Towards understanding hydrology and water quality impacts from the mountain pine beetle infestation in the Rocky Mountain west

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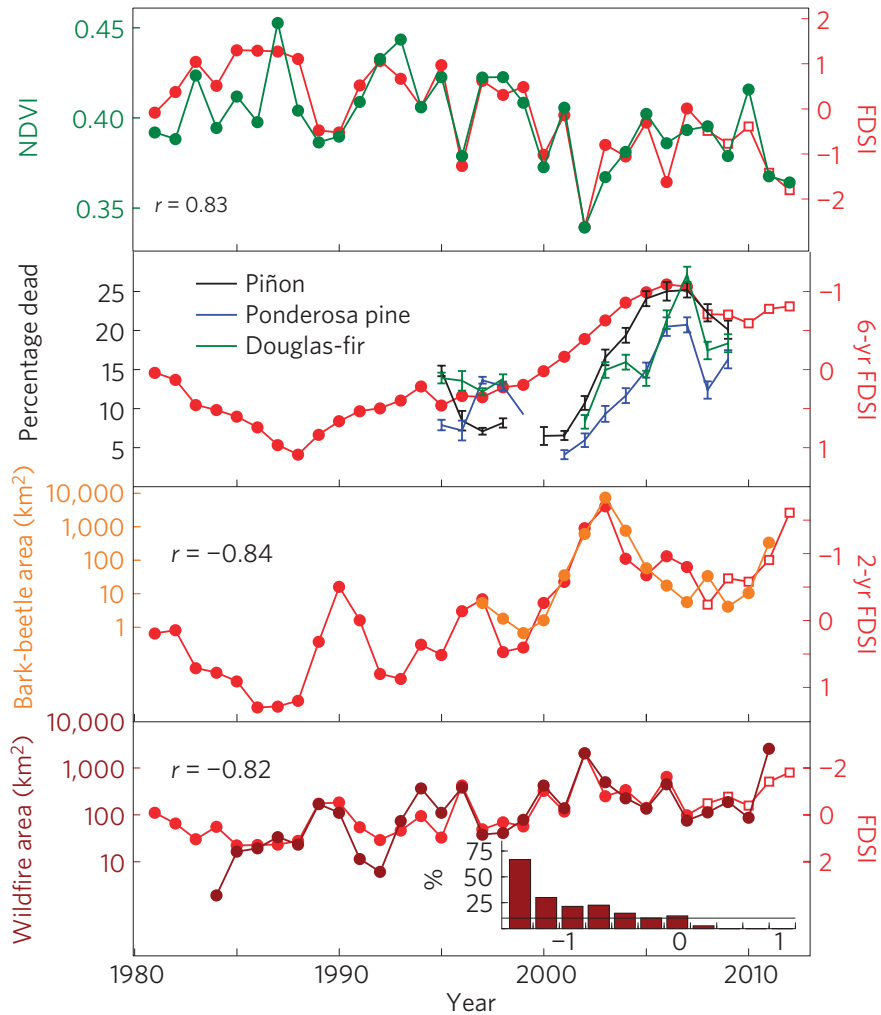
students, postdocs, faculty

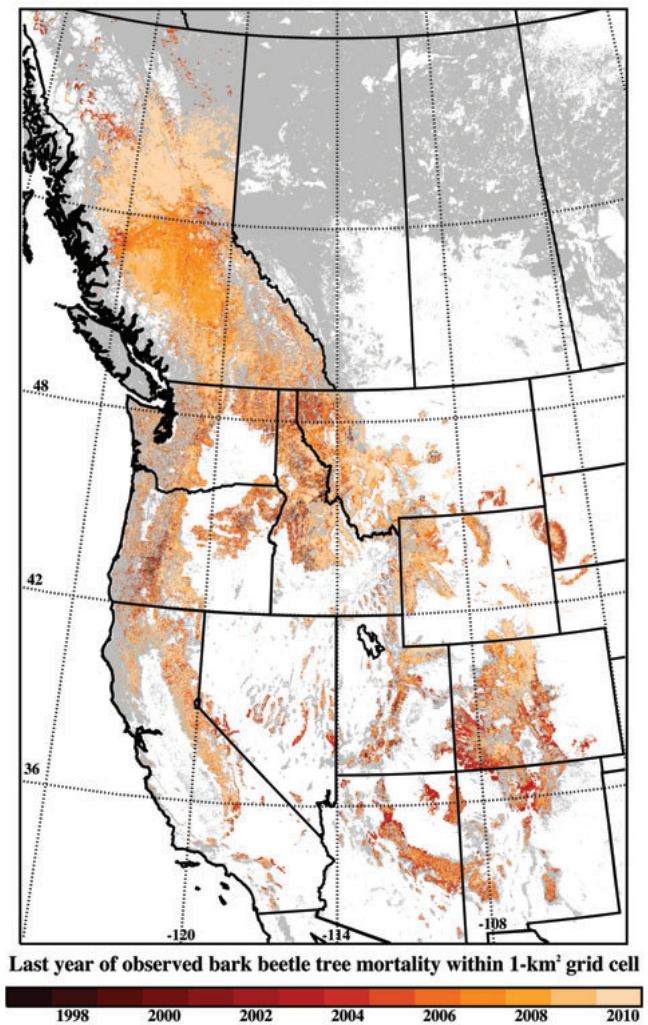
Colorado School of Mines,
Colorado State University

Temperature and insect-driven tree mortality is increasing

Forest drought stress has increased, increasing beetle infestations and tree mortality

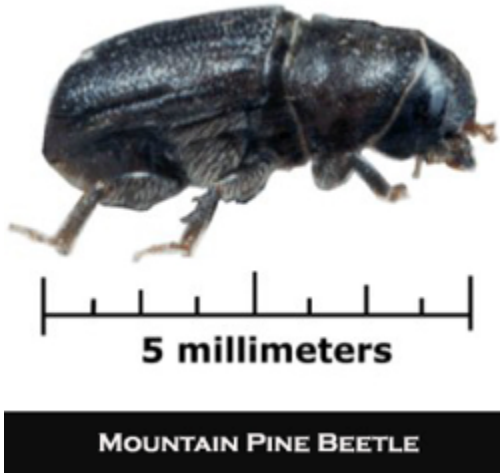


Williams *et al* NCC (2013)



Edburg *et al* FEE (2012)

Mountain Pine Beetle (MPB)
Dendroctonus ponderosae



4 Stages of MPB Infestation

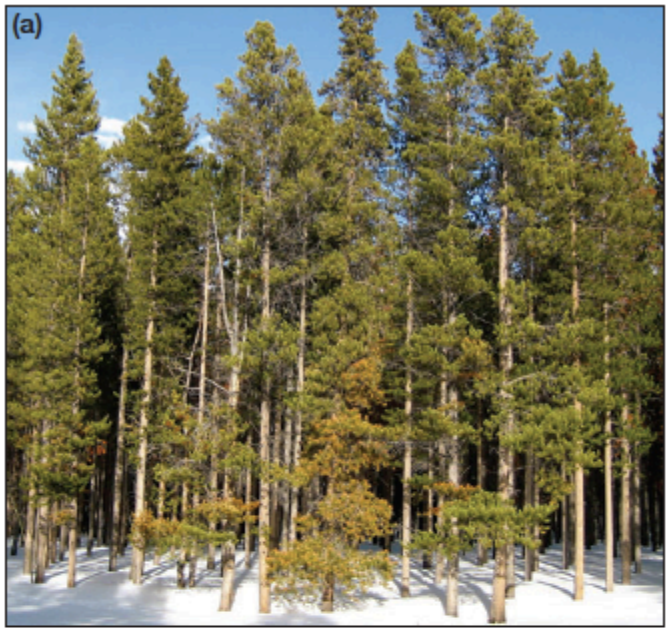
(a) Green

(b) Red

(c) Grey

(d) Regrowth

Edburg et al 2012



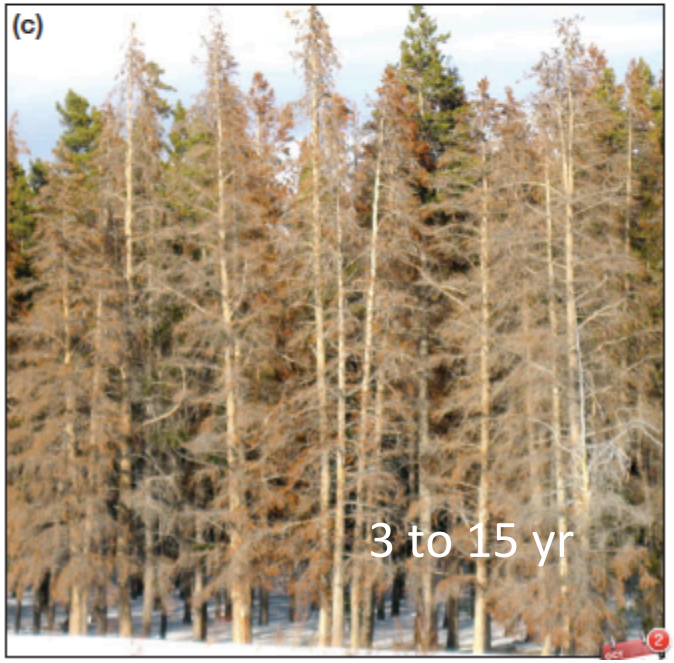
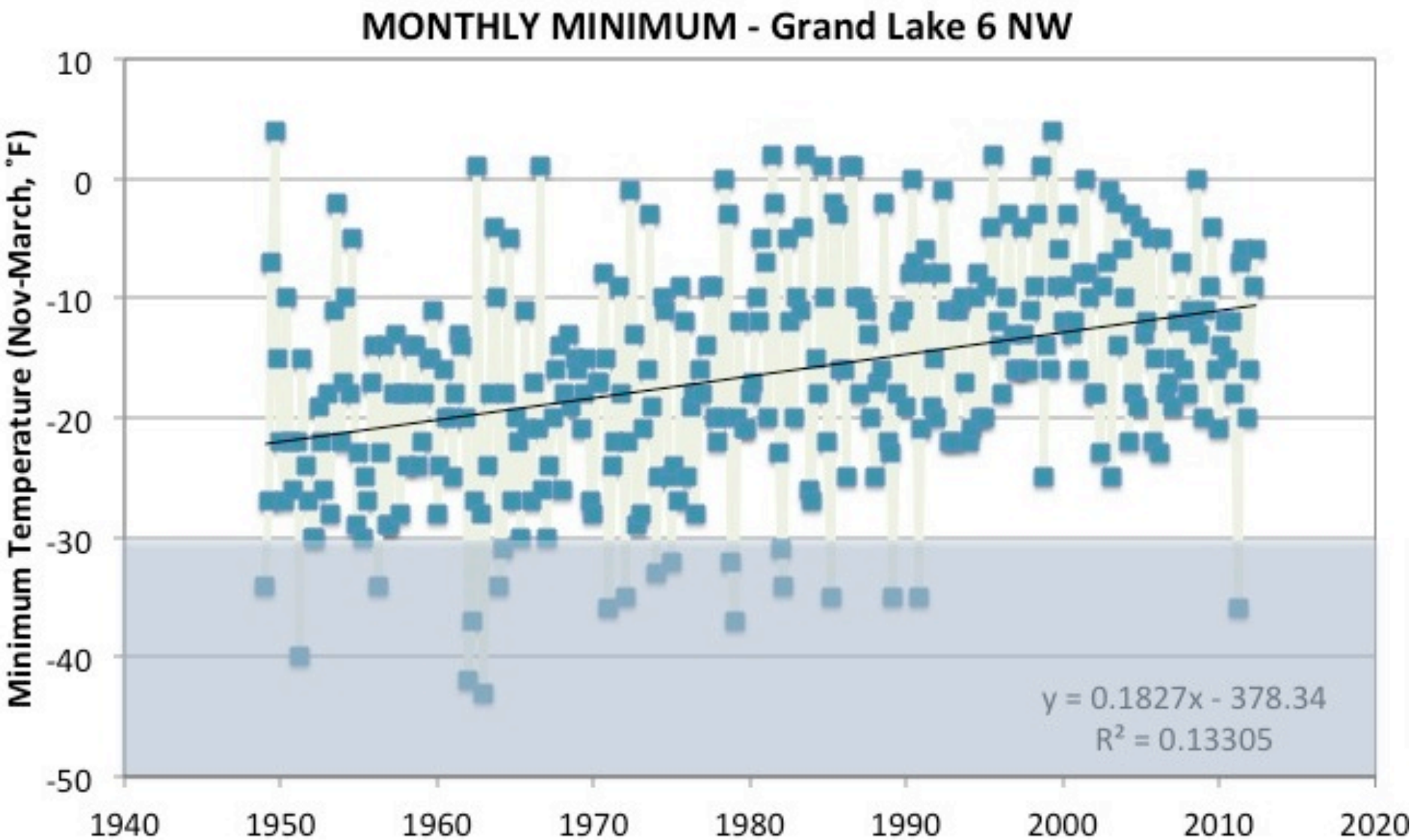
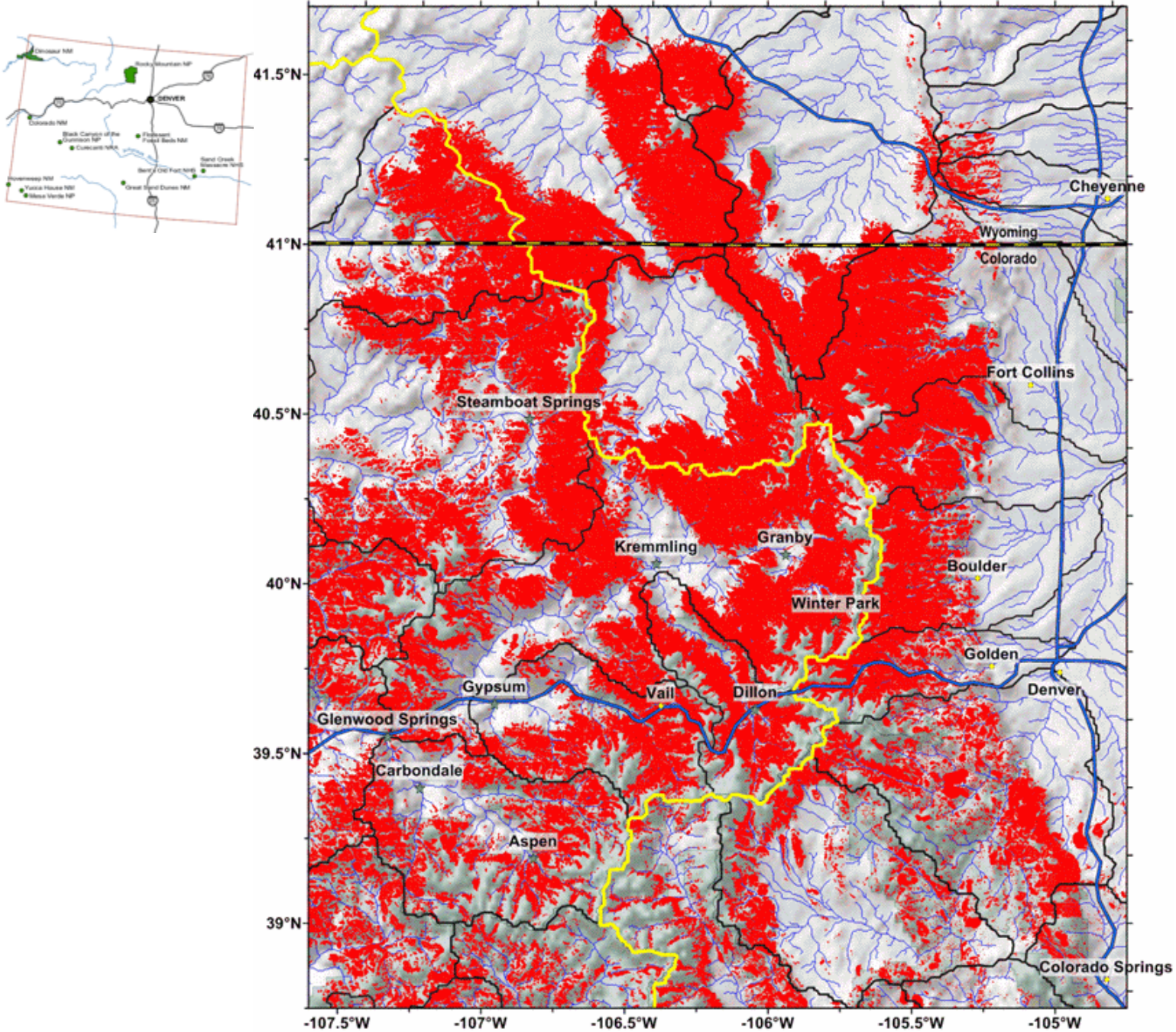


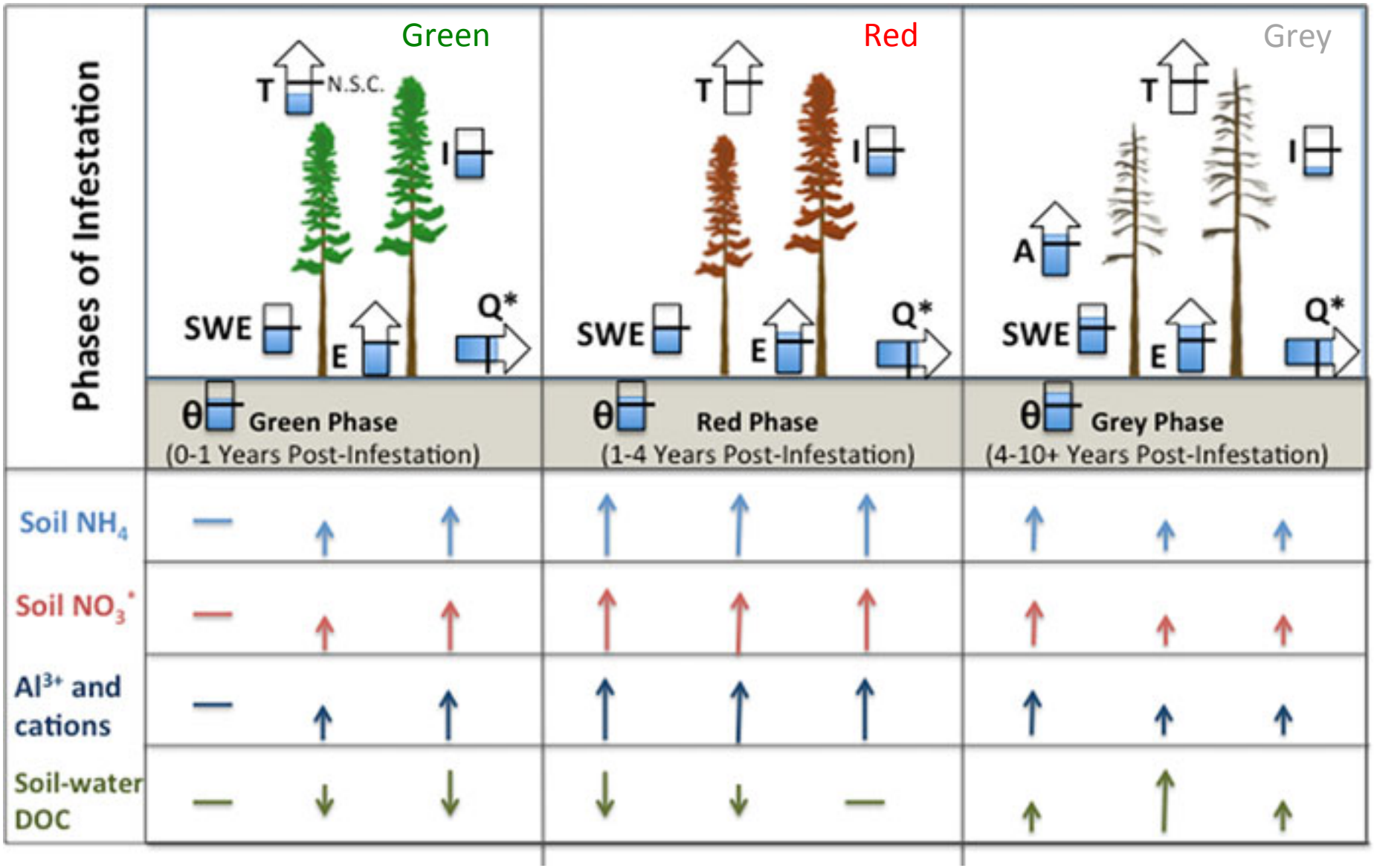
Figure 3. Photographs of different stages of bark beetle outbreaks. (a) Stage 1, green attack; (b) stage 2, red attack; (c) stage 3, gray phase; (d) stage 4, snagfall and re-growth.


MONTHLY MINIMUM - Grand Lake 6 NW
Minimum Temperature (Nov-March, °F)
10
0
-10
-20
-30
-40
-50
1940
1950
1960
1970
1980
1990
2000
2010
2020
y = 0.1827x - 378.34
R² = 0.13305


41.5°N
41°N
40.5°N
40°N
39.5°N
39°N
-107.5°W
-107°W
-106.5°W
-106°W
-105.5°W
-105°W
Cheyenne
Wyoming
Colorado
Fort Collins
Steamboat Springs
Kremmling
Granby
Boulder
Winter Park
Golden
Gypsum
Vail
Dillon
Denver
Glenwood Springs
Carbondale
Aspen
Colorado Springs

2011

How might this impact water?

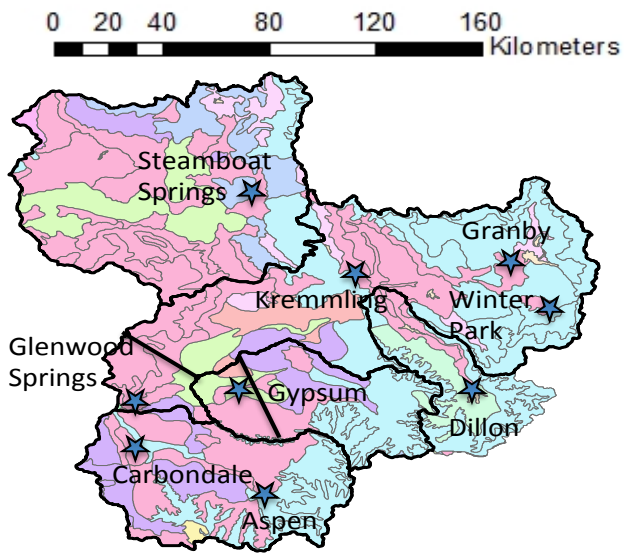


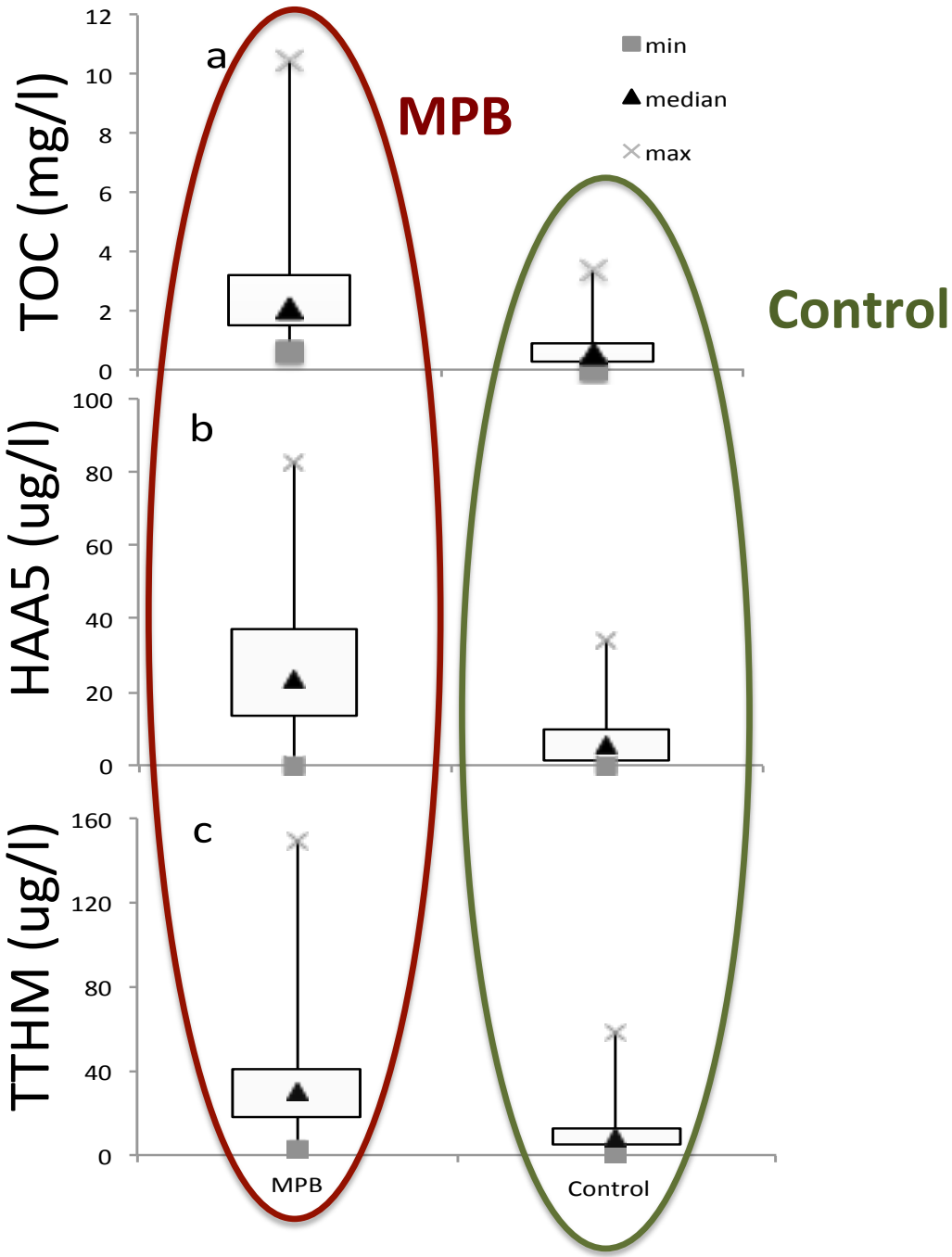
Mikkelson, Bearup, Maxwell, Stednick, McCray, Sharp, *Biogeochemistry* 2013

A few project results

- *Predicted hillslope changes in hydrology*
- *Observed water quality impacts*
- **Isotopic observations demonstrate changes in transpiration**
- ***Multiscale modeling***
- **Stakeholder perception and communication**
- Tree-scale metals transport
- Education and outreach

Comparisons between beetle-impacted (MBP) and control watersheds show decreases in water quality. These are first observed drinking water-quality impacts due to climate change.





Mikkelson et al *Nature Climate Change* 2013

We have a range of field sites across the Rocky Mountain headwaters region

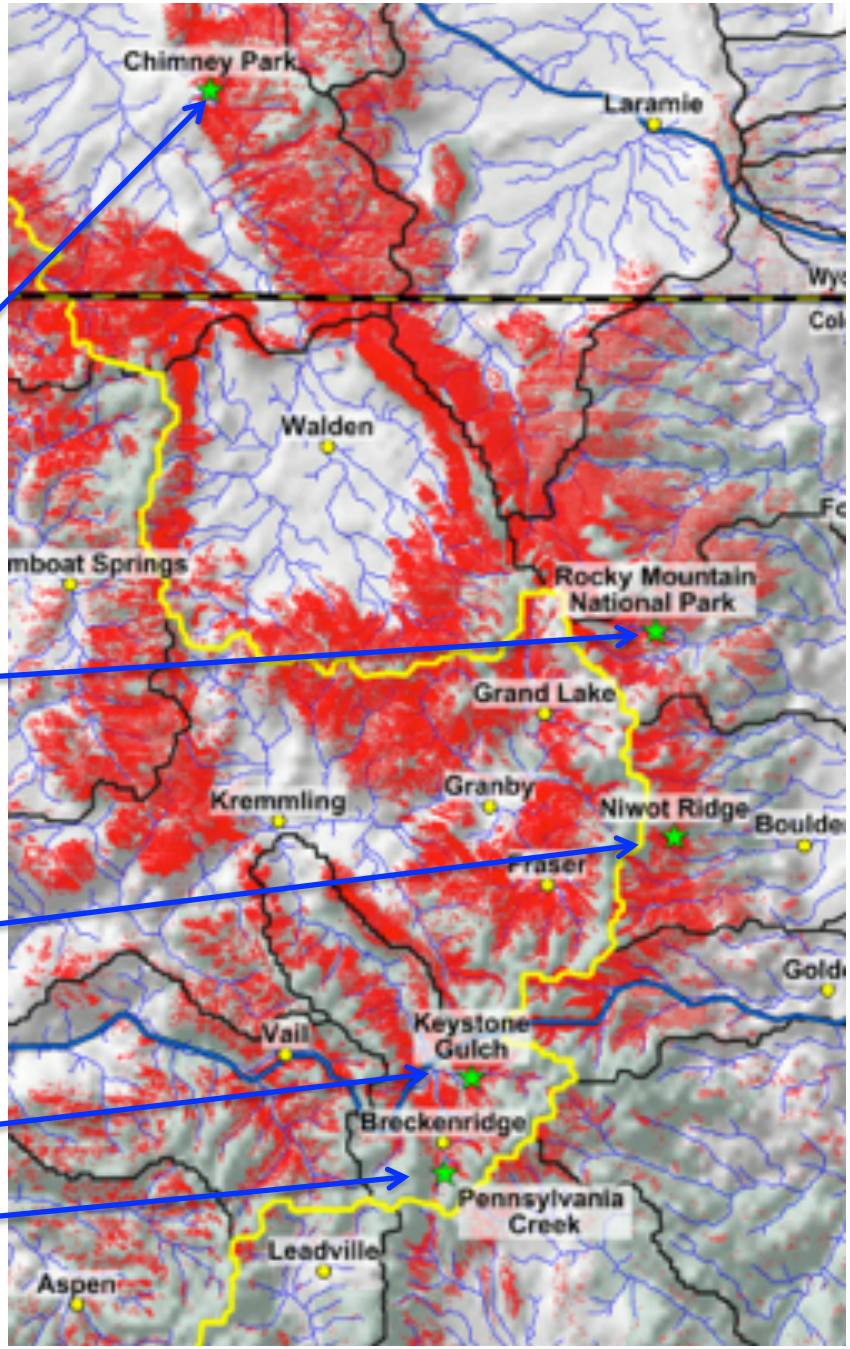
Chimney Park

RMNP

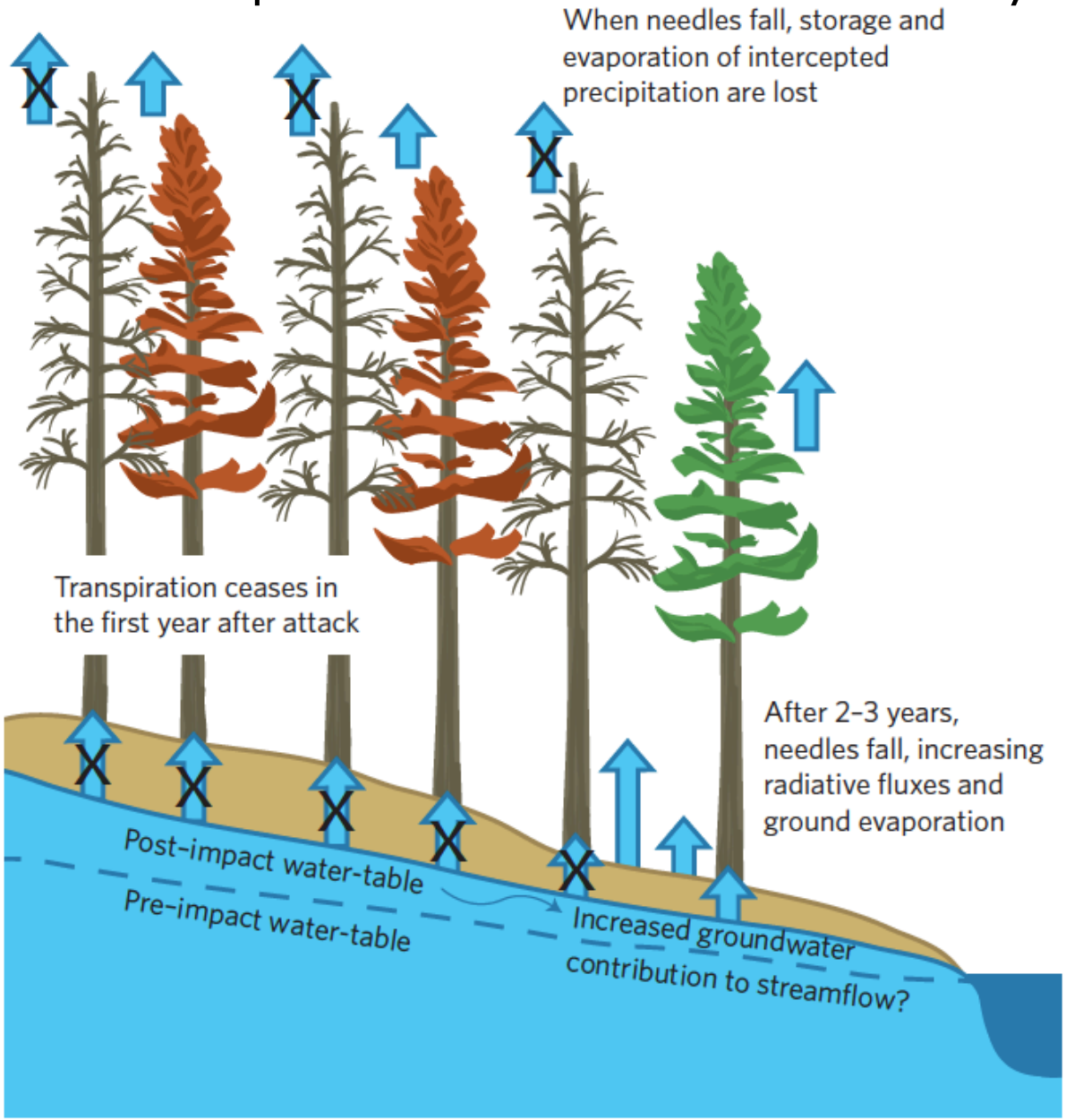
Niwot Ridge (LTER)

Keystone Gulch

Penn Gulch

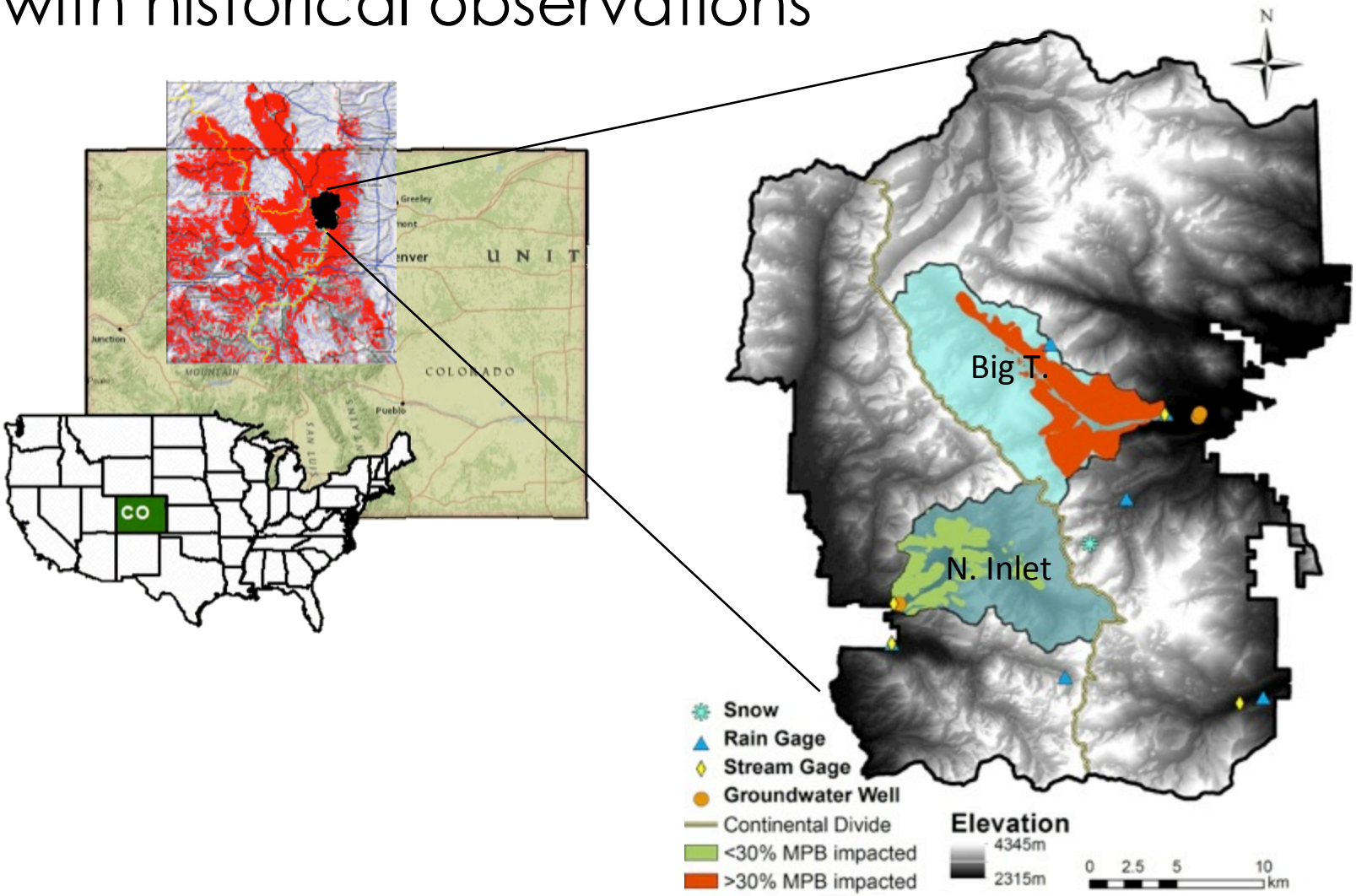


Our conceptual model links late summer groundwater uptake and tree mortality



(Bearup et al *NCC* 2014)

We use a paired-watershed approach combined with historical observations

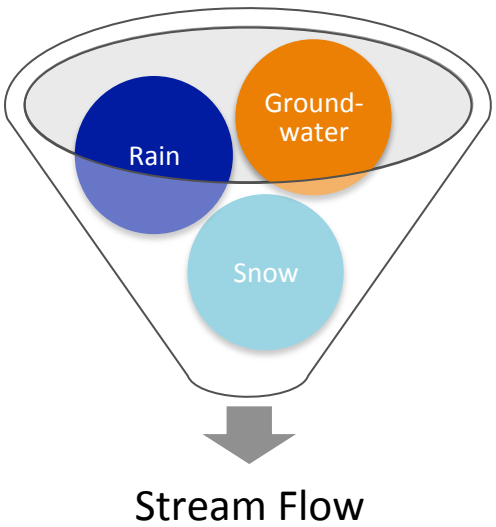


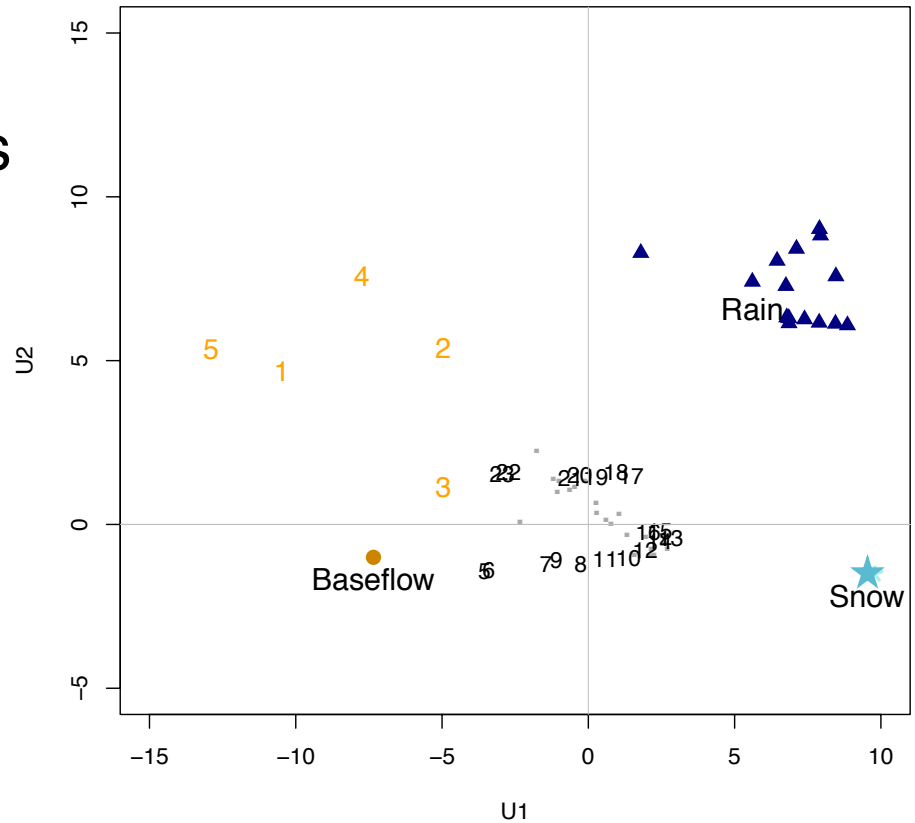
Watershed	Area (km^2)	Sampling Elevation (m)	MPB-impacted area (%)	Onset of Infestation
Big Thompson	95.02	2468	32.3%	2006
North Inlet	72.82	2590	23.7%	2004

(Bearup et al *NCC* 2014)

We use end-member mixing to determine contributions to the hydrograph

End Member Mixing Analysis (EMMA)



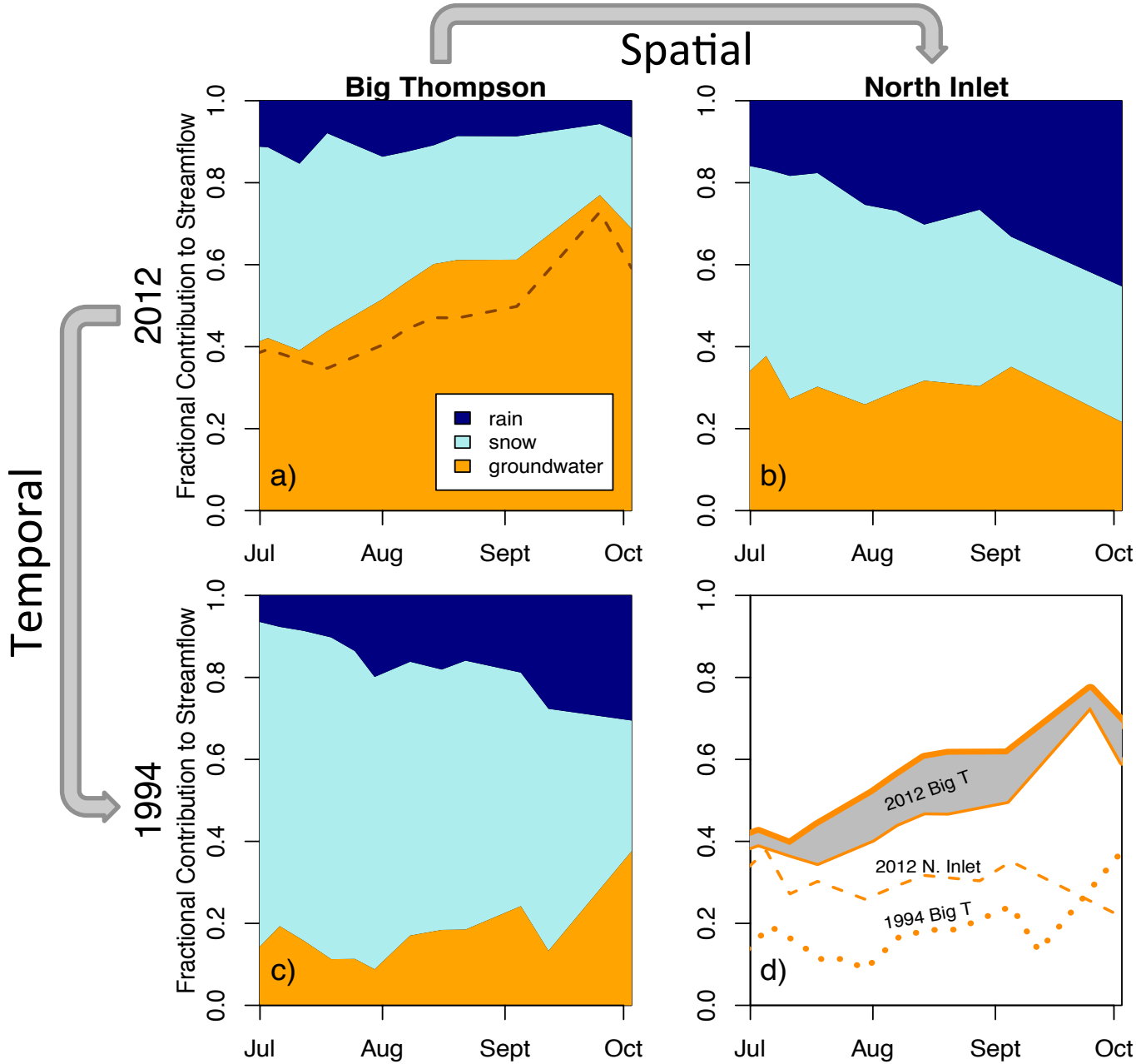


Three end-member hydrograph separation

$$\begin{cases} Q_s \times EC_s = Q_r \times EC_r + Q_n \times EC_n + Q_g \times EC_g \\ Q_s \times \partial^{18}O_s = Q_r \times \partial^{18}O_r + Q_n \times \partial^{18}O_n + Q_g \times \partial^{18}O_g \\ Q_s = Q_r + Q_n + Q_g \end{cases}$$

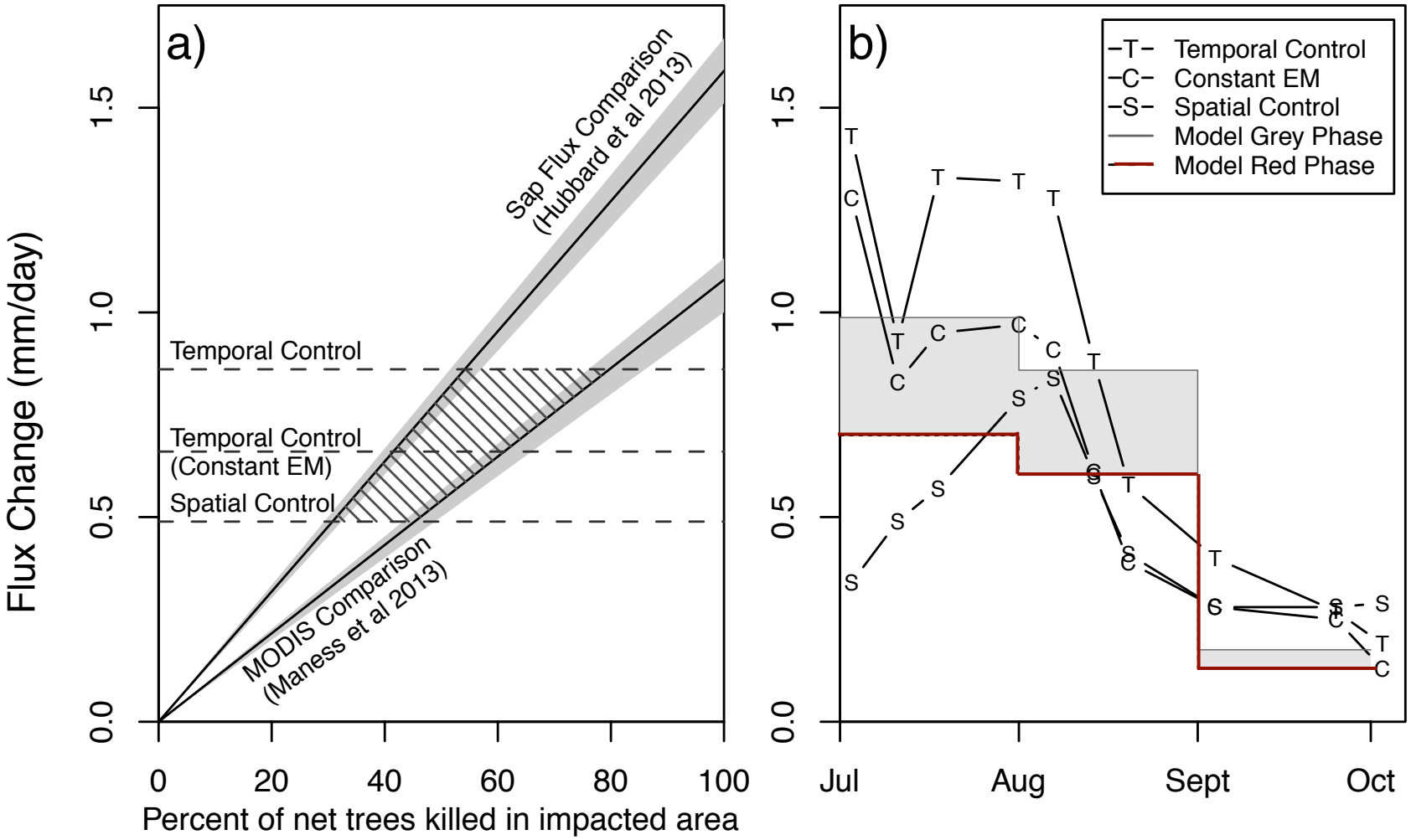
(Bearup et al *NCC* 2014)

We found an increase in GW contributions for impacted watersheds



(Bearup et al *NCC* 2014)

Which allowed a scale-up of ET fluxes to the watershed



(Bearup et al *NCC* 2014)

Using models to predict streamwater age and composition is an important topic in hydrology

HYDROLOGICAL PROCESSES
Hydrol. Process. **24**, 1745–1754 (2010)
Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/hyp.7796

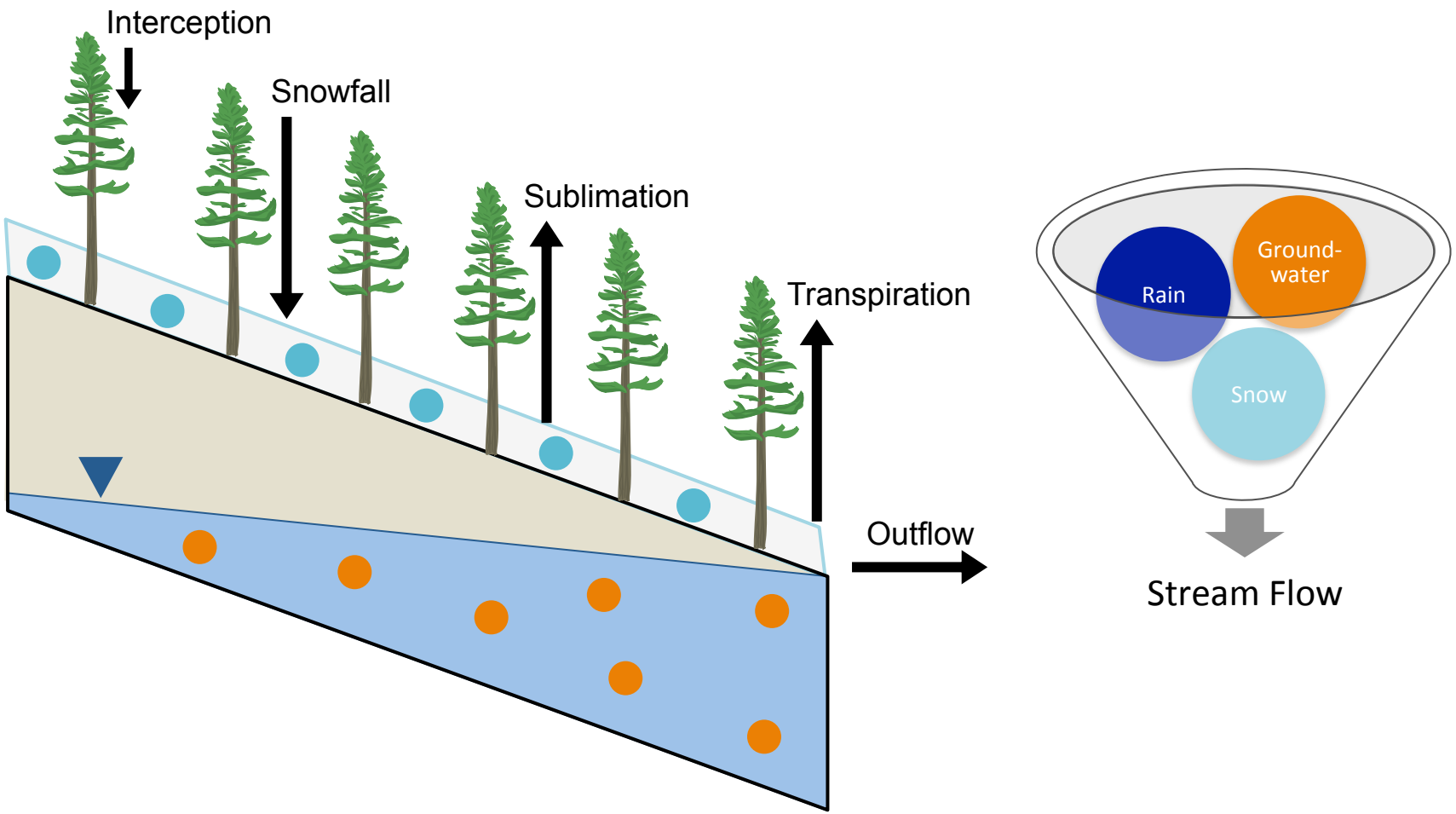
How old is streamwater? Open questions in catchment transit time conceptualization, modelling and analysis

J. J. McDonnell,[1]* K. McGuire,[2]
P. Aggarwal,[3] K. J. Beven,[4] D. Biondi,[5]
G. Destouni,[6] S. Dunn,[7] A. James,[8]
J. Kirchner,[9] P. Kraft,[10] S. Lyon,[11]
P. Maloszewski,[12] B. Newman,[13]
L. Pfister,[3] A. Rinaldo,[14] A. Rodhe,[15]
T. Sayama,[16] J. Seibert,[17] K. Solomon,[18]
C. Soulsby,[19] M. Stewart,[20] D. Tetzlaff,[21]
C. Tobin,[22] P. Troch,[23] M. Weiler,[24]
A. Western,[25] A. Wörman[26] and
S. Wrede[27]

"What are the physical processes and material properties that control transit time distribution? How and why do these processes vary with ***time***, ambient conditions, and place?"

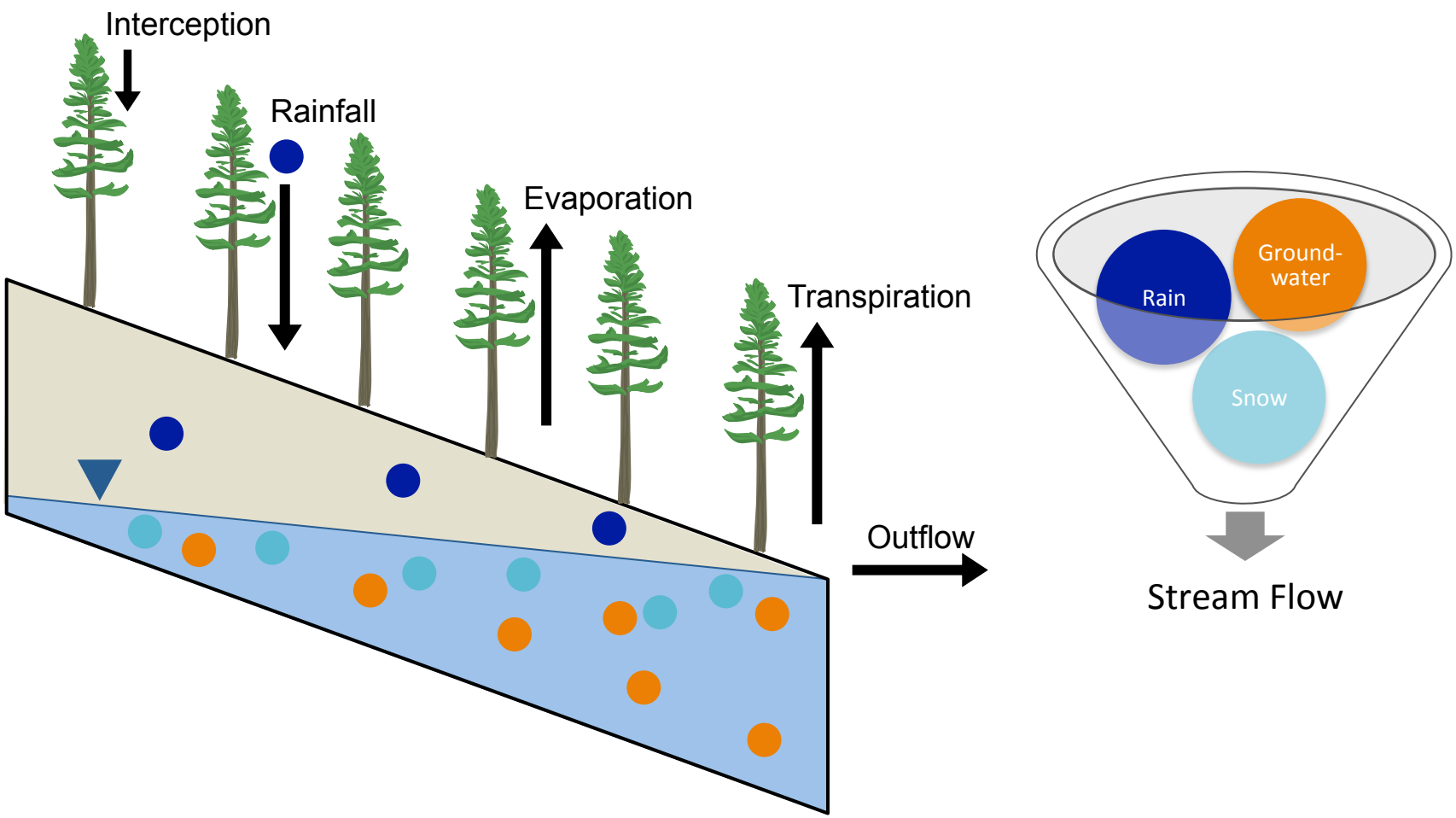
"How can we deal with the effects of … ***ET partitioning*** in 'predicting' transit time distributions…"

Integrated hydrologic models may be used to attribute source and to study the effects of disturbances such as ET



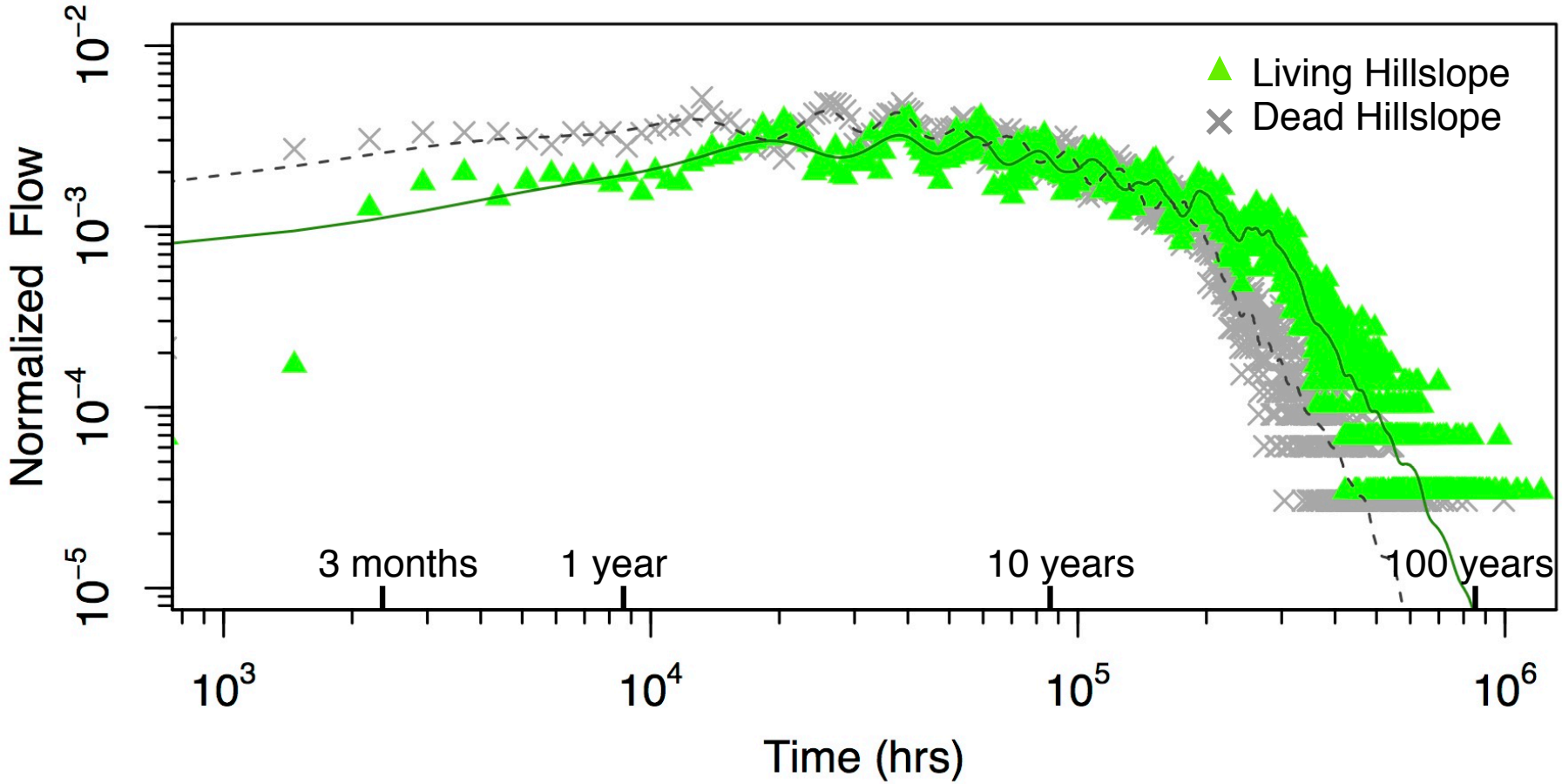
(Bearup et al, *in review*)

Integrated hydrologic models may be used to attribute source and to study the effects of disturbances such as ET



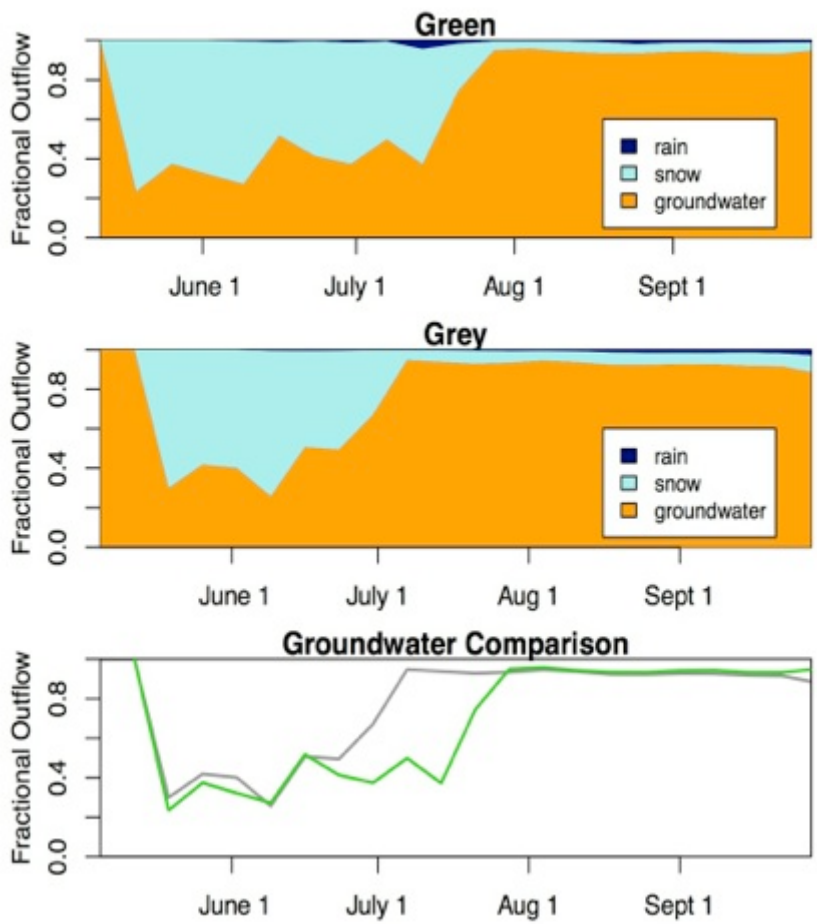
(Bearup et al, *in review*)

Steady-state hillslope simulations show shorter residence times under beetle-kill scenarios



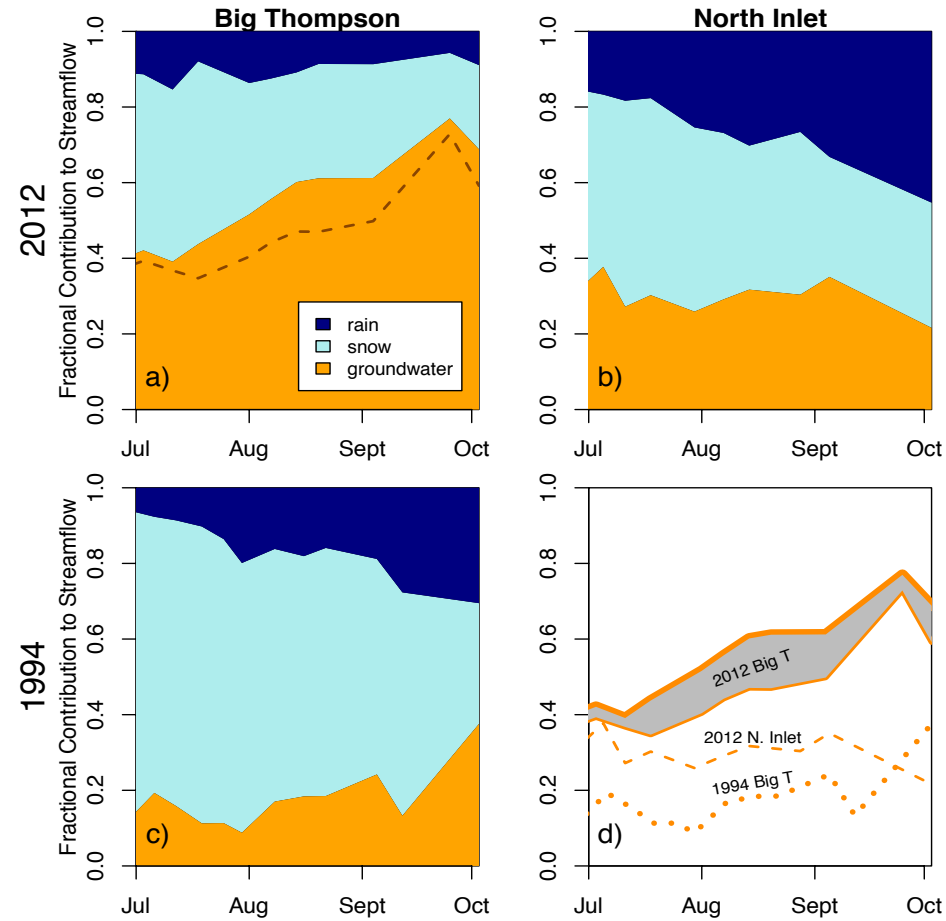
Transient model simulations allow a *virtual* hydrograph separation and show an increase in groundwater contribution and demonstrate *similar behavior* to observations

Model Results



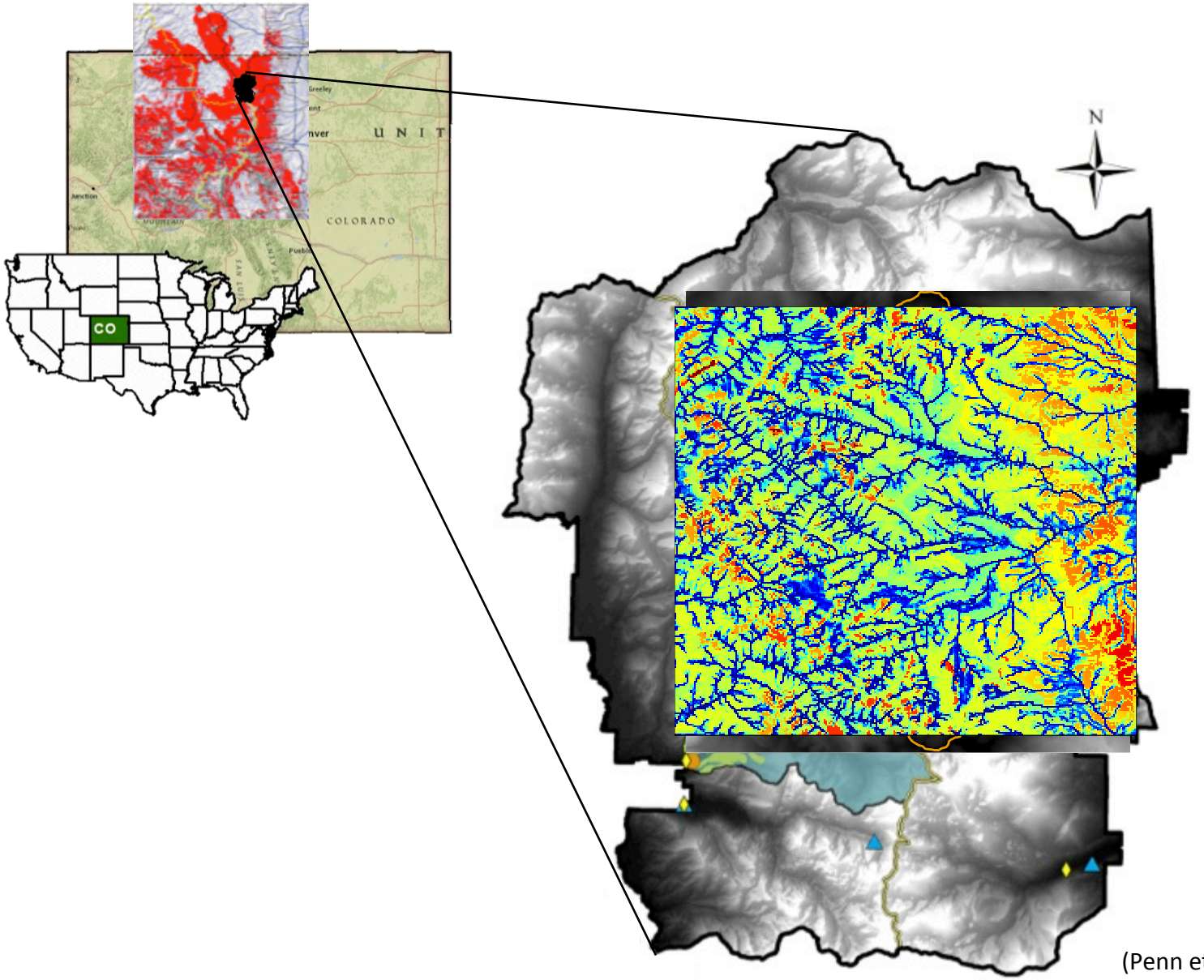
(Bearup et al, *in review*)

Field Observations



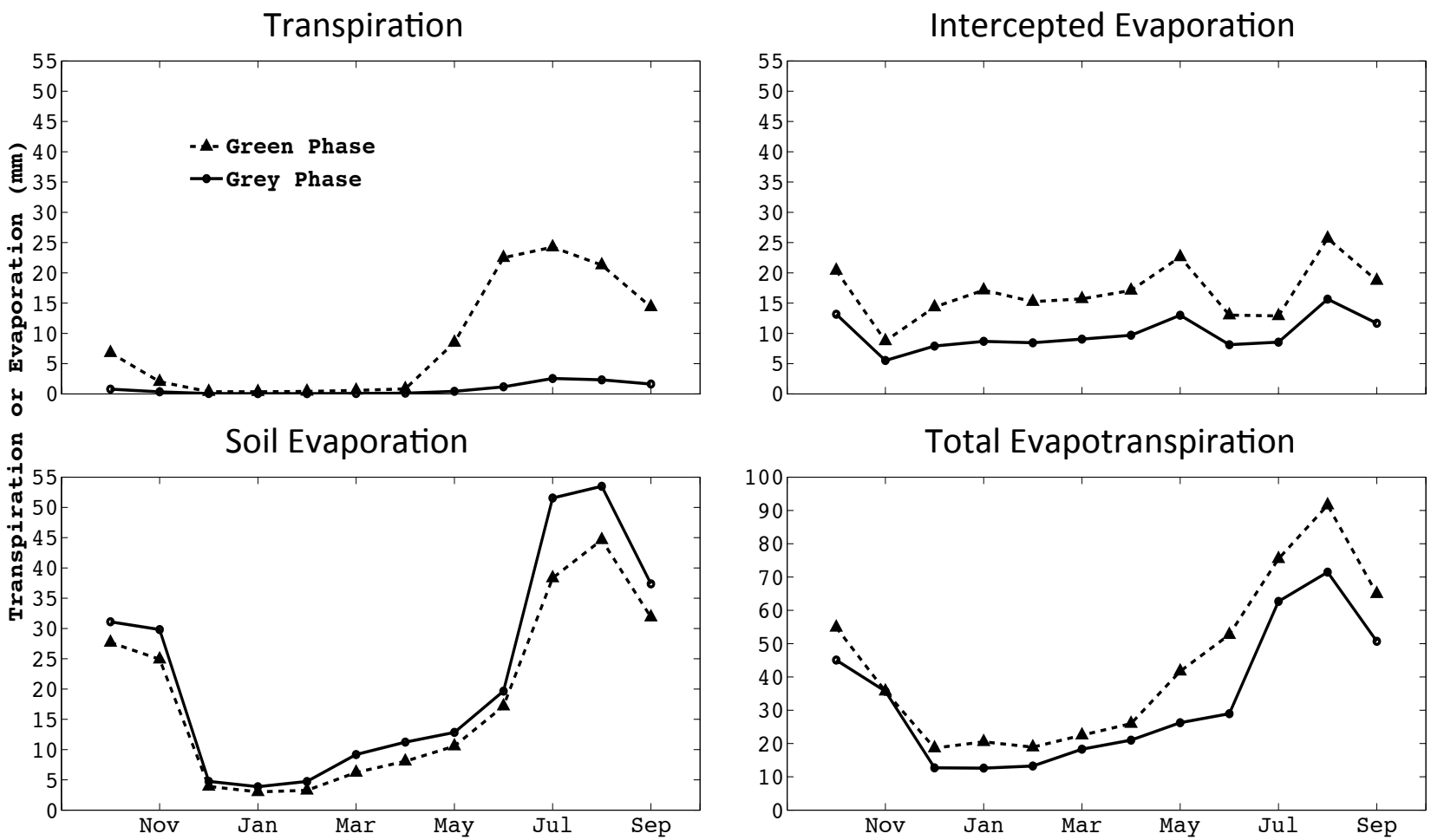
(Bearup et al *NCC* 2014)

We are using an integrated hydrologic model to study scaling implications of beetle infestation



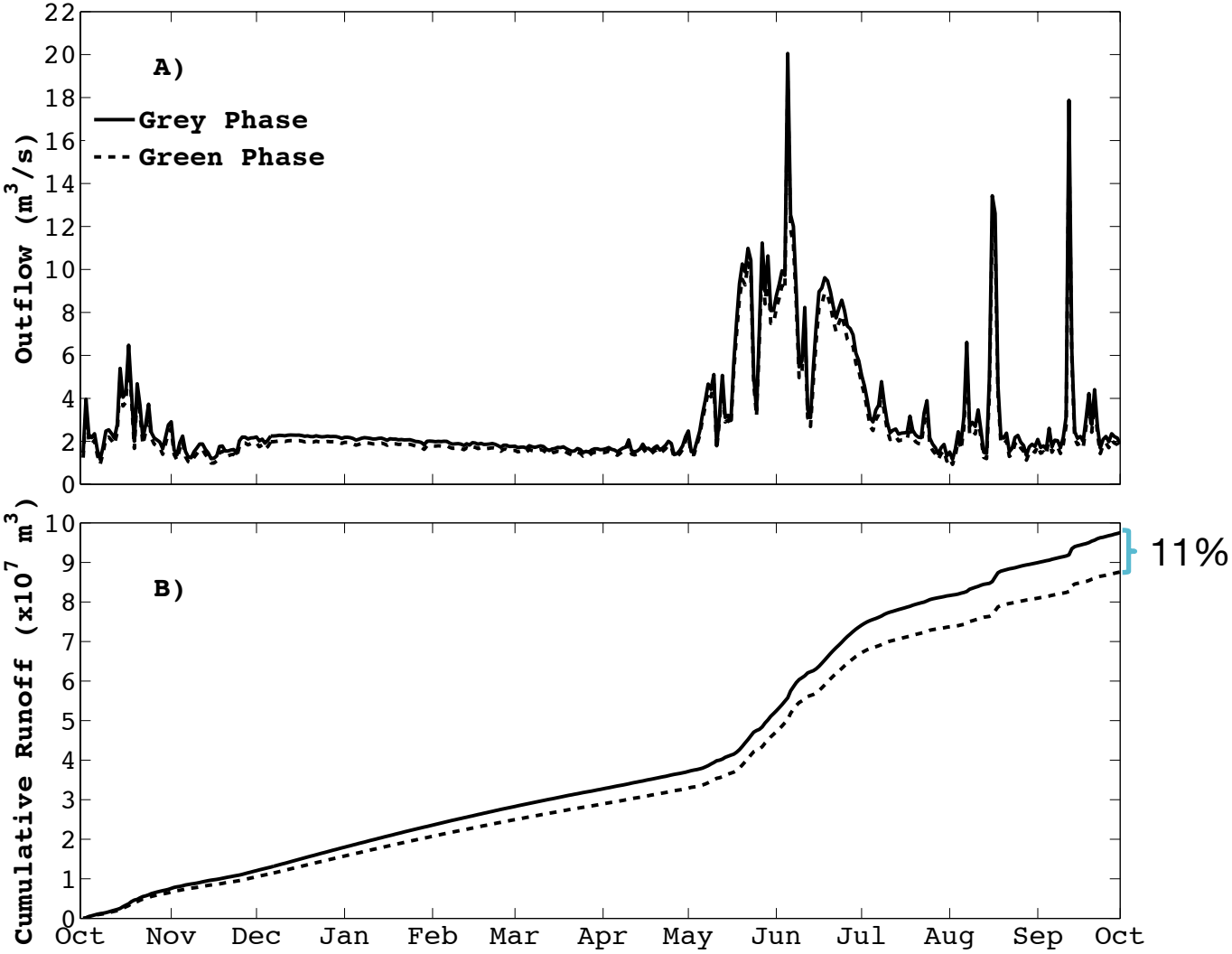
(Penn et al, *in review*)

Models exhibit compensation in evapotranspiration



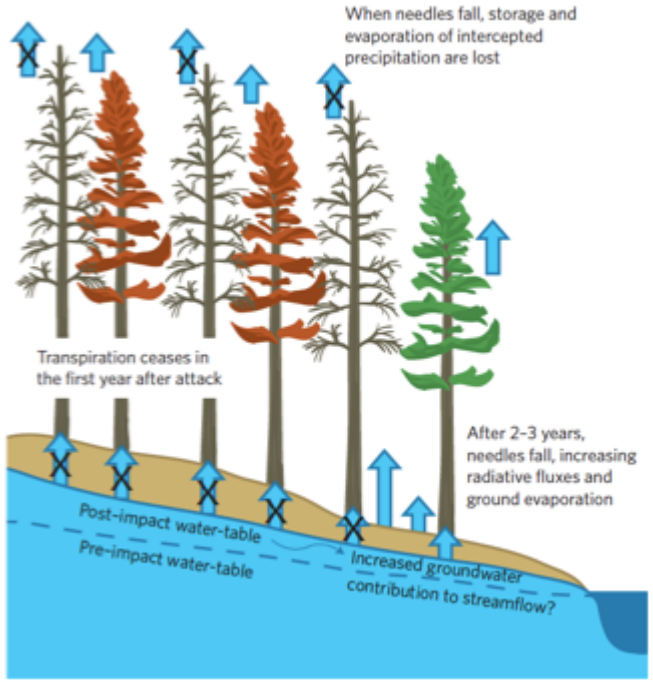
(Penn et al, *in review*)

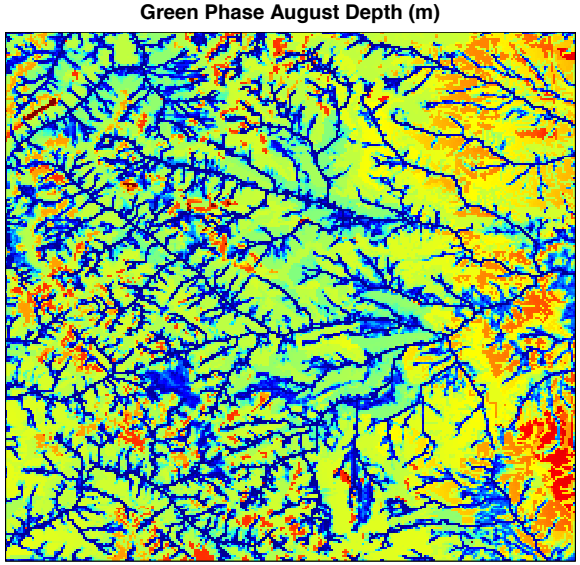
Modeled streamflow response is muted



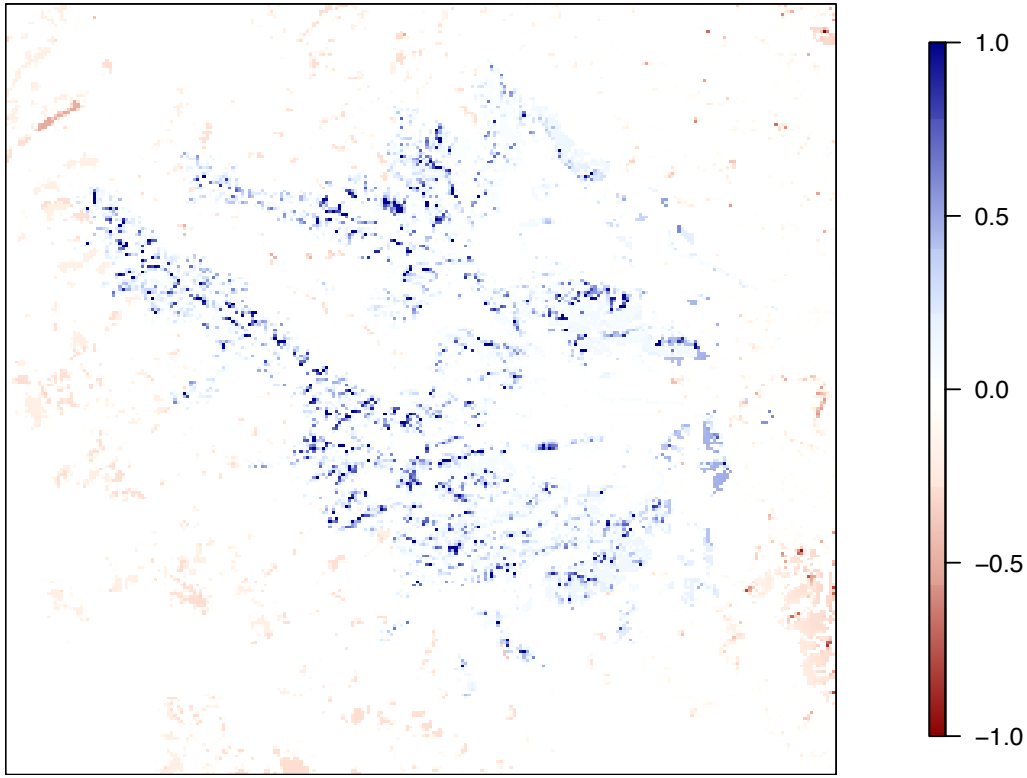
(Penn et al, *in review*)

Models indicate higher groundwater tables in infested areas



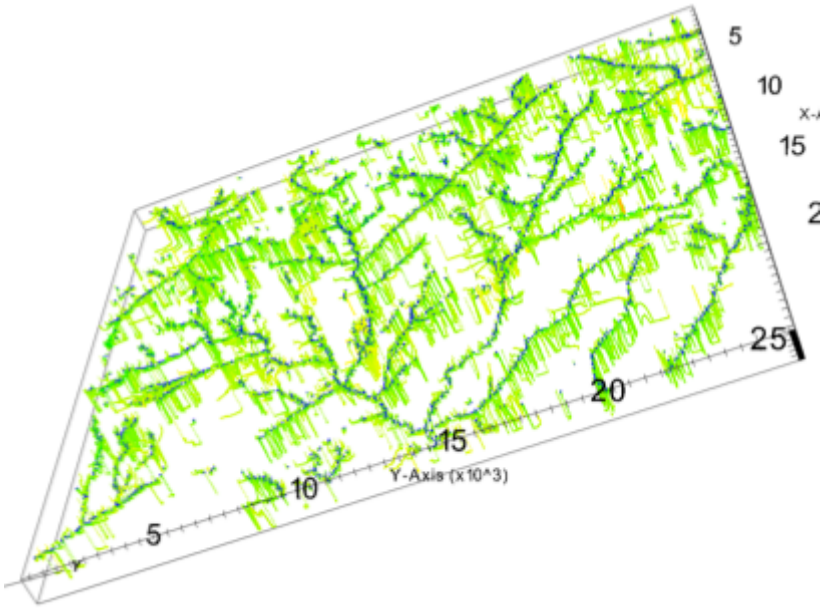


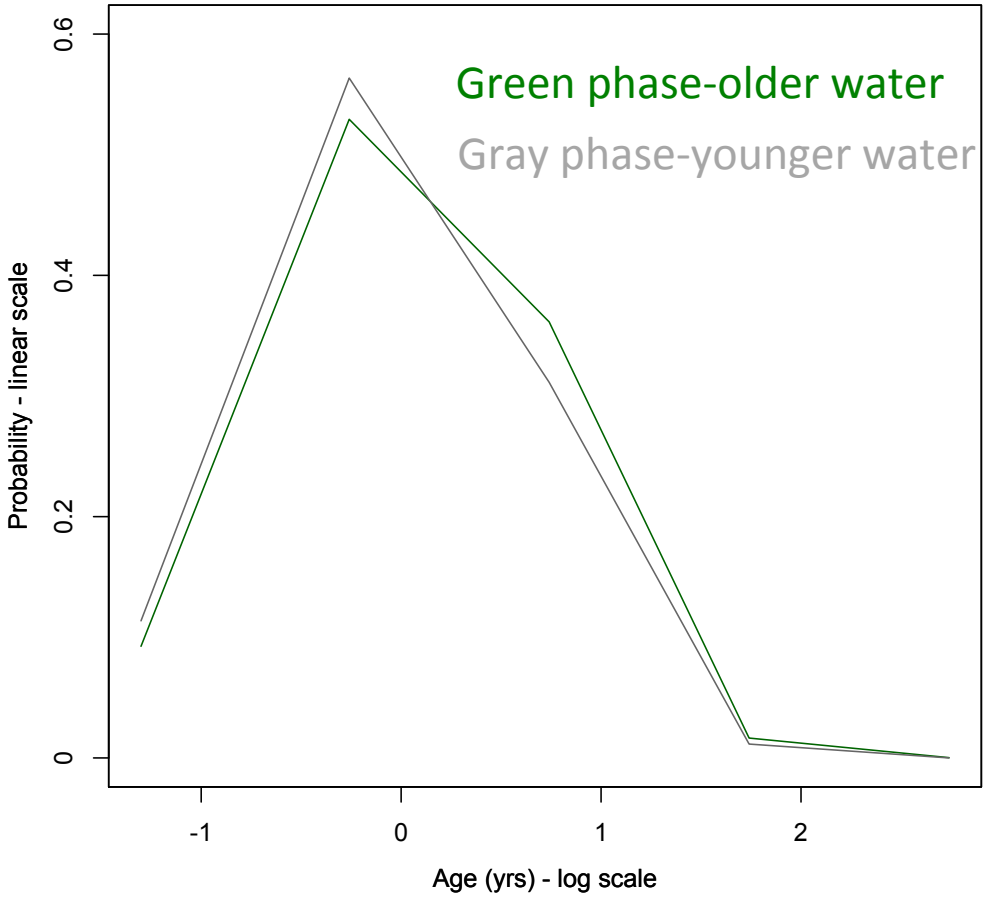
Water table difference (grey – green)



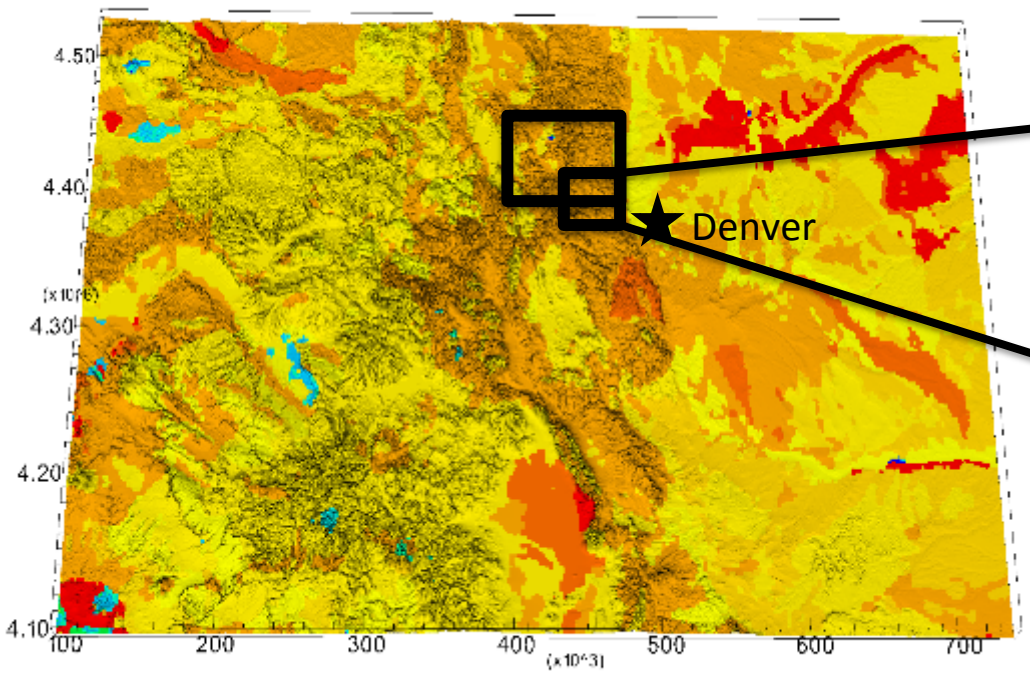
(Penn et al, *in review*)

We can use these watershed simulations to understand shifts in residence time

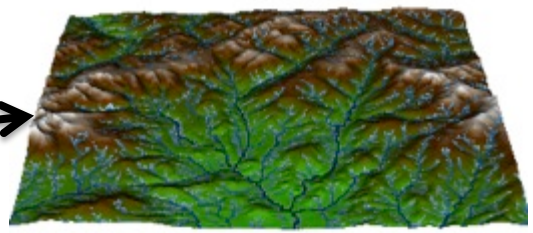




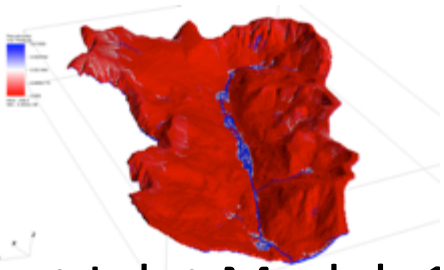
Next Steps: We are using a multi-scale modeling approach to complement the observational work



Colorado Model: 1 km Resolution



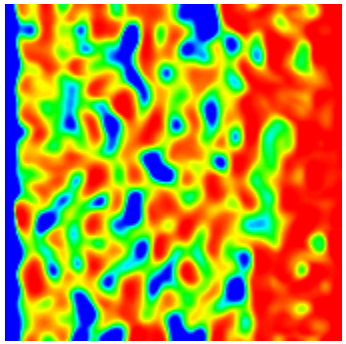
Big Thompson Model: 100 m Resolution



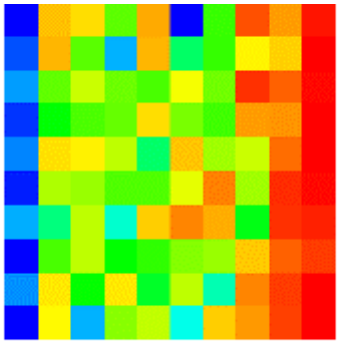
East Inlet Model: 10 m Resolution

1 km^2 Forested Domain: ET at Variable Resolution for 8% slope

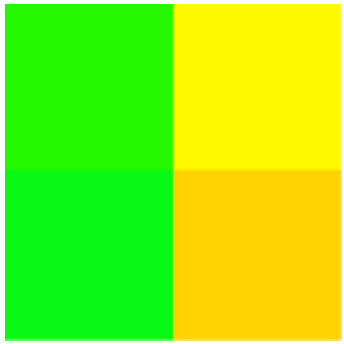
2 m resolution



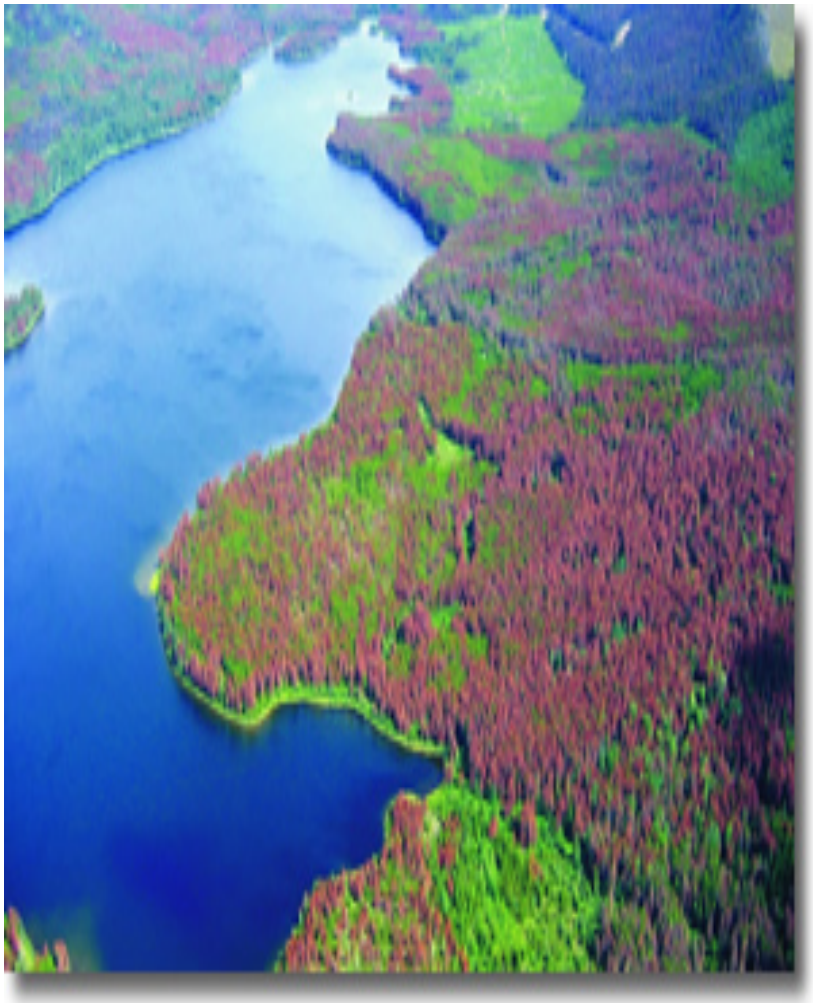
100 m resolution



500 m resolution



Integrated Social Science and Outreach



Online Survey Results: *Perceptions of Impacts of Mountain Pine Beetle on Drinking Water Resources*

Cottrell, Czaja, Stednick, Dickenson, and Mitchell & Maloney (undergraduates)

Process

- Online Elicitation Survey Responses
  - 2013 AWWA Conference - Denver, CO
- World Café & MPB Technical Session, RMSAWWA Joint Annual Conference –Keystone, CO

Recommendations: Challenges of MPB on water

- Impact Mitigation
  - Forestry & Watershed Management
  - Water Treatability
- Water Quality
  - Mineral, Organic Carbon Levels
  - Erosion Rates & Sediment Flows
- Wildfire Potential
  - Post-Fire Impacts
  - Flooding & Heavy Debris Flow
- Water Yield
  - Run-off Quantity and Timing

Beetle Café - Schematic results

Summary

- We see increased groundwater contributions from beetle-killed watersheds which allow us to estimate transpiration
- We can use hydrologic models to predict source contribution and water age
- We can use hydrologic models to scale-up land-cover disturbances

Thank You!

This material was based upon work supported by the National Science Foundation (WSC-1204787) and U.S. Geological Survey (G-2914-1). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of these organizations.