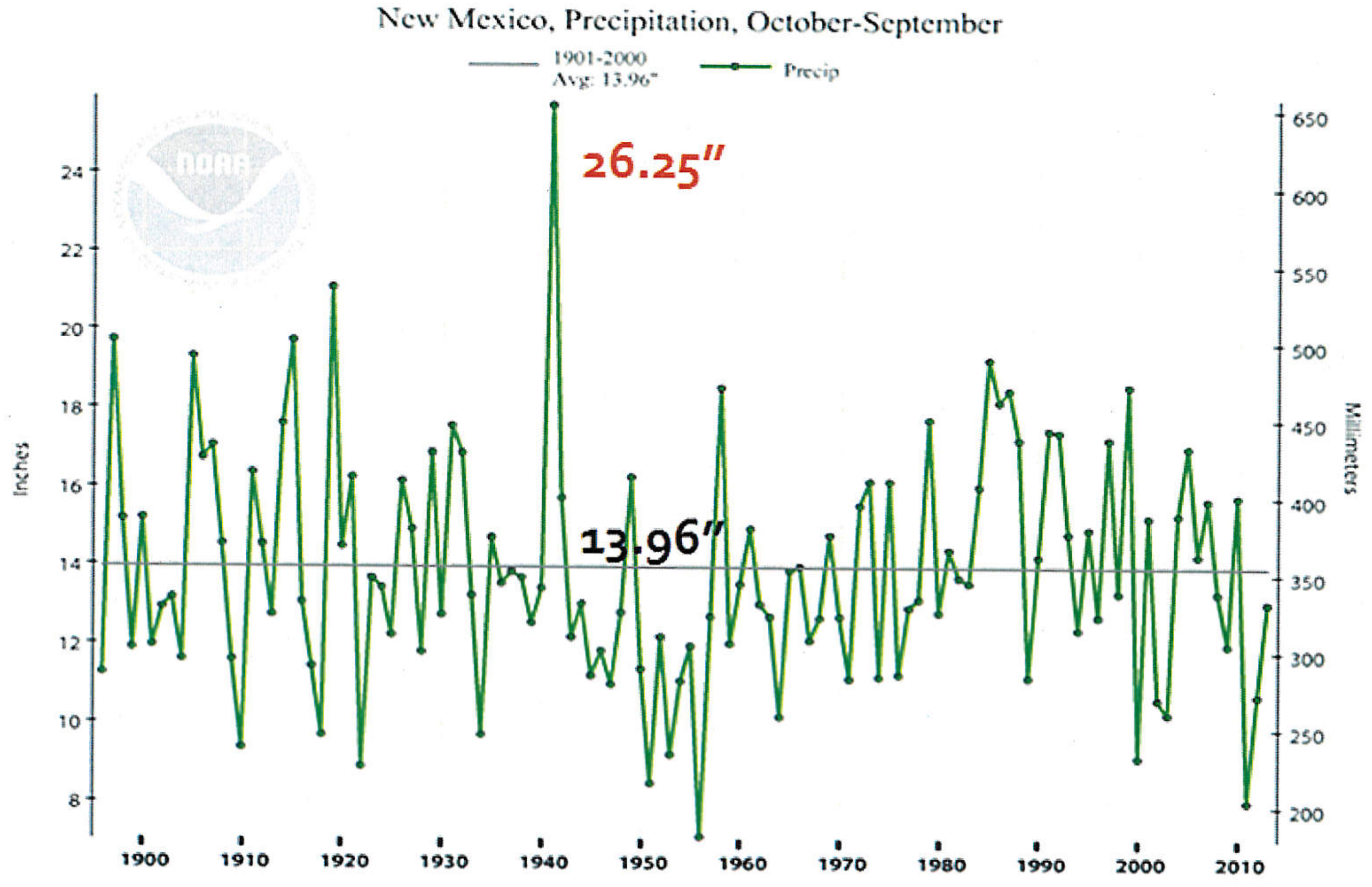
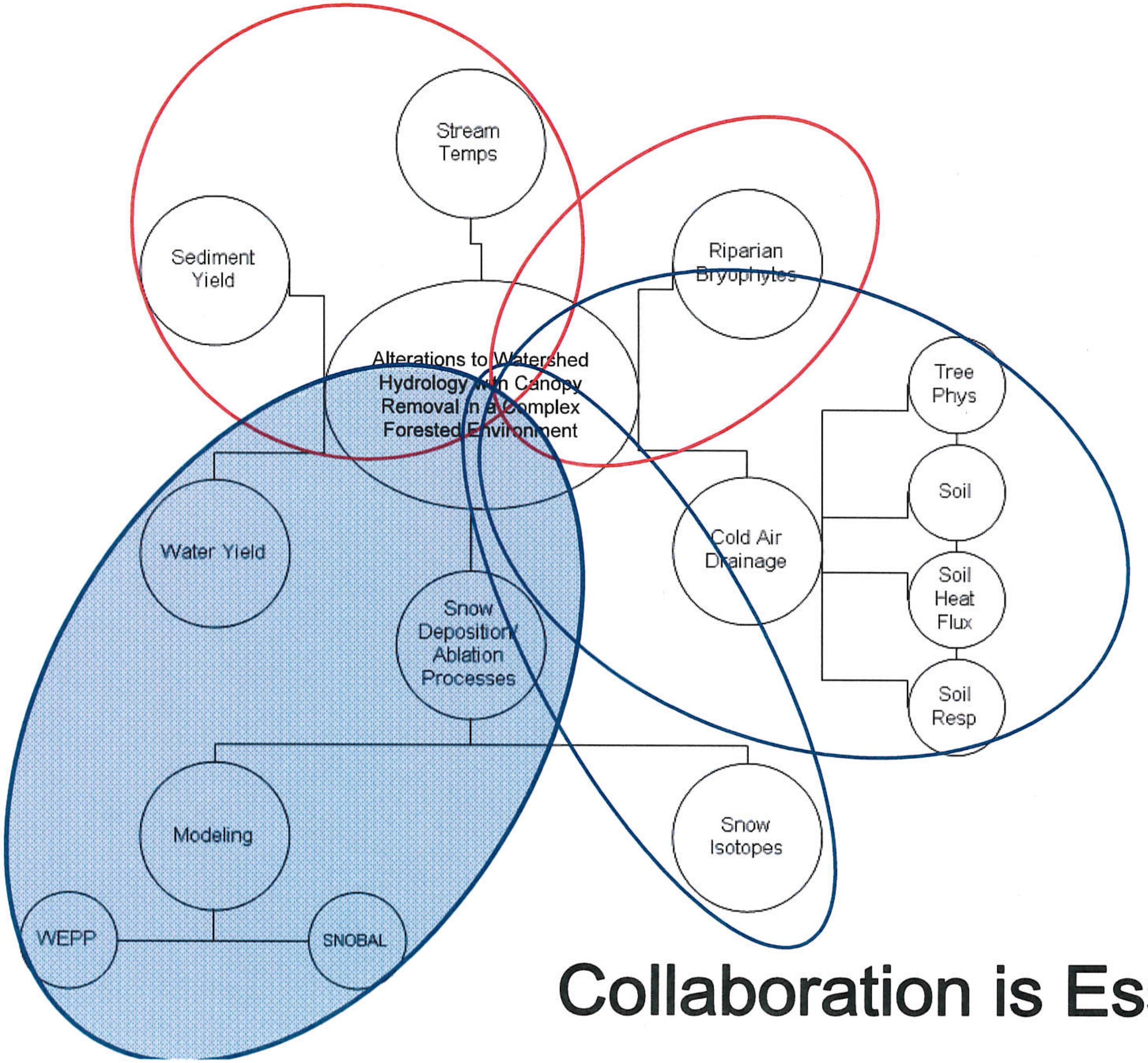

New Mexico, Precipitation, October-September
1901-2000 Avg: 13.96"
Precip
26.25"
13.96"
Inches
24
22
20
18
16
14
12
10
8
Millimeters
650
600
550
500
450
400
350
300
250
200
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

MEASURING AND MODELING HYDROLOGIC RESPONSES TO TIMBER HARVEST IN A CONTINENTAL/MARITIME MOUNTAINOUS ENVIRONMENT

By

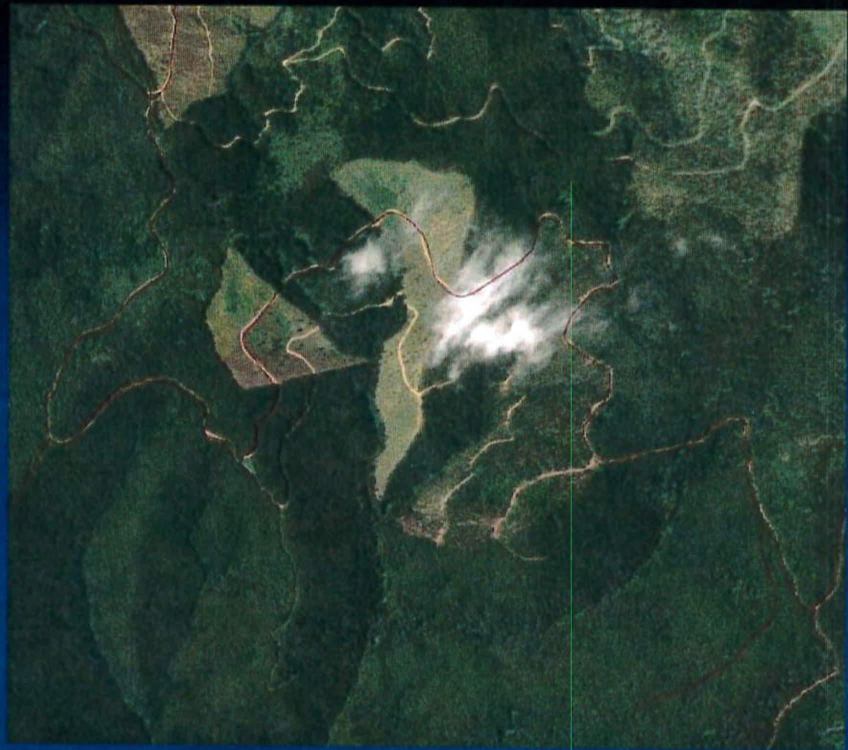
Jason A. Hubbart

Current Research



Collaboration is Essential!

Seminar Overview



- Research Context
- The MCEW
- Study Approach
- Study Results
  - Harvest and water yield
  - Snow deposition - ablation
  - Modeling (WEPP, SNOBAL)
- Peripheral studies & Future work

Historical Studies

- Questions:
  - Effect of forests on water balance
  - Water yield augmentation
  - Impacts on water quality
- 1909: Wagon Wheel Gap, CO
- 1950s – 60s: Many studies initiated
- 1990: Mica Creek instrumented

Research & Management Needs

- Data from “typical” managed forestlands
  - Second growth forests
  - Contemporary management practices
  - Watershed scale studies
- Mechanistic understanding of processes
- Interdisciplinary connections
  - Environmental concerns
- Integrated, spatially-explicit management tools

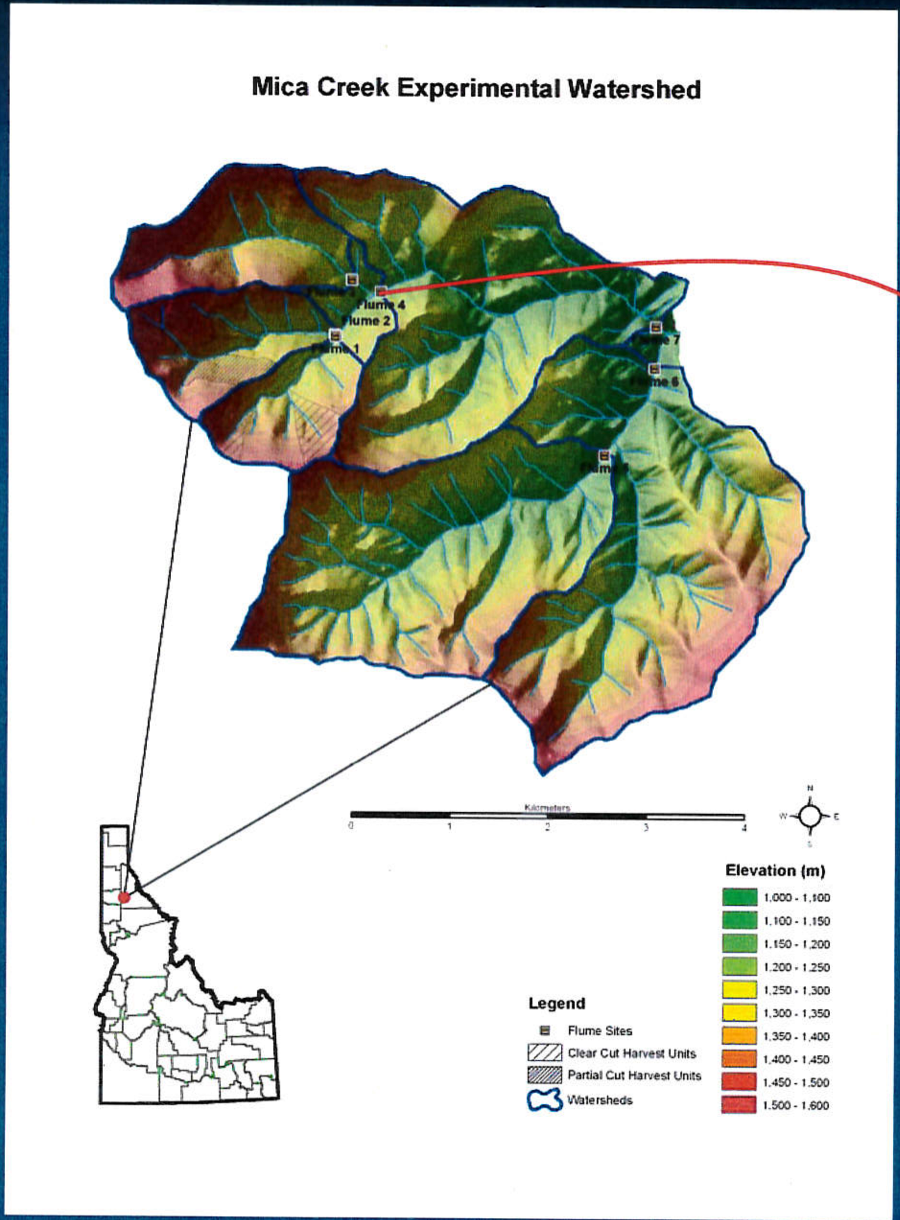
Study Goals

- Water yield
  - Assess changes in annual water yield due to contemporary timber harvest practices
- Snow deposition – ablation
  - Obtain a better understanding of the key processes that influence snow accumulation and ablation in forested mountainous watershed in the northern panhandle of Idaho
- Hydrological modeling
  - Validate model results by comparison to observed data, leading to improved models and hence predictive power
- Inversion processes
  - Provide vertically stratified temperature data in forested mountainous terrain
  - Assess the magnitude to which temperature inversions affect soil temperature by elevation
- Isotopes in snow
  - Describe effect of altitude on snow cover isotopic composition
  - Describe the influence of elevation, and leaf area index (LAI) to the contribution of snowmelt to spring runoff

Potlatch Corporation

MCEW Location

- Unique climate region
  - Continental/Maritime



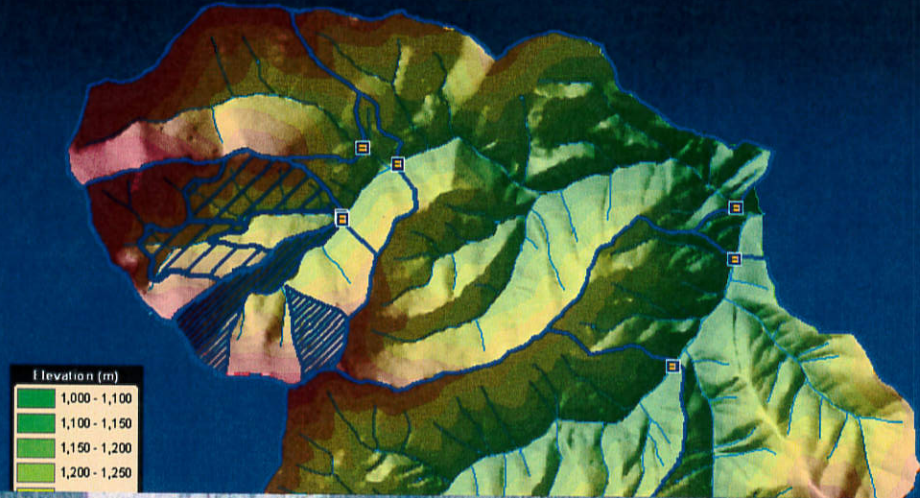
Historical Context

- Extensive logging
  - 1920-1930's
- Limited anthropogenic disturbance since that time

Site Characteristics

- Tributary of St. Joe River
- Size: 27 km^2 (10.5 mi^2)
- Elevation: 1000 – 1625m (3200 – 5240 ft)
- Precipitation: 1440 mm/yr (~57 in/yr)
- Vegetation: 65-75 yr. old mixed conifer
- Geology: Metamorphic - Gneiss, quartzite, granofels

MCEW Study Design



- 50% clearcuts
- 50/50 partial cuts

Annual Water Yield (mm) - Results

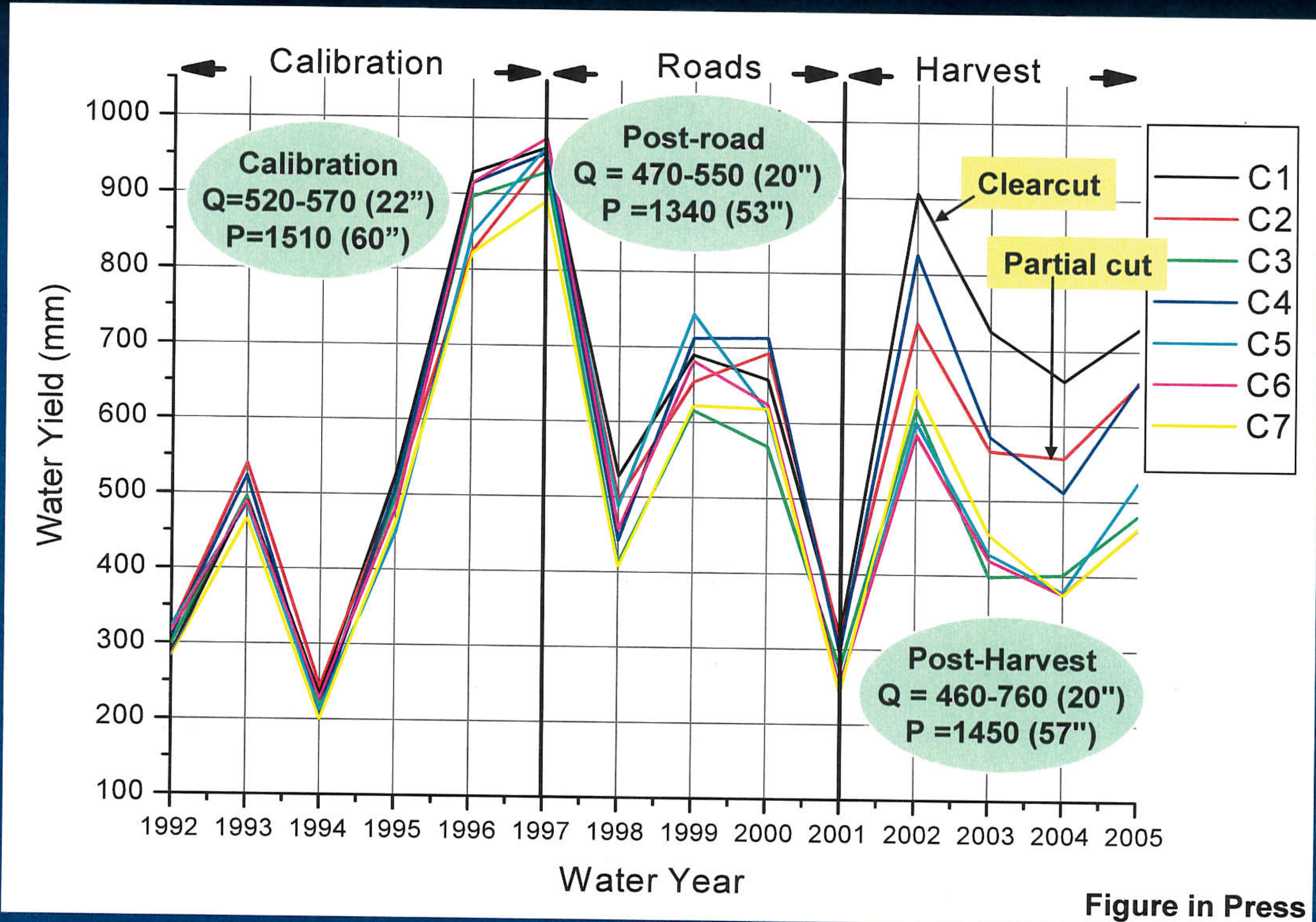


Figure in Press

Hubbart, J.A., T.E. Link, J.A. Gravelle, and W.J. Elliot. 2007. *In Press. In: Special Issue on Headwater Forest Streams, Forest Science*. Timber Harvest Impacts on Hydrologic Yield in the Continental/Maritime Hydroclimatic Region of the U. S.

Annual Water Yield (mm) - Results ($p \leq 0.05$)

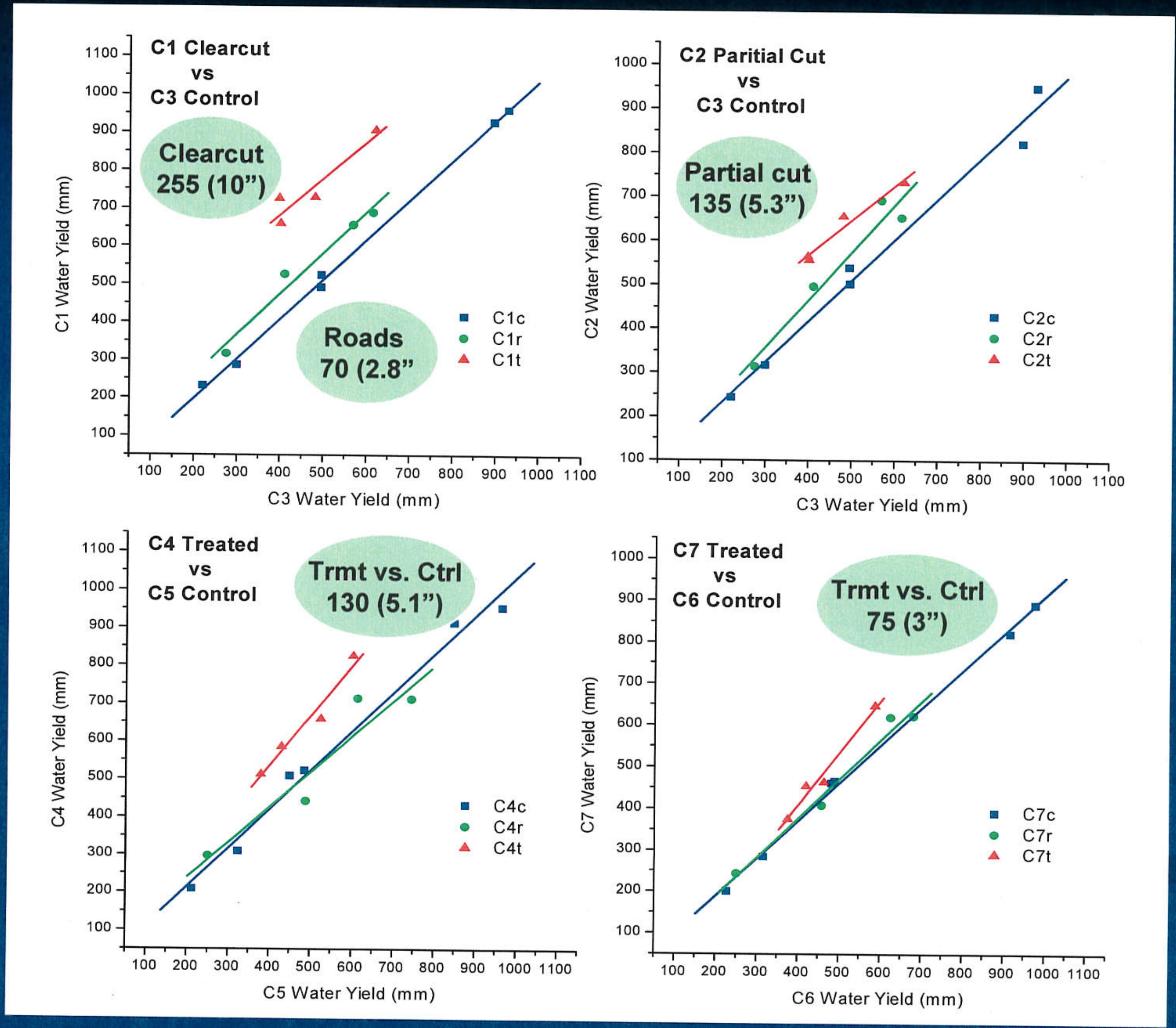


Figure in Press

Water Yield (mm) - Results

<u>Monthly</u>

- Roads
  - Negligible
- Harvest ($p \leq 0.05$)
  - Clearcut
    - ↑ Dec-June, 10-60mm/mo (0.4-2.4"), 35-55%
  - Partial cut
    - ↑ Dec-June, 4-30mm/mo (0.2-1.2"), 9-37%

<u>Seasonal</u>

- Deposition season (Nov – Feb)
  - Clearcut, 14mm (0.5"), 38%↑
  - Partial cut, 10mm (0.4"), 29%↑
- Big Player - melt season (Mar – June)
  - Clearcut, 45mm (1.8"), 35%↑
  - Partial cut, 20mm (0.8"), 20%↑

<u>ET (residual of P-Q)</u>

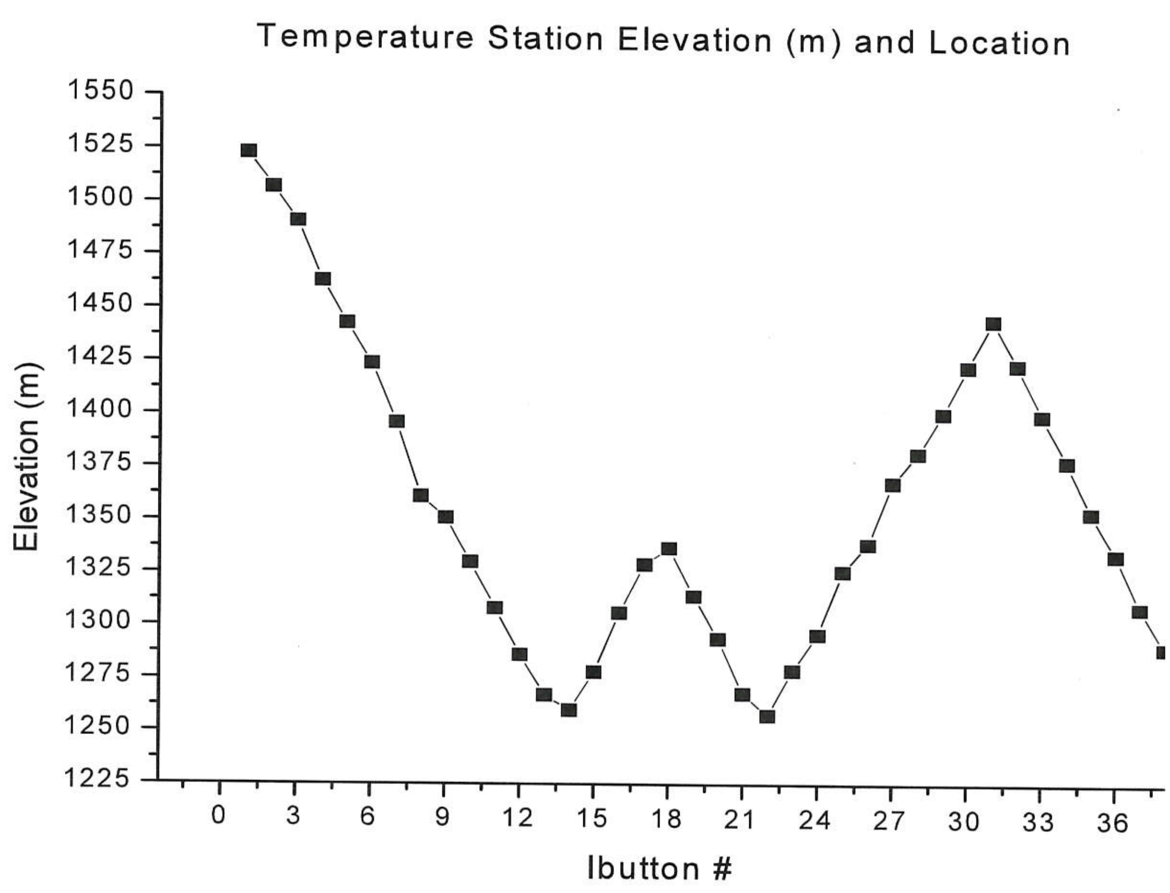
- CC = 62% ↓ to 46% annual budget
- PC = 63% ↓ to 55%

Mechanisms

What are the Mechanisms Contributing to the Changes in Water Yield?

- Snow dominated system
  - Deposition and ablation processes
- Topographic influences
  - Microclimate

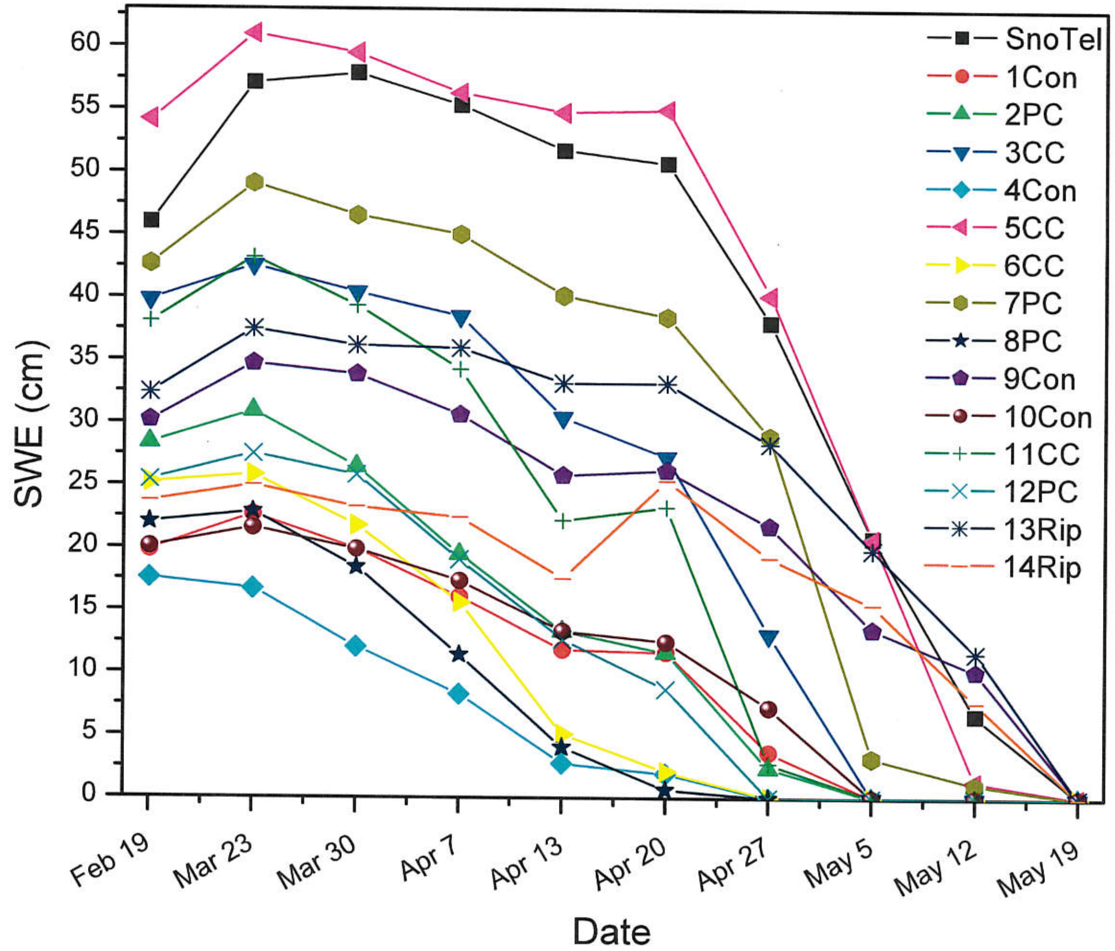
Snowmelt Processes - Methods



- 38 temp/data loggers
  - 3 m height
  - 20 m vertical Dist.
- 14 snow courses
  - 20 m length
  - 2 m sampling
- 7 climate stations
  - Air temp
  - Windspeed
  - Wind direction
  - Relative Humidity
  - Soil moisture
  - Soil Temp
  - Snow Depth

Results – 14 Snow courses

- Peak SWE not correlated with elevation
- Positively correlated to canopy removal.



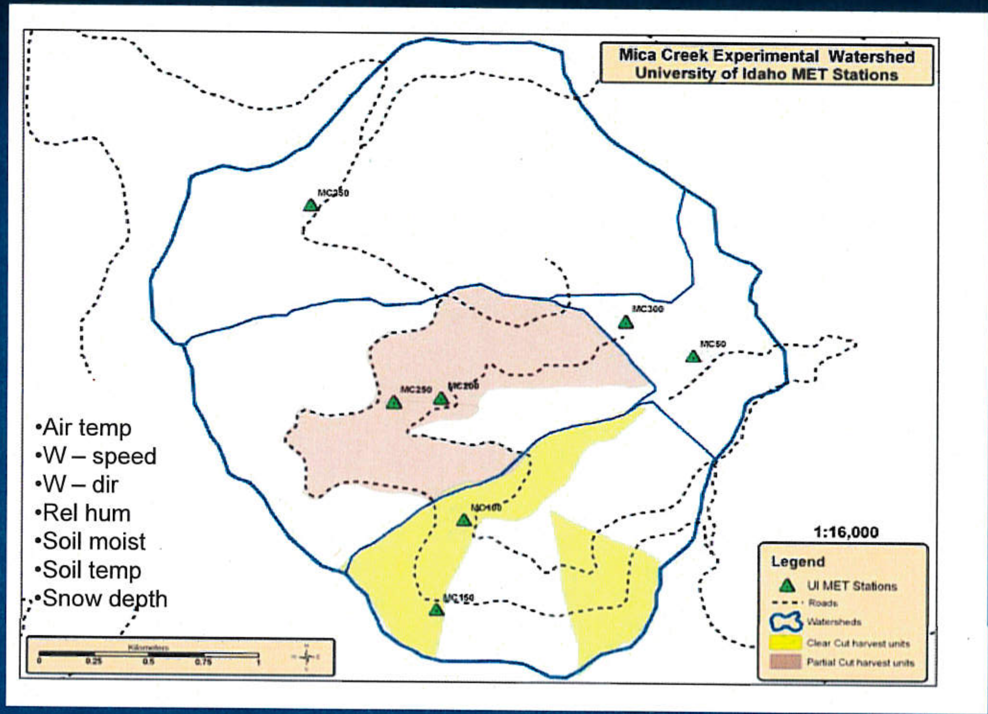
Hubbart, J.A., and T.E. Link. *In: Preparation*. A spatially distributed investigation of snowcover dynamics in a complex mountain environment. Targeted journal: Hydrological Processes.

Snow Course Results

- Peak SWE
- Clearcut
  - 1.3 times greater than peak SWE in partial cut forests
  - 1.6 times greater than the control and riparian sites
- Daily Melt
- Clearcut
  - 1.3 times greater than average daily melt in the partial cut forests
  - 2 times greater than the control and riparian forests

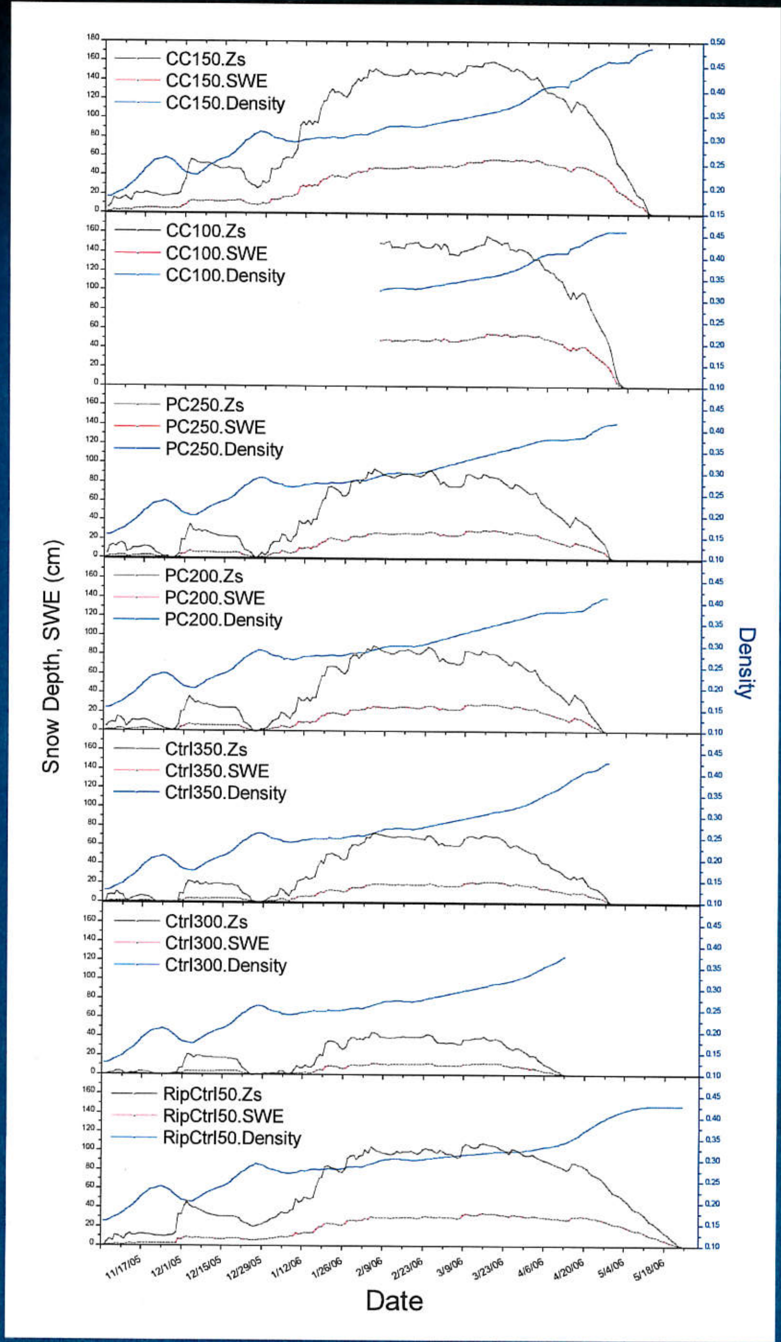
Climate Stations - Methods

- 7 Climate stations
  - Stratified
    - Elev & treatments
  - Data collection
    - 2003 - present
      - 2006 WY to quantify variability of snowmelt



Climate Station Snowmelt

- Peak SWE
  - Clearcut: 56 cm
  - Partial cut: 29 cm
  - Control: 18 cm
  - Riparian: 34 cm
- Average daily melt
  - Clearcut: 1.08 cm/day
  - Partial cut: 0.66 cm/day
  - Control: 0.48 cm/day
  - Riparian: 0.5 cm/day



Preliminary Results/Discussion

- Snow cover is spatially variable
- Canopy reduction and topographic variability can result in considerable differences in snow accumulation and melt rates
- The largest differences in accumulation and ablation rates are observed in the clearcuts
  - Melt rates are approximately twice as fast at the fully forested (control) sites
- Peak SWE and increased daily melt rates appear to be correlated to tree removal (e.g. clearcut), but not to elevation

Synthesis – Modeling - Methods

- Data from 7 climate stations drive the physical process-based snowmelt model SNOBAL (Marks et al., 1999)
  - Output used to assess snowmelt algorithms of WEPP

- Modeling outputs will be compared to observed melt, and in terms of the basic snowmelt energy balance equation:

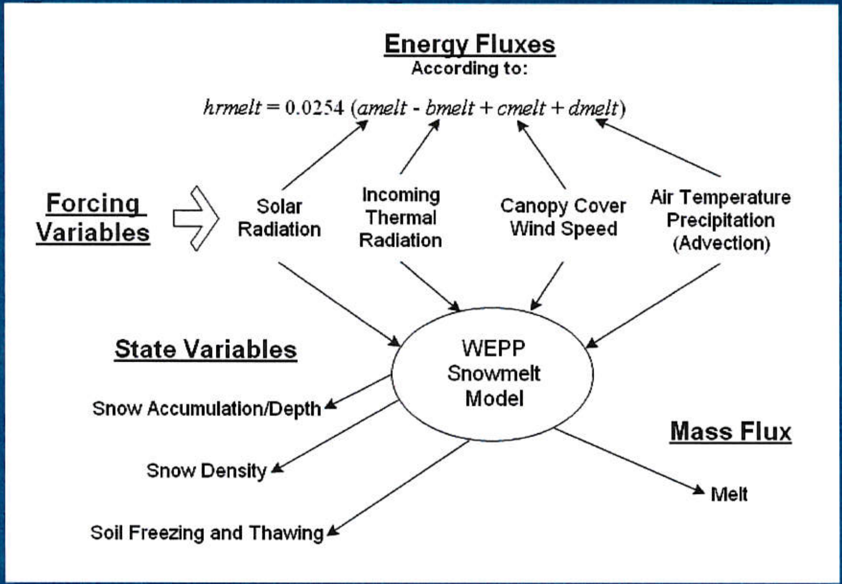
$$\Delta Q = Qn + Qe + Qh + Qg + Qm$$

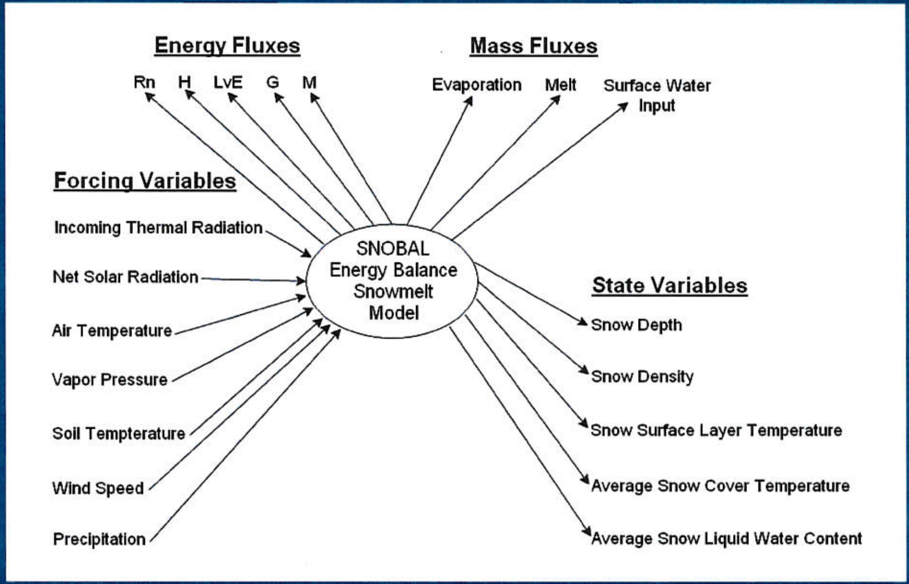
  - ΔQ is change in heat storage of snow cover
  - Qn is net radiation transfer
  - Qe is latent heat transfer
  - Qh is sensible heat transfer
  - Qg is heat transfer from the soil to the snowpack
  - Qm is advected heat.

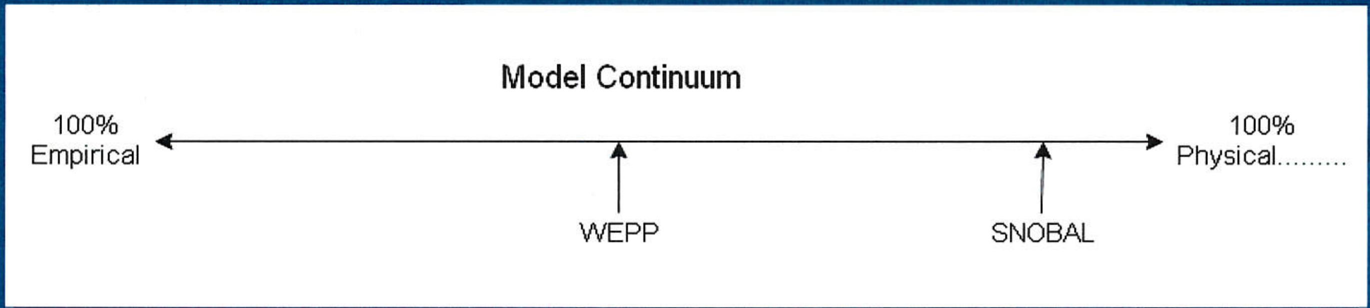
Hubbart, J.A., T.E. Link, and W.J. Elliot. *In: Preparation*. A detailed evaluation of snowmelt dynamics as simulated by Water Erosion Prediction Project (WEPP). Targeted journal: Trans. of ASAE.

WEPP vs. SNOBAL Conceptual Diagrams

- Empirical/Process Based
- Physical/Process Based

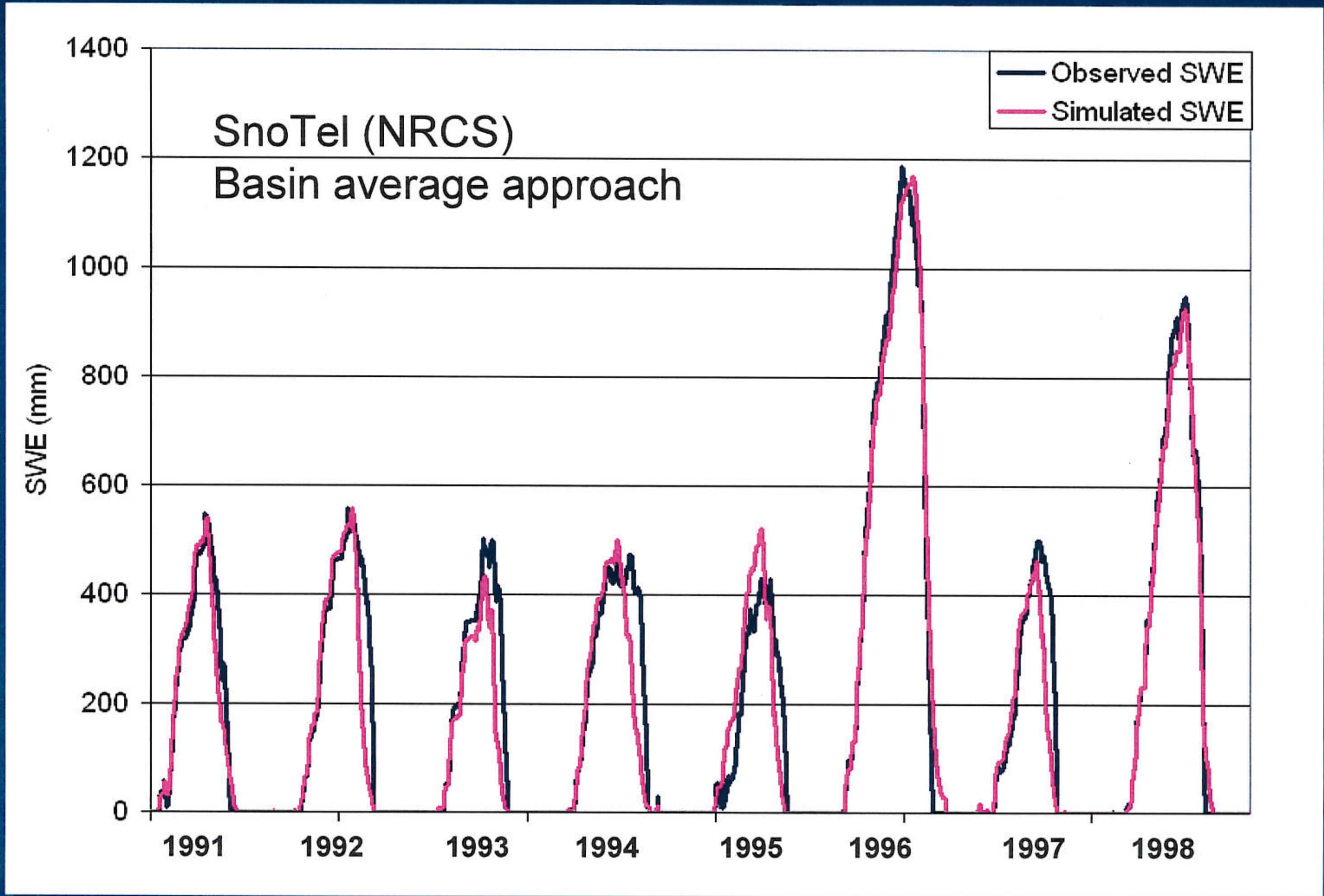






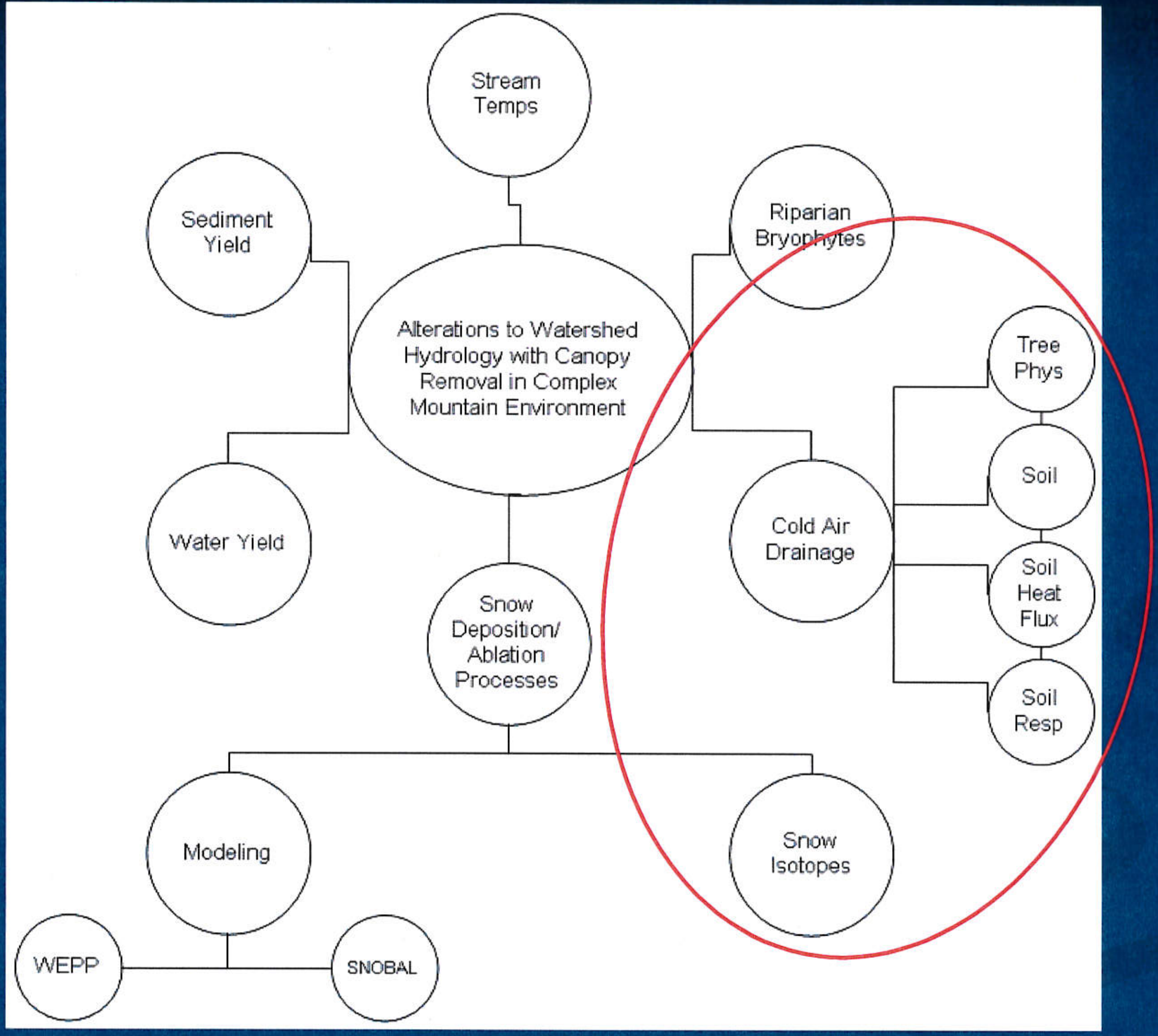
Preliminary Modeling Results

(WEPP) Simulated Snow Water Equivalent (SWE)



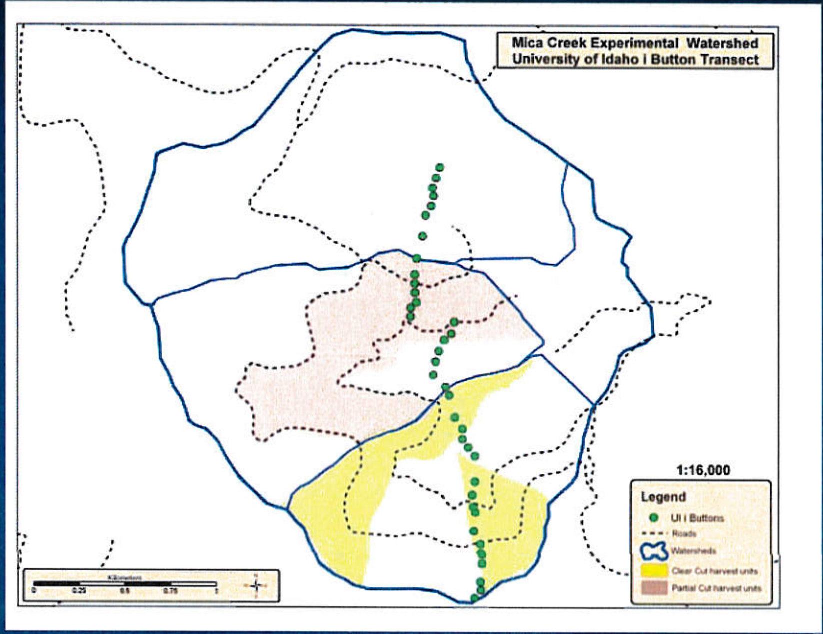
Courtesy: Erin Brooks, BAE, UI

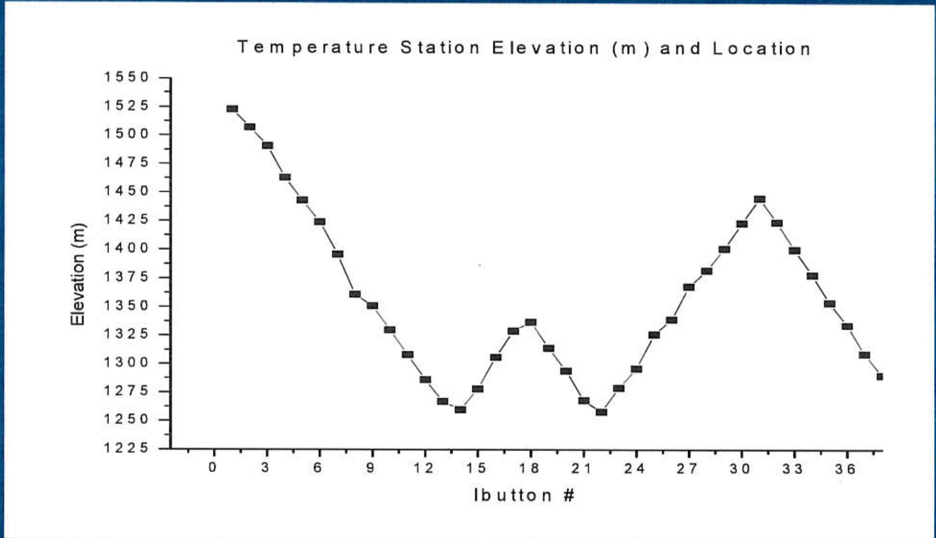
Peripheral Projects



Microclimate - Temperature Inversions

- Temperature transect
  - Elevation, topography, land-use
  - Cold-air drainage/temperature inversions
    - Snowmelt variability
    - Noc cond, soil water pot (Ψ_s)
    - Soil heat, heat flux, respiration



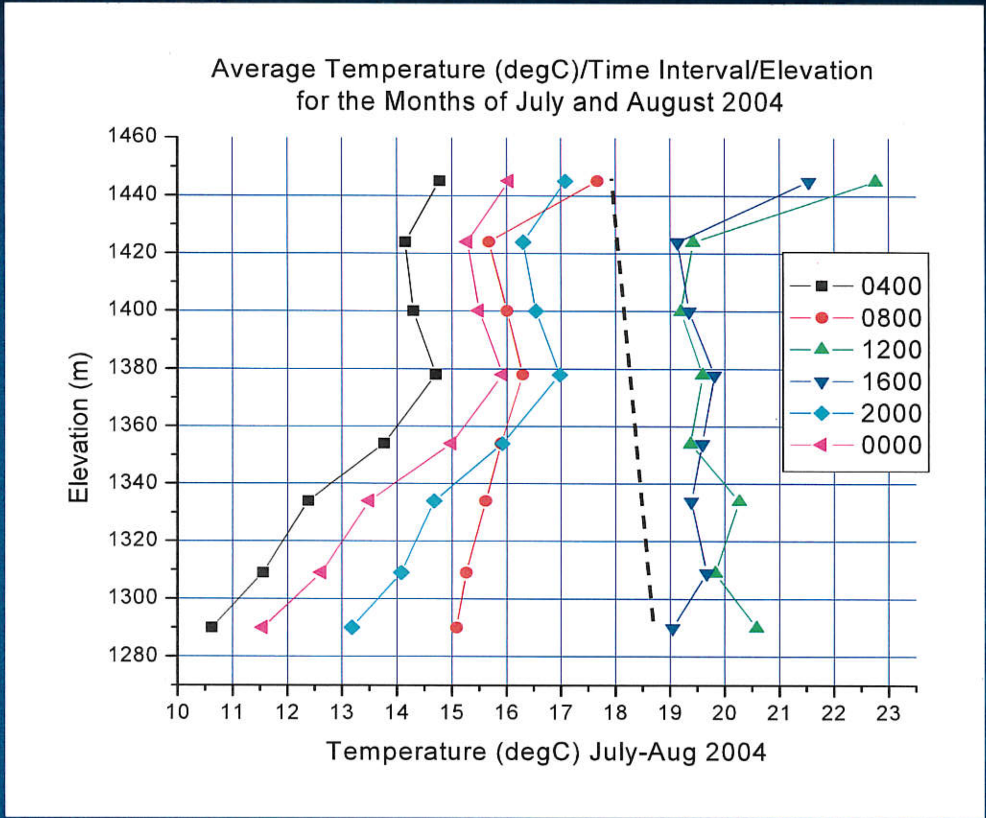


Hubbart, J.A., T.E. Link, C. Campbell, and D. Cobos. 2005. An evaluation of a low-cost temperature measurement system. Hydrologic Processes, 19: 1517-1523.

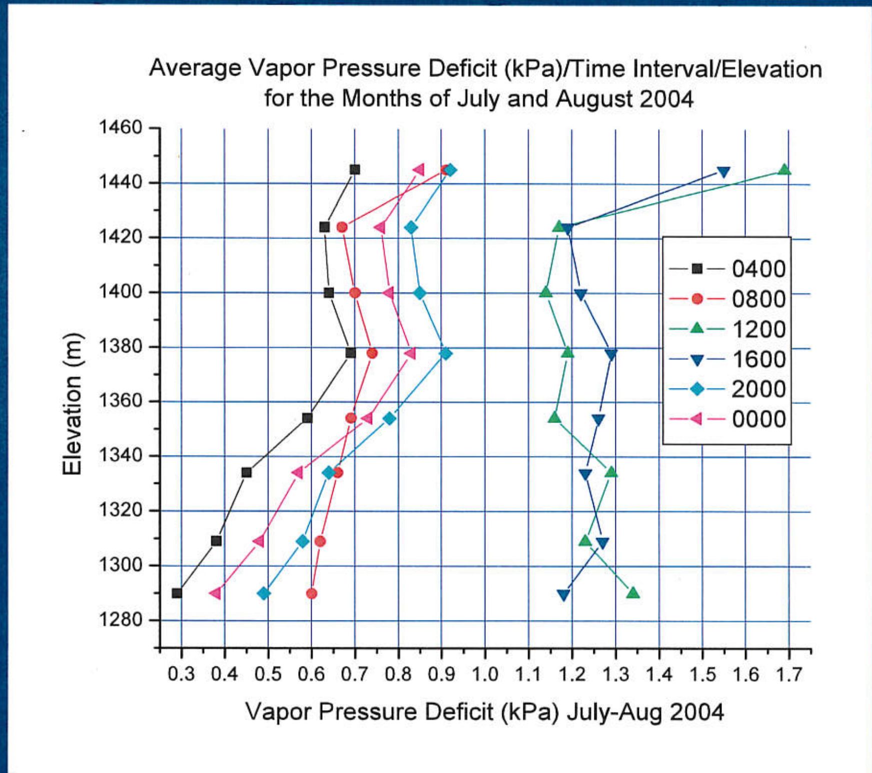
Current Status & Need

- Conventional thought
  - "Normal" lapse rate (~6.5ºC/km)
- Why study?
  - Hydrology - energy balances
    - Snow-melt dynamics
  - Soil Temperature response
    - Soil heat flux
    - Soil respiration
  - Plant physiological response(s)
    - Leaf/stomatal/soil conductance

Lapse Rates/Cold Air Drainage (2004)

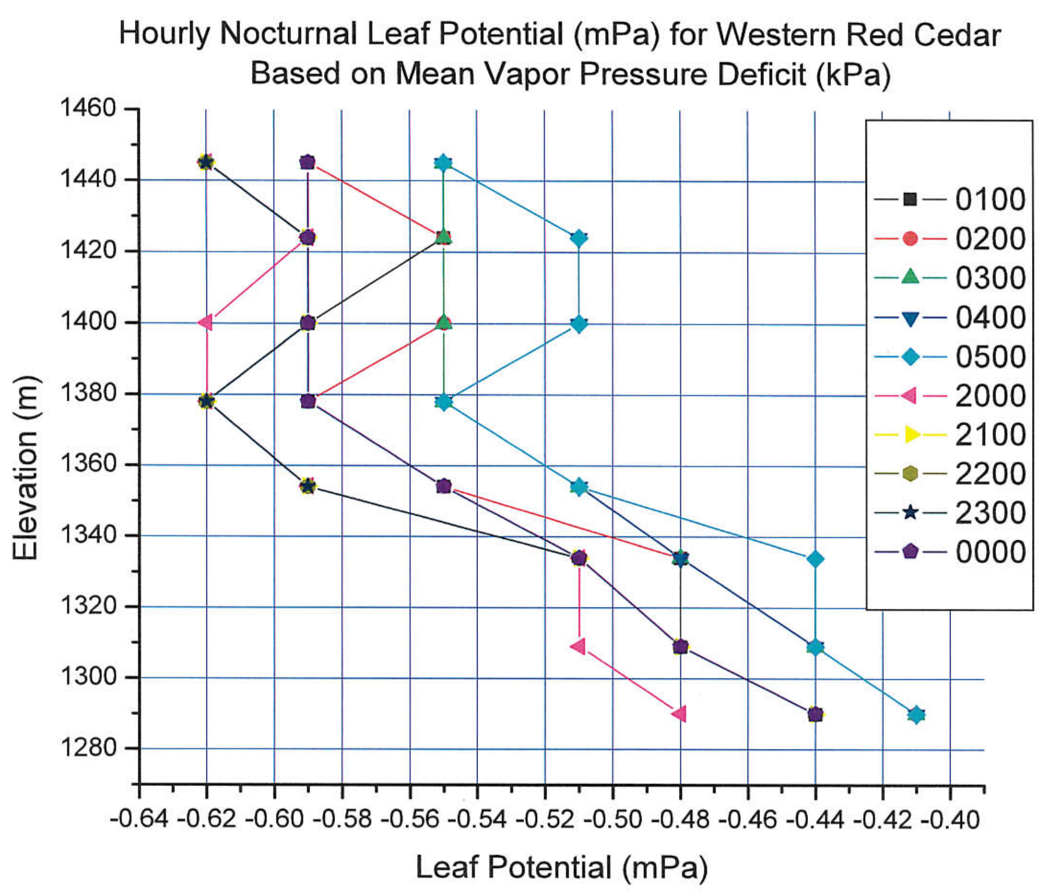


- Mean Air Temperatures
  - Full slope avg ELR (155m): 20.0 °C
  - Cold air pool (88m): 35.0 ° C
- Change in VPD
  - Full slope avg: 0.35 kPa
  - Cold air pool: 0.40 kPa



Hubbart, J.A., K.L. Kavanagh, R. Pangle, T.E. Link, and A. Schotzko. 2007. Cold air drainage and modeled nocturnal leaf water potential in complex forested terrain. *In* Special Issue Tree Physiology 27: 631-639.

Leaf Water Potential (nocturnal)



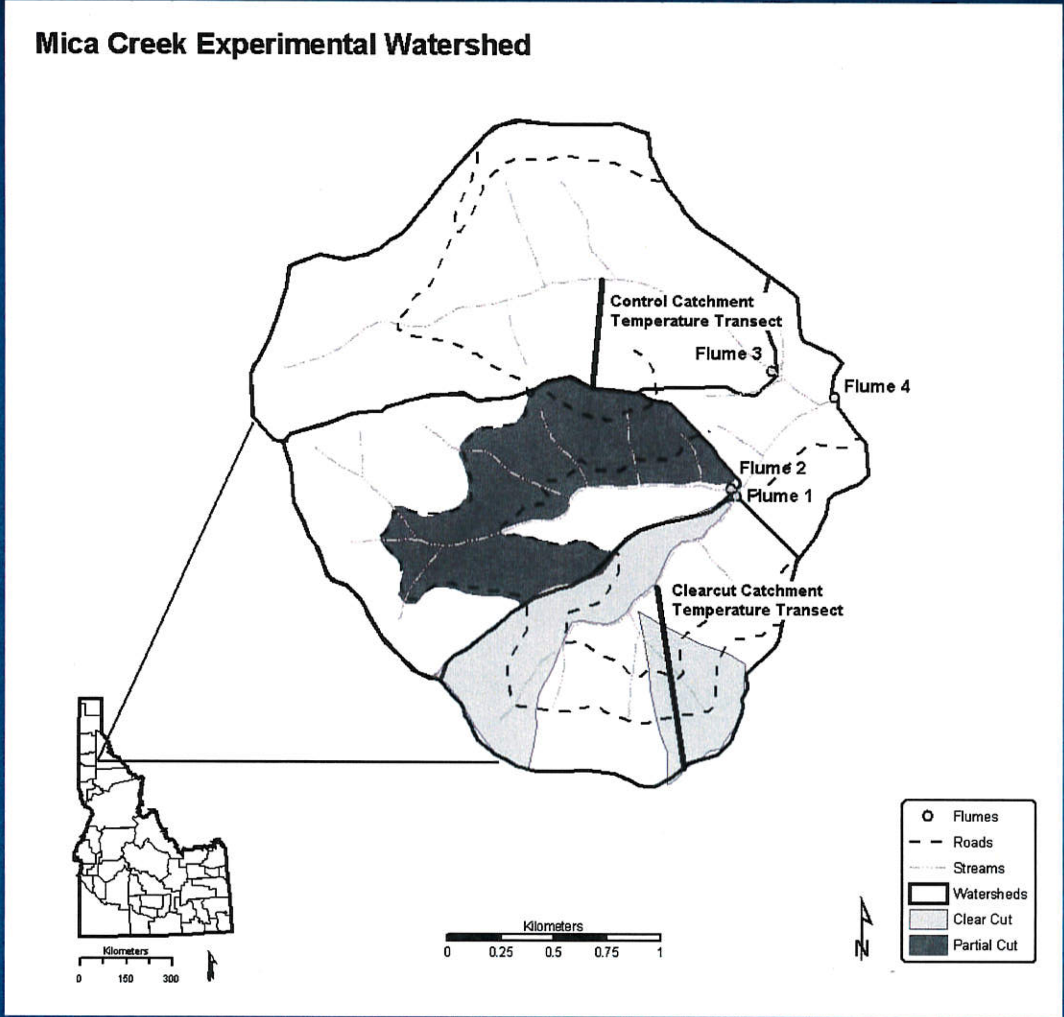
Time	Change in Y_{leaf} (mPa) From Bottom to Top of Slope: Full Slope (155m)	Inversion Layer (88m)
1:00	-0.15	-0.15
2:00	-0.18	-0.18
3:00	-0.14	-0.14
4:00	-0.14	-0.14
5:00	-0.14	-0.14
20:00	-0.14	-0.14
21:00	-0.18	-0.18
22:00	-0.18	-0.18
23:00	-0.18	-0.18
0:00	-0.15	-0.15

Nocturnal ELR, VPD, and modeled Ψ_{leaf} based on mean temperatures for the months of July through August 2004

Discussion (2004)

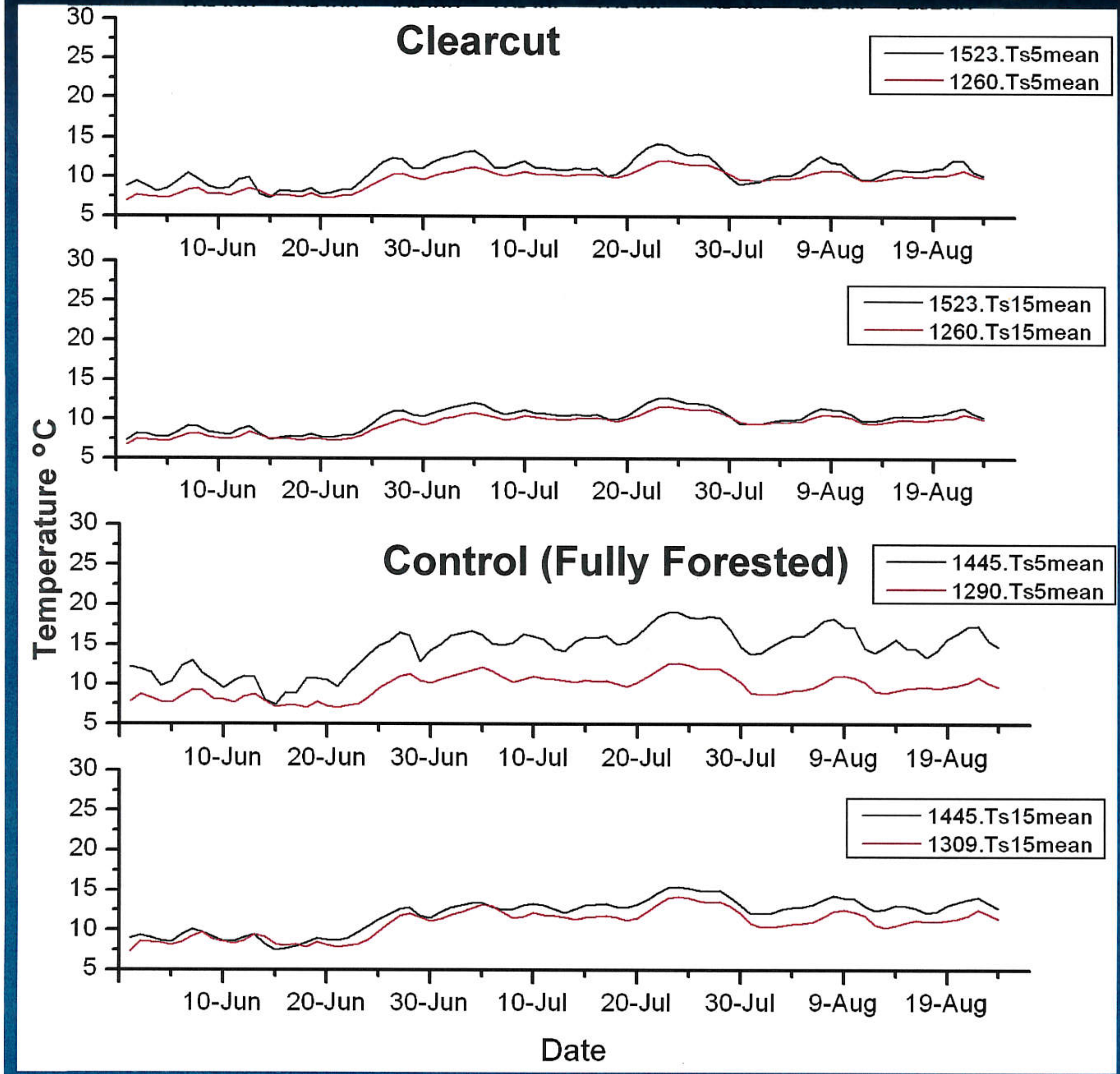
- Inversions/Cold Air Drainage
  - Persistent (the norm)
    - Mean temps
      - ELR = 28.0°C full slope
      - ELR = 48.3°C w/in inversion layer (42% ↑ full slope)
    - VPD tracks
- Based on mean temps
  - Ψ_{leaf} increasingly negative (+25%) towards top of inversion (88m)
    - Max Temps = 37%
    - Min Temps = 13%
- Clear night (Worse case scenario cold air drainage)
  - ELR = 75°C (88m inversion)
  - Ψ_{leaf} was -0.39mPa more negative from bottom to top of COD
- Cloudy night
  - ELR = 1.85°C (88m inversion layer)
  - Ψ_{leaf} –0.04mPa more negative from bottom to top of COD

Effects of Cold Air Drainage on Soil Temperature Analysis (Summer 2006)



Hubbart, J.A., T.E. Link, J. Marshall, E. Du, K. Kavanagh, P. Koeniger, and J.A. Gravelle. *In: Preparation.* Soil Temperature and Modeled Soil Respiration Response to Persistent Temperature Inversions and Timber Harvest in Northern Idaho. Targeted journal: Journal of Agricultural and Forest Meteorology.

Summer 2006 Soil Temperatures



Clearcut

- Ts(5)
  - Avg SLR (263m): 6.5 °C
- Ts(15)
  - Avg SLR 3.0 ° C

Control

- Ts(5)
  - Avg SLR (155m): 53.5 °C
- Ts(15)
  - Avg SLR 11.8 ° C

Take Home Messages

- Not safe to assume a normal temp regime
  - I.e. Cooling with elevation
  - Clear night not same as cloudy night
- Classic assumption of normal lapse rates may not be true
  - ↓ ↑ hydrologic processes
- Classic assumptions of plant physiological responses based on assumed lapse rates may not be true
  - ↓ ↑ nocturnal transpiration
- Assumptions of carbon allocation, forest productivity may not be true
  - ↓ ↑ forest productivity
    - Soil Respiration

Inversions - Future Directions

- 5 slope analysis
    - Clearcut
    - Partial cut
    - Control
  - Winter – snowmelt implications
  - Summer
    - Hydrological implications
    - Plant physiological implications
- Improved forest productivity analyses
  - Soil moisture, and others
  - NPP
- Improved forest management
  - New and improved predictive models
- Temperature Inversions: Dynamic fluid model
  - Collaboration with Dr. Paul Gessler (GIS)
- Inversions and fire effects
  - Movement and transport, modeling

Isotopes in Snow

Why Isotopes?

- Helpful tool for investigating snowmelt contributions to runoff.
- Initial isotope signals are stored in snow layers (Stichler et al. 2000).

Need:

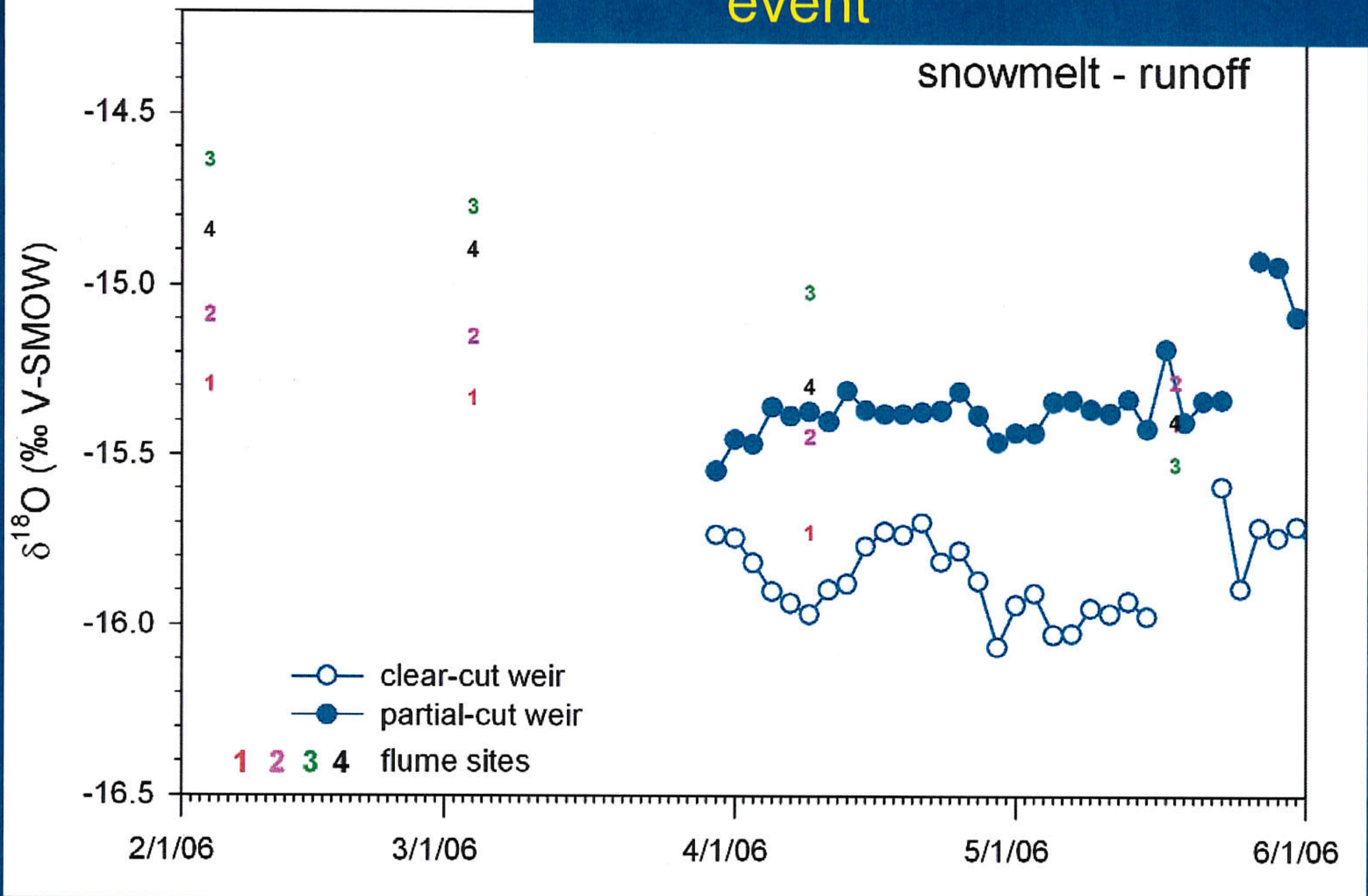
- Consideration of spatial variations of isotopes in snowpacks as tracer inputs to catchment studies (Unnikrishna et al. 2002).

Objectives:

- Quantify the isotope distribution in snow layers vs. variations in meteorological parameters and management practices (e.g. clear-cut, partial-cut and fully forested sites).
- Quantify spatial variability of elevation, canopy structure on snow cover isotopic composition (^{18}O), and the contribution of snowmelt to spring runoff.

Isotopes in snowmelt

- No altitude effect in snow
- Spatial variability vs. LAI
- Differences in spring snowmelt event



Koeniger, P., **J.A. Hubbart**, T. Link, and J.D. Marshall. *In Submission*. Stable isotope variability in snowcover and snowmelt in response to forest management at the Mica Creek Experimental Watershed, Northern Idaho. Hydrological Processes.

Research Synopsis

- Water Yield
  - ~30% increase post clearcut
  - ~20% increase post partial cut
- Snow deposition/ablation processes
  - Peak SWE ~1.5x higher in clearcut relative to control
  - Melt ~2x higher in clearcut relative to control
- Modeling – coming soon…….
- Inversions
  - Persistent
  - Effects – tree physiological response, soil heat flux, soil respiration
- Isotopes
  - Provide mechanism to better understand relative contributions to runoff
- Sediment
  - Increase 3x post clearcut for 12 months
- Tstream
  - Increased from clearcut
  - Highly variable (hyporheic exchange?)
- Bryophytes
  - Bioindicators of forest management impacts

Research Funding

- USFS Research Joint Venture Agreement #03-JV-11222065-068
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- USDA-CSREES 2003-01264
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Graduate Committee Members

- Timothy Link
- Katy Kavanagh
- Jan Boll
- Bill Elliot

Thank You