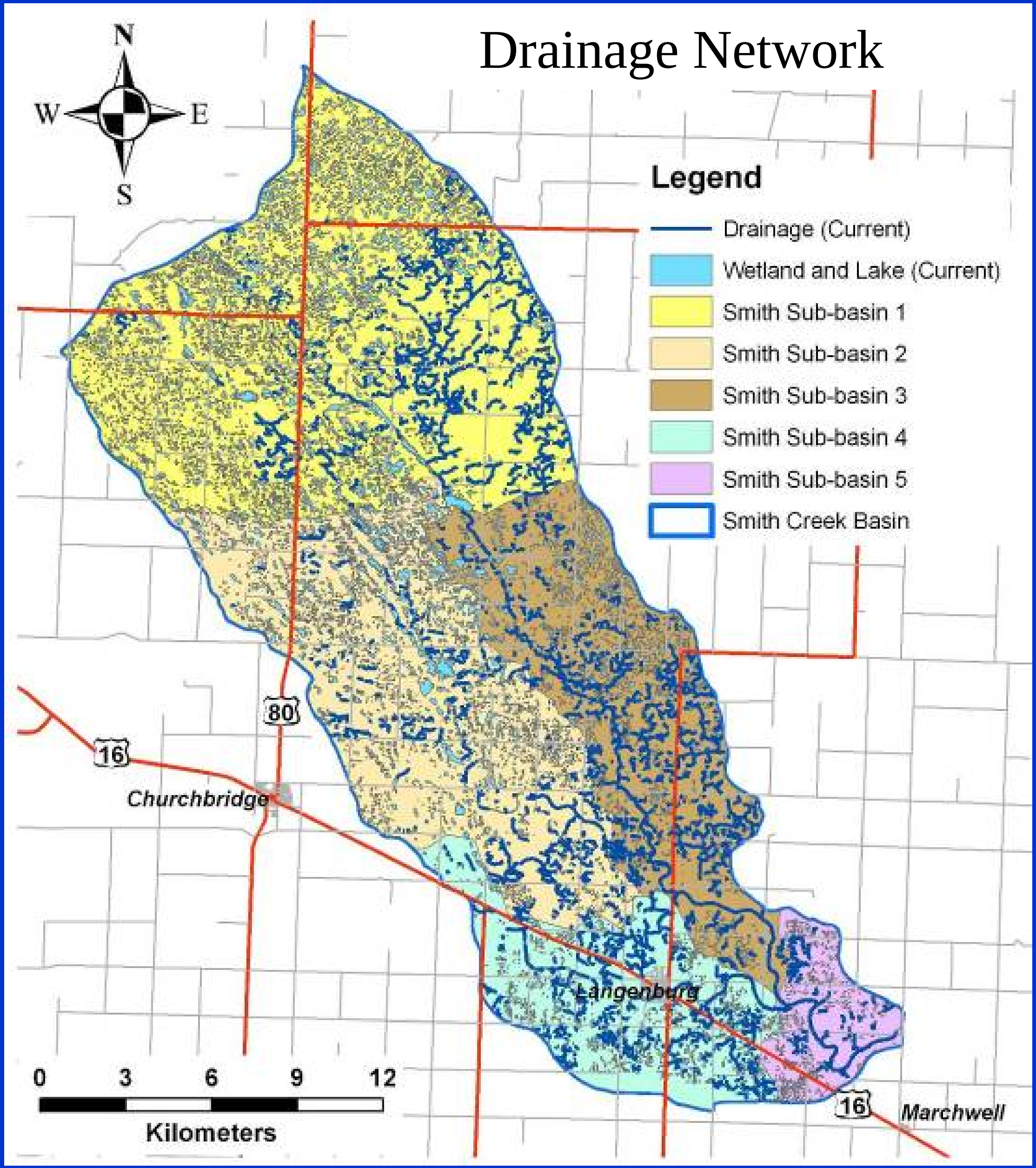
Main Hydrometeorological Station



Temperature, humidity, wind speed, shortwave radiation, longwave radiation, soil moisture, soil temperature, soil heat flux, snow depth, rainfall, snowfall

Snow and Wetland Surveys

Smith Creek Basin Characteristics

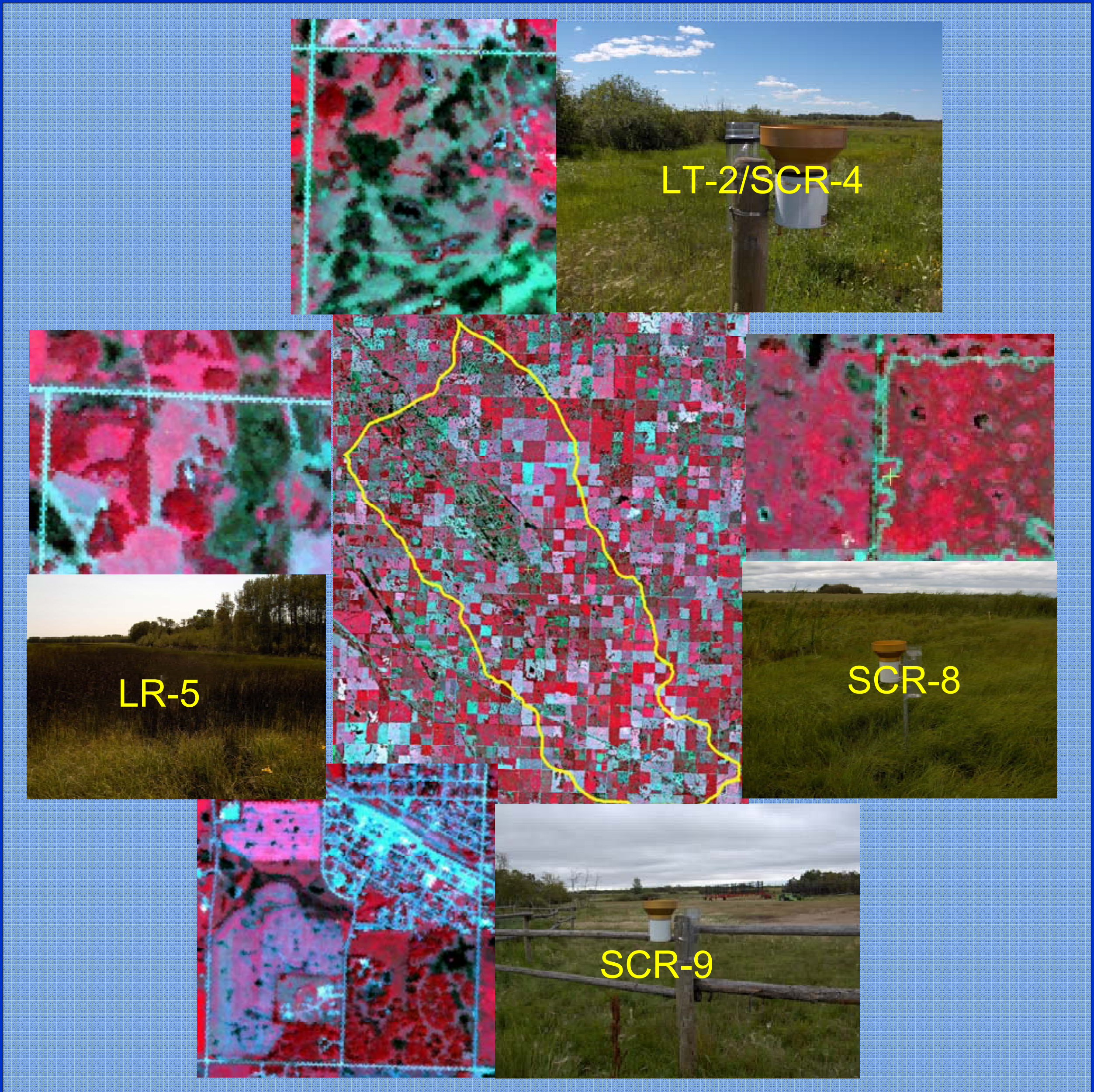


Spot Image

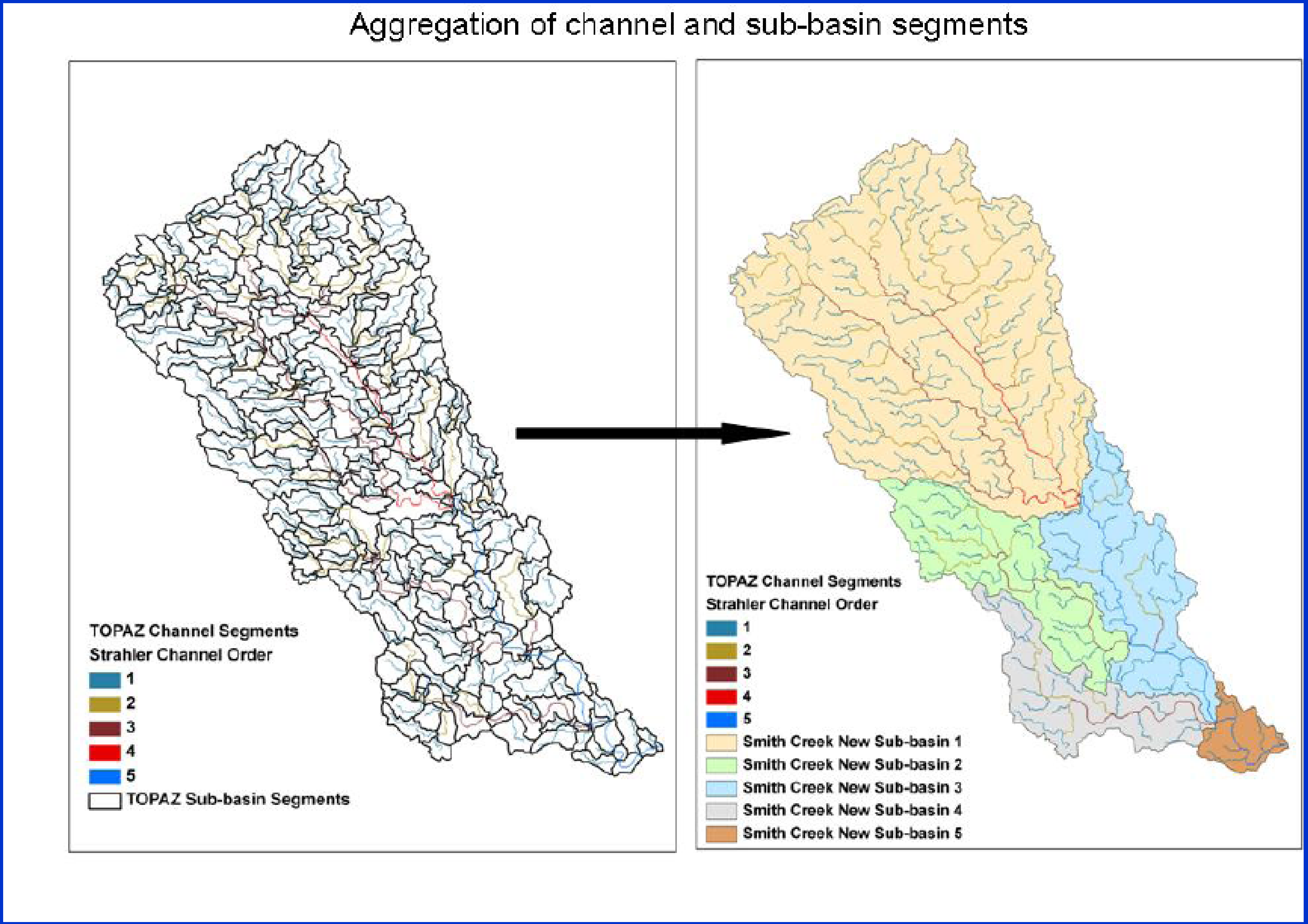
Remote Sensing Supervised Classification

SPOT5
Field tests of vegetation classification

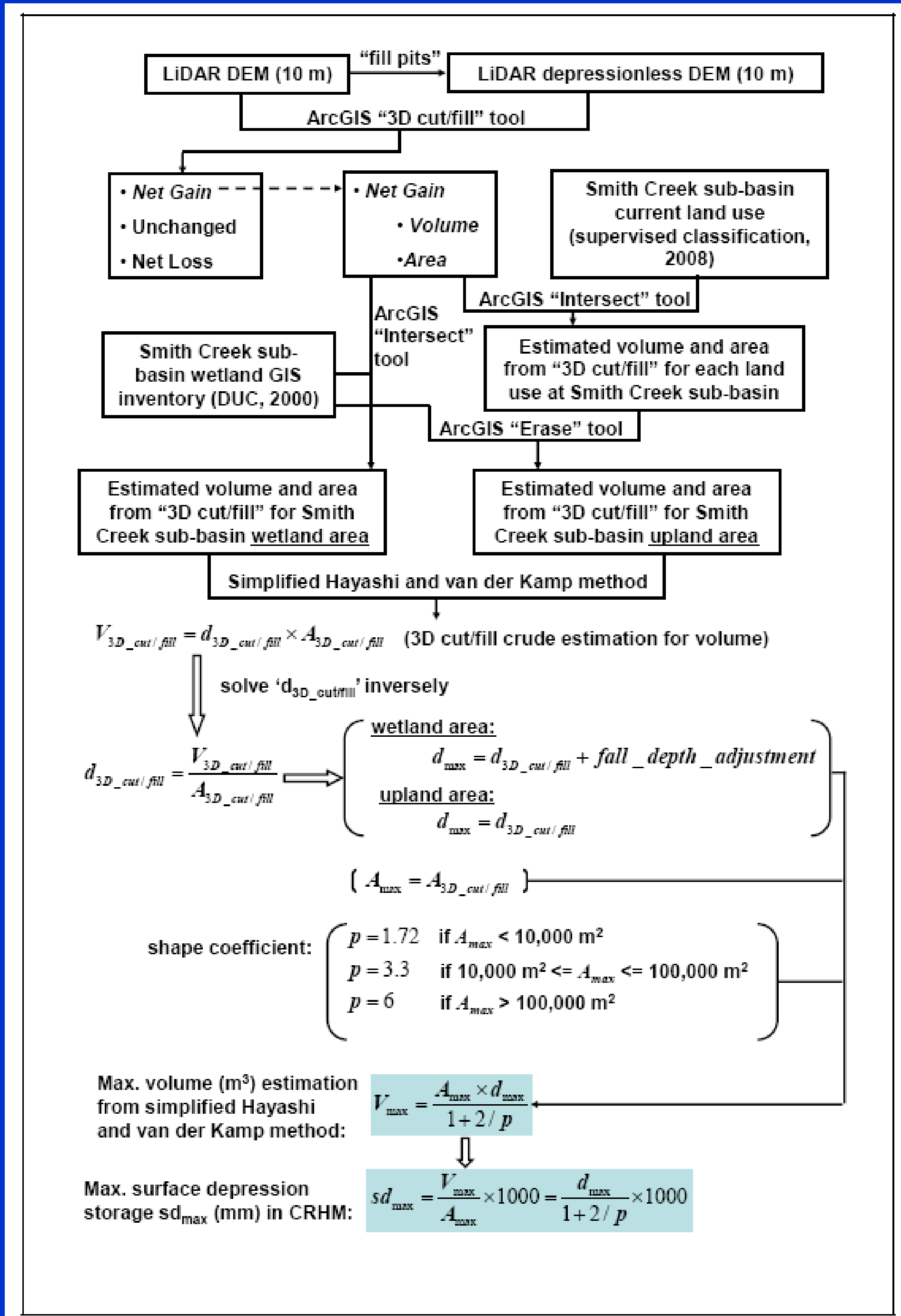
vegetation used to define HRU area, HRU location & vegetation parameters

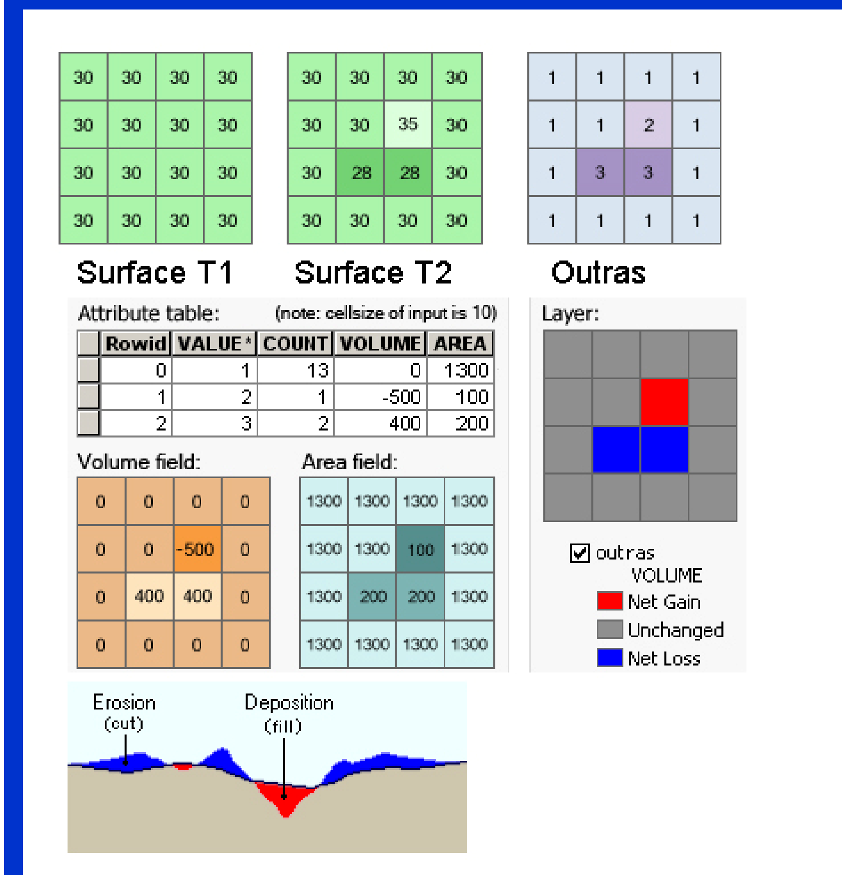


LiDAR-Derived DEM Drainage Network



LiDAR DEM to Calculate Depression Storage using pond volume-depth-area relationship





Derivation of Wetland Depressions

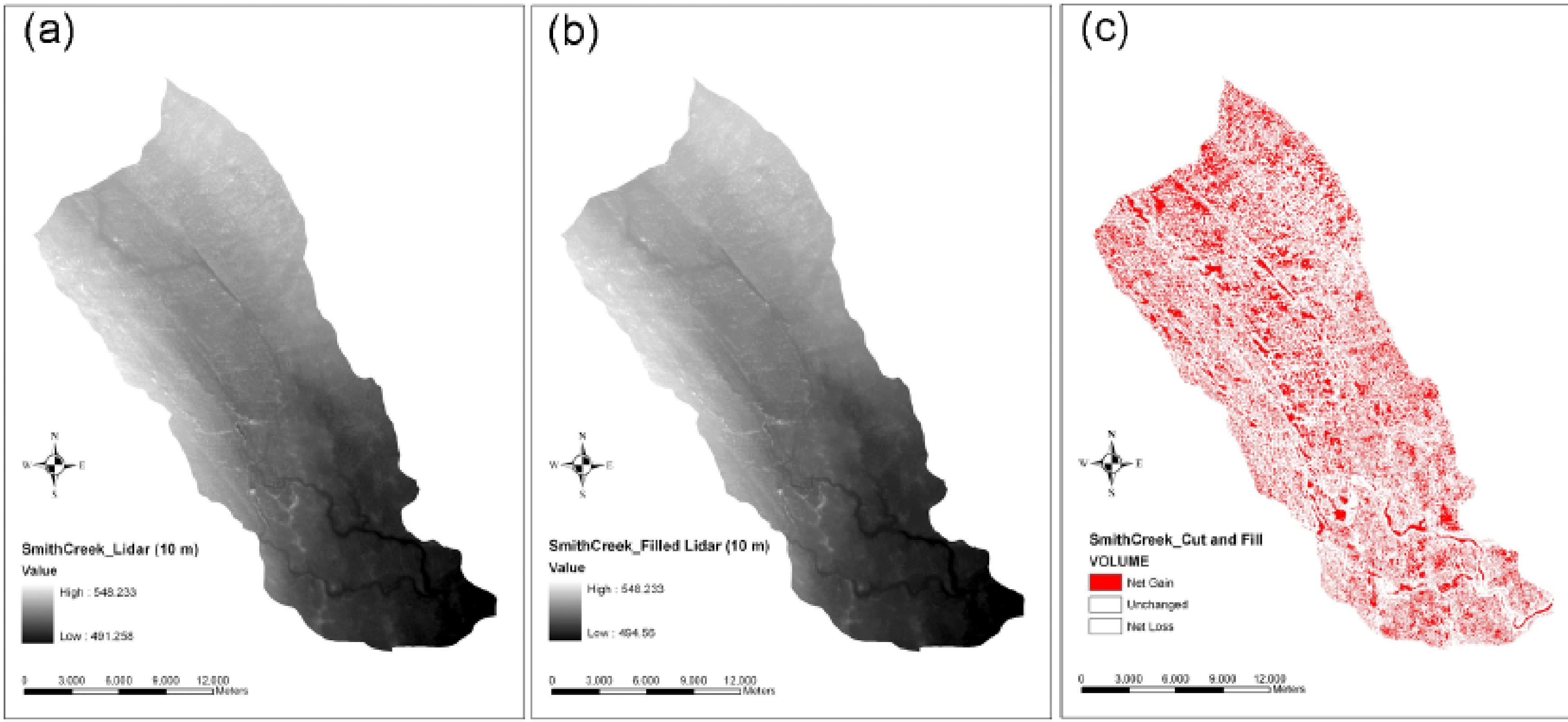
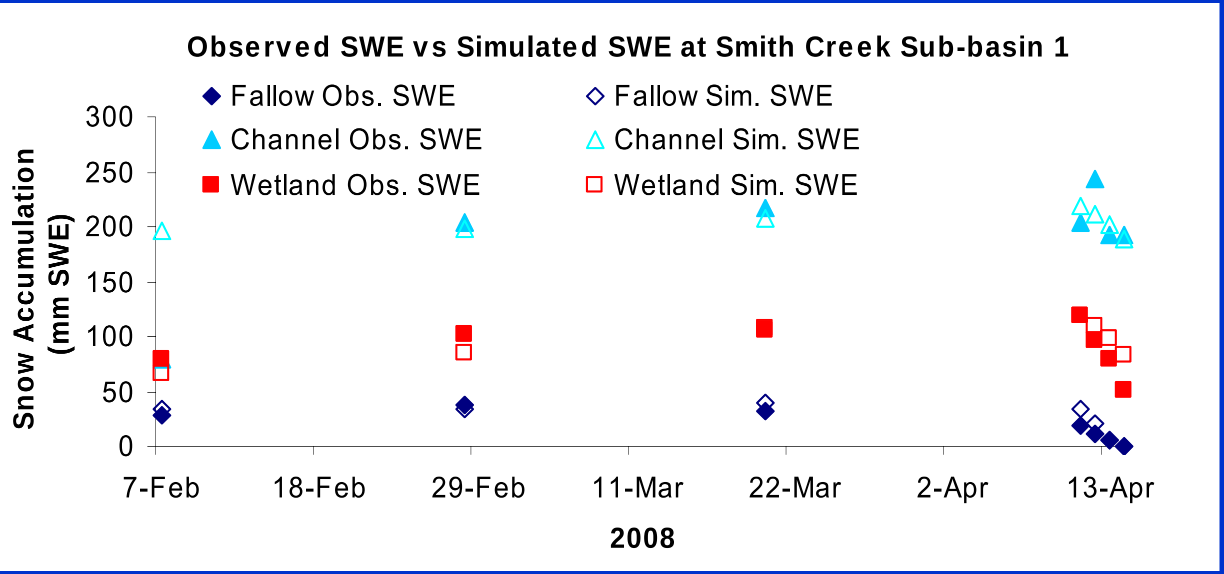
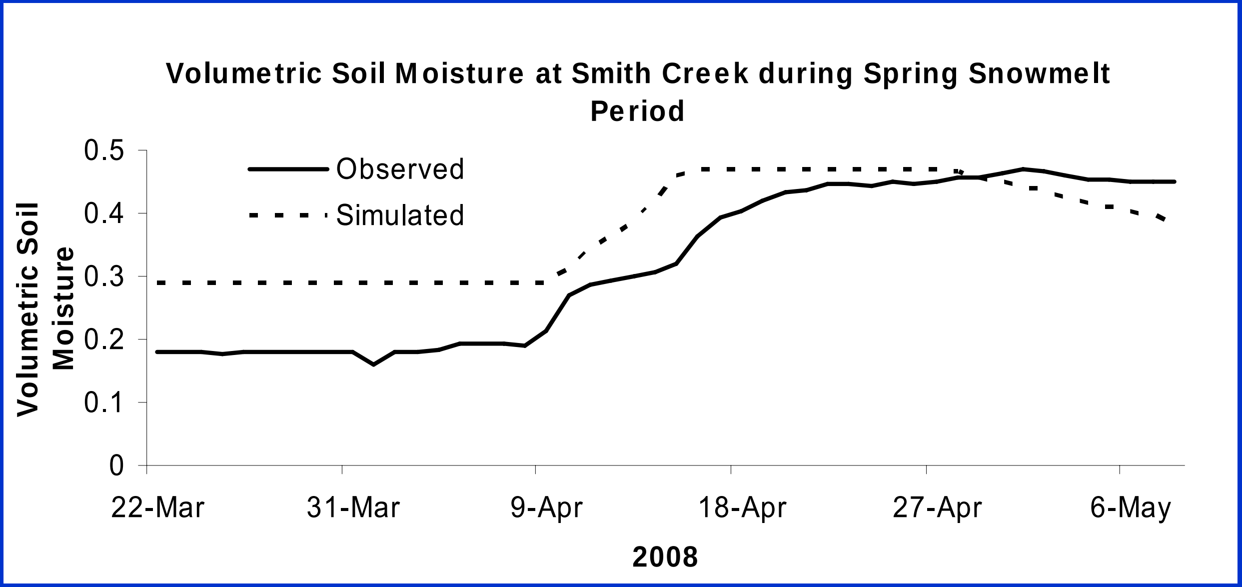


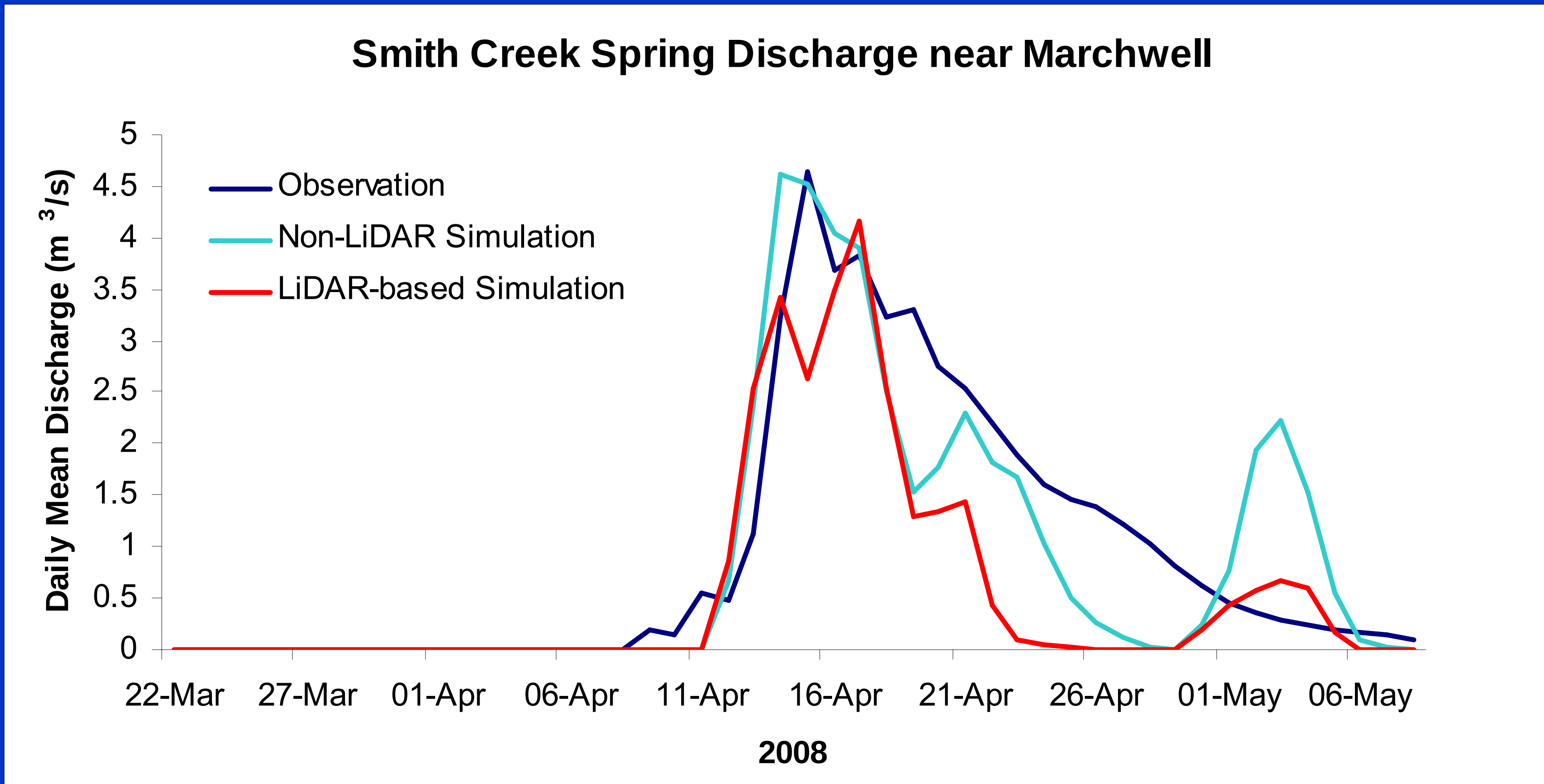
Figure 3. (a) Original 10-m LiDAR DEM, (b) filled depressionless 10-m LiDAR DEM, and (c) “cut/fill” output for Smith Creek basin.

CRHM Tests Smith Creek – No Calibration



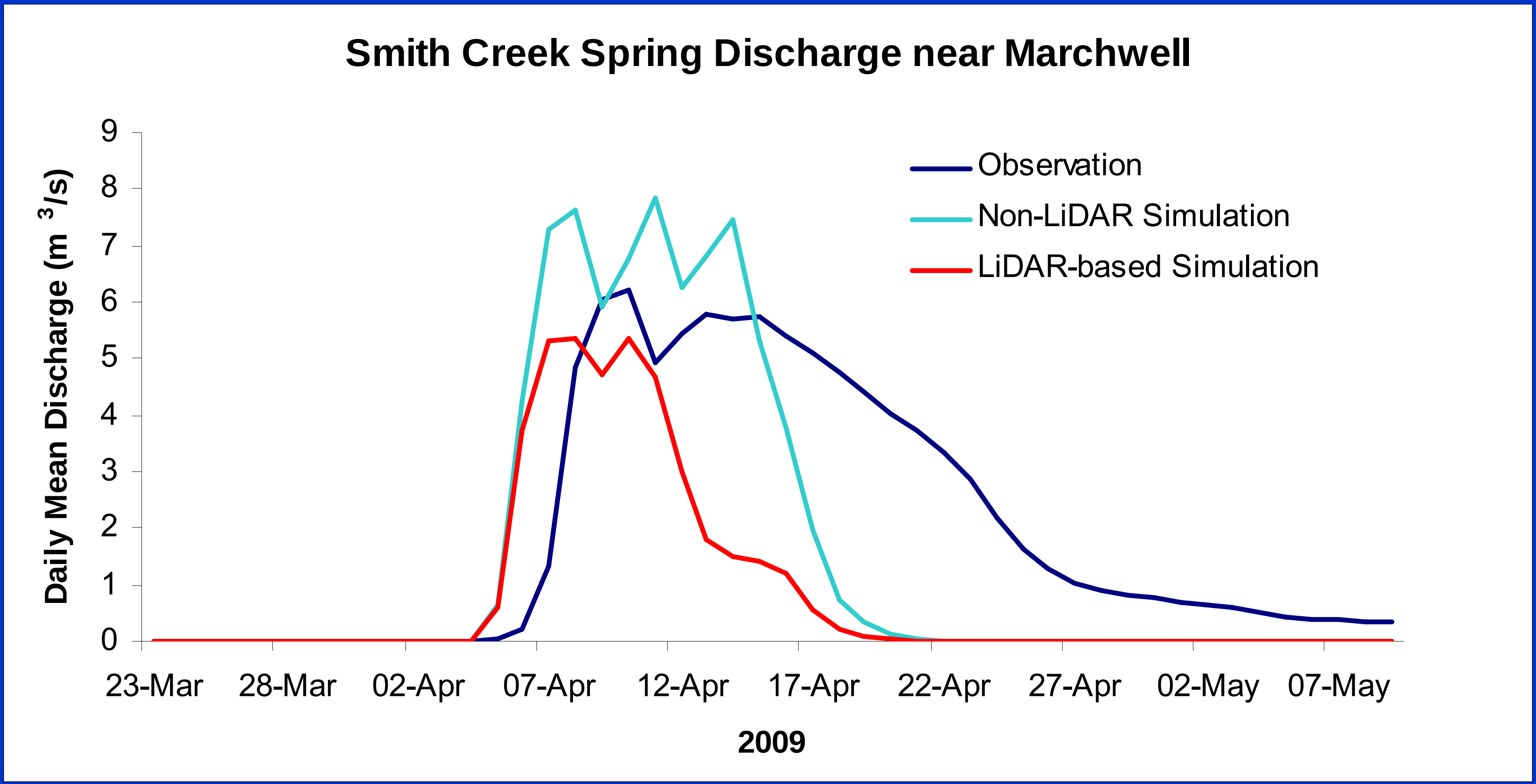


Runoff Prediction 2008



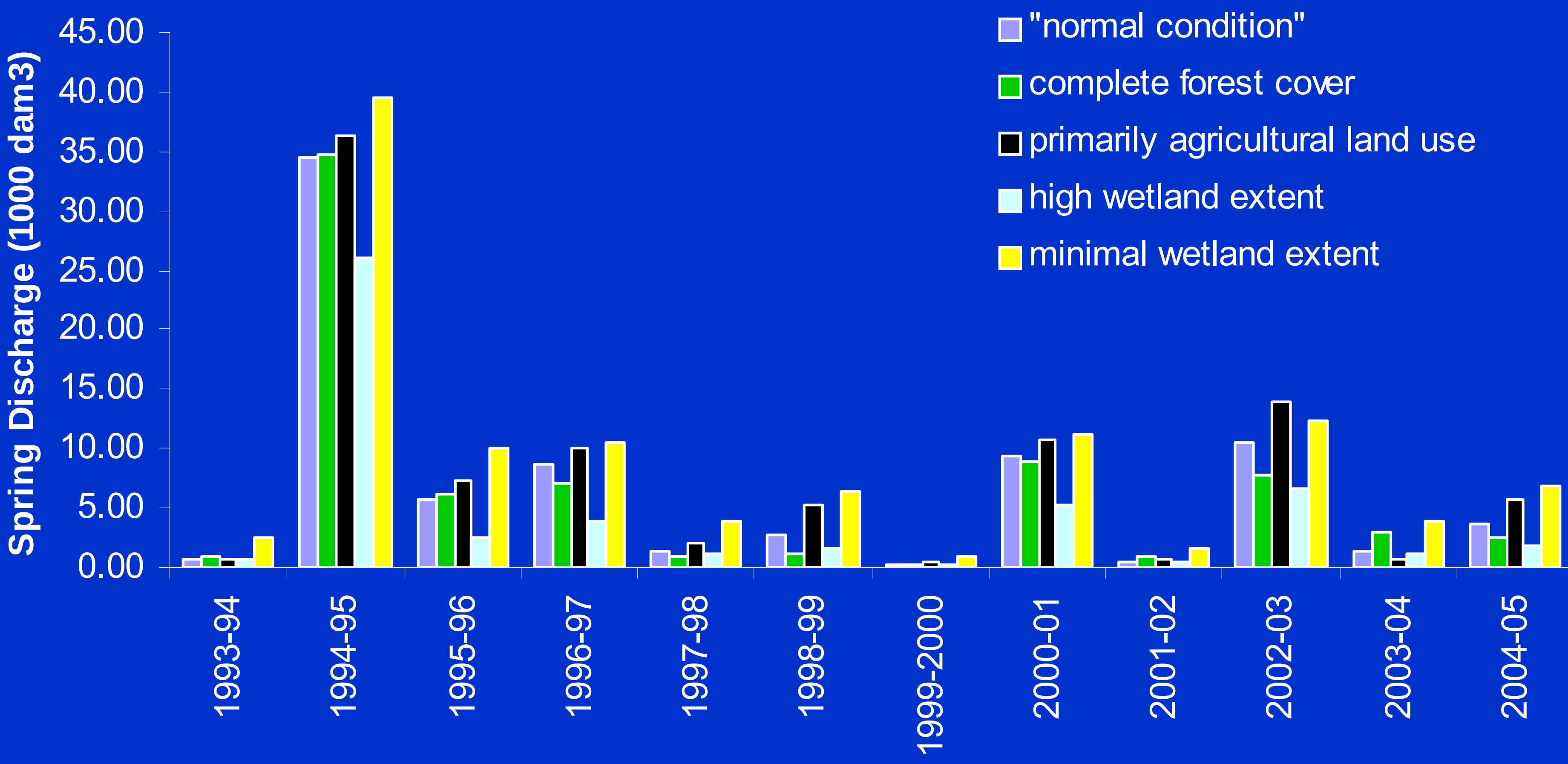
	MB	RMSD (m^3/s	Peak Discharge (m^3/s)
Non-LiDAR Simulation	-0.07	0.10	4.61
LiDAR-based Simulation	-0.39	0.12	4.17
Observation			4.65

Runoff Prediction 2009

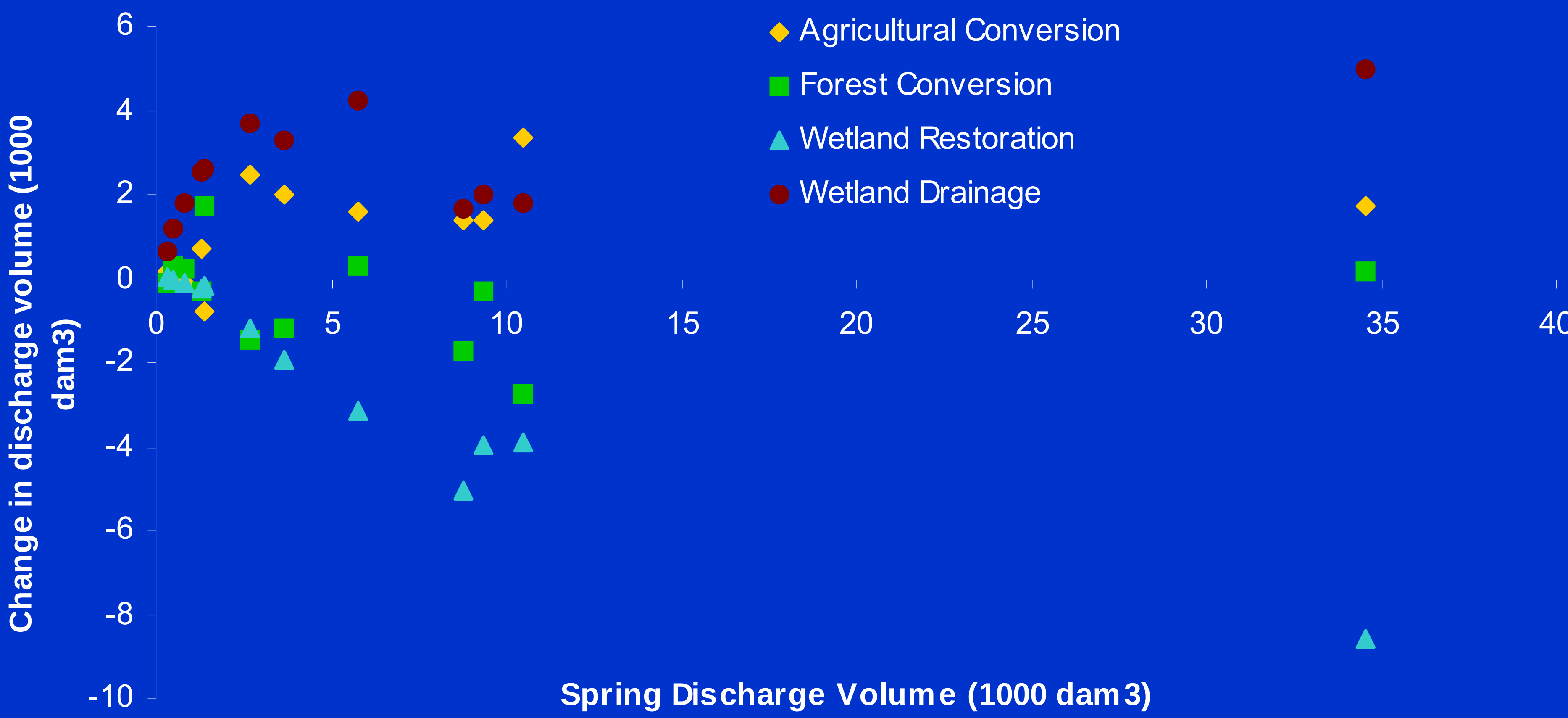


	MB	RMSD (m^3	Peak Discharge (m^3/s)
Non-LiDAR Simulation	-0.21	0.28	7.83
LiDAR-based Simulation	-0.57	0.31	5.37
Observation			6.22

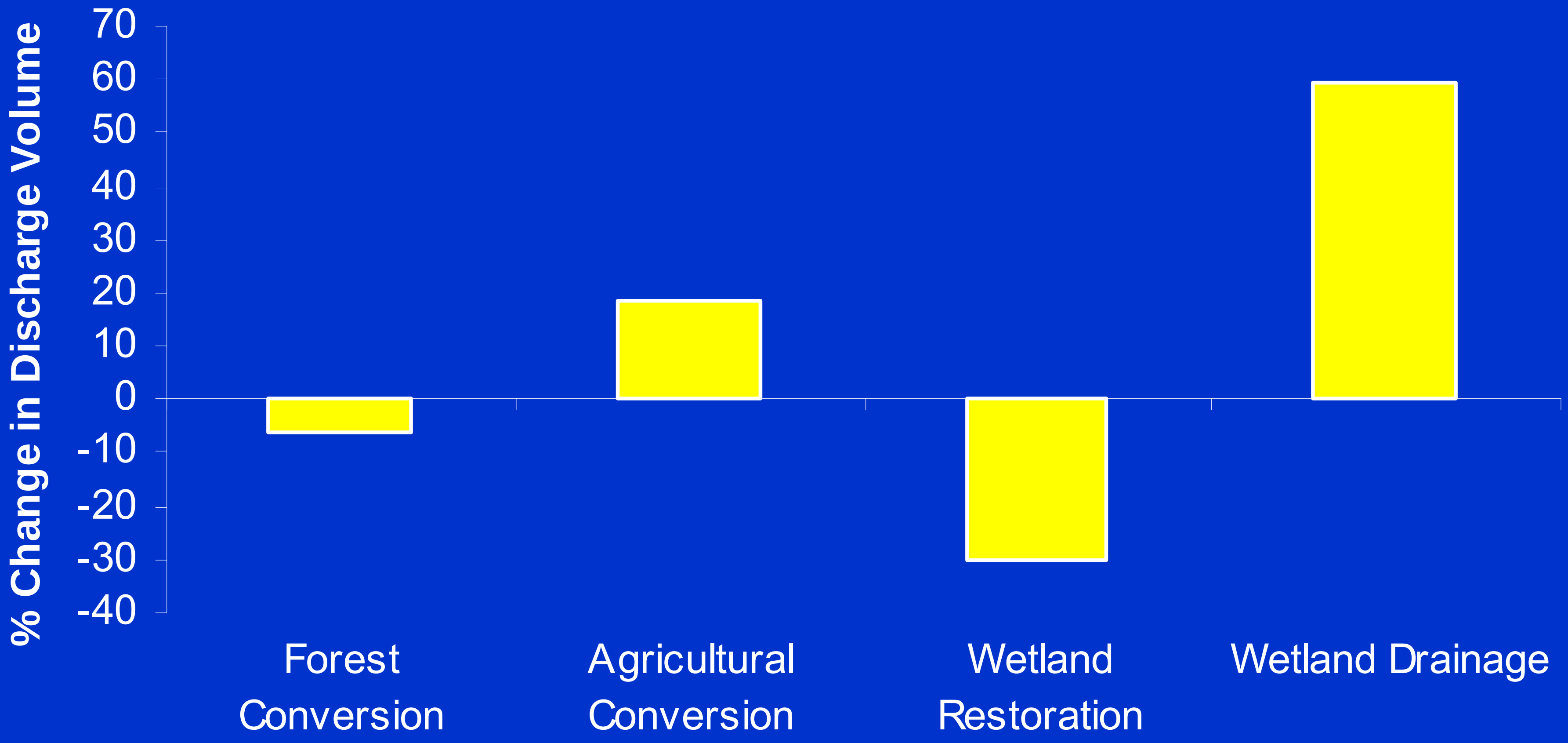
Sensitivity Analysis: Change in Spring Discharge



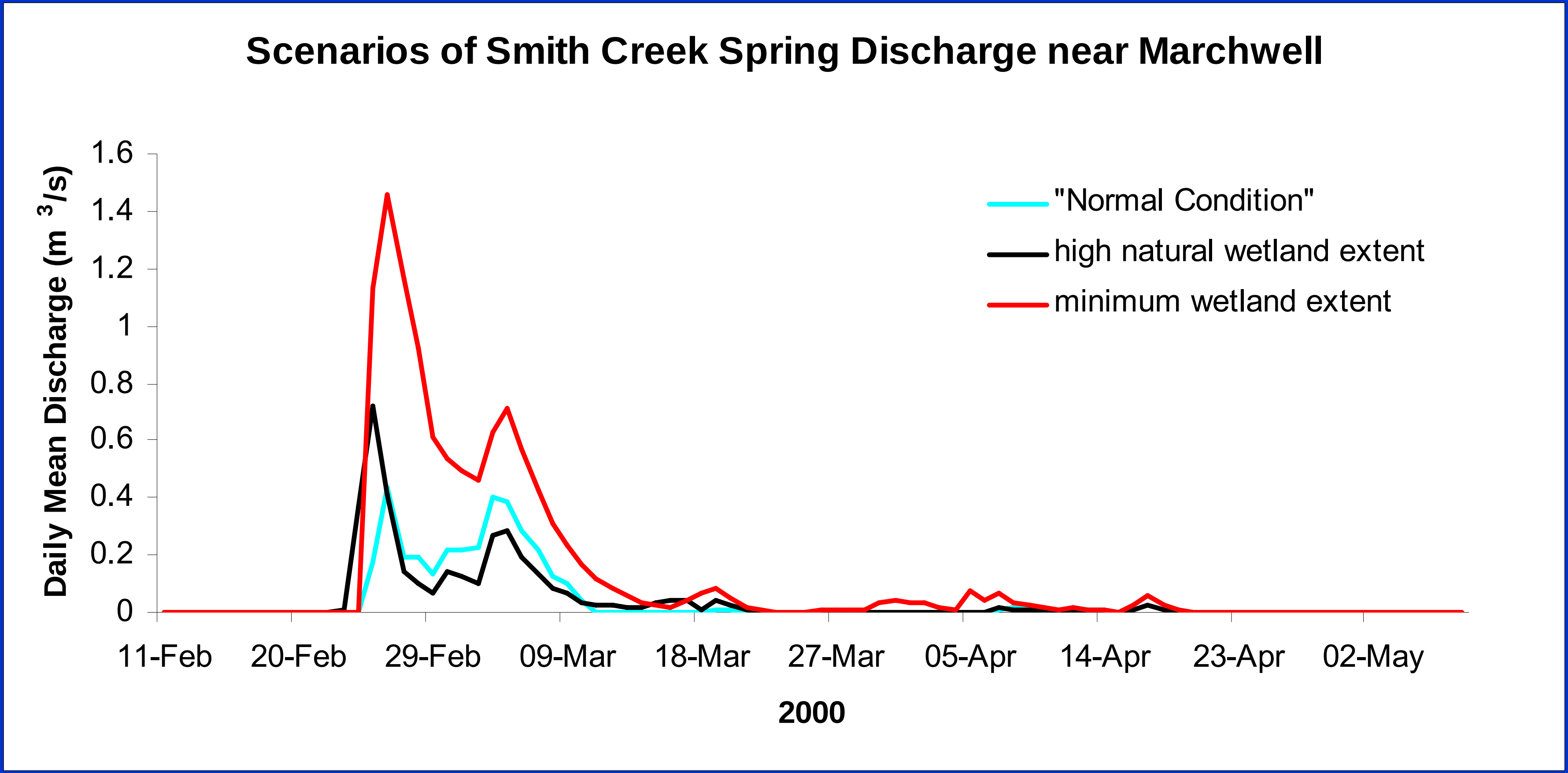
Sensitivity of Spring Discharge Volume to Land use and Drainage



Long-term Impact of Land Use and Drainage Change

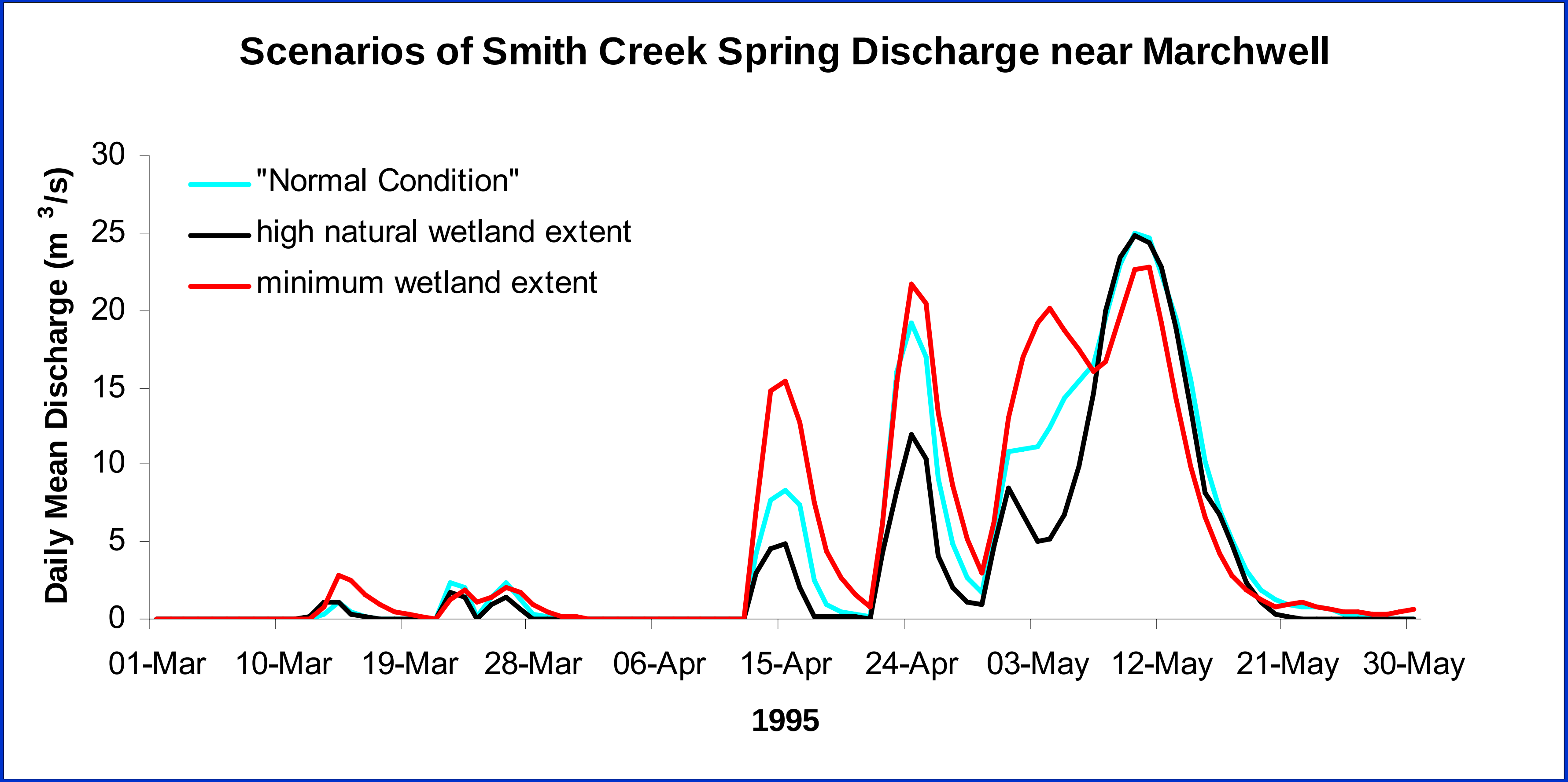


Wetland Change in Low Discharge Volume Year



2000 Drought: Lowest Discharge Volume on Record

Wetland Change in High Discharge Volume Year



1995 Flood: Record High Discharge Volume

Discussion on Scenarios

- Changes in wetland extent often are accompanied by changes to land use.
- Increasing forest cover decreases discharge volume.
- Increasing agricultural land increases discharge volume.
- Increasing wetland area reduces discharge volume, whilst decreasing wetland area results in an increase.
- The changes to discharge volume due to decreasing wetland area are similar for almost all discharge volumes, but changes due to increasing wetland area tend to increase with discharge volume.
- In dry conditions, when storage is small, wetland drainage increases discharge volume, whilst wetland restoration has little impact.
- In flooding conditions, when storage is filled, neither wetland drainage nor restoration has an effect on the hydrograph.

Conclusions

- Consideration of snow, frozen soil and surface storage processes are essential to calculating spring runoff in the Prairies.
- Depressional storage is exceedingly difficult to calculate in this flat, poorly drained environment – LiDAR permits estimation of depressional and wetland storage volumes.
- It is possible to model prairie snowpack, soil moisture and streamflow without calibration using physically based simulations that aggregate landscape scale hydrological cycle calculations, **<u>if</u>** high resolution information is available on catchment characteristics.
- There is moderate sensitivity of streamflow volumes to changes in agricultural and forest land use.
- There is strong sensitivity of streamflow volumes to wetland drainage and restoration.