Water Connects All: Climate Change and Mountain Hydrology in a Watershed Context



Anne Nolin

Oregon State University

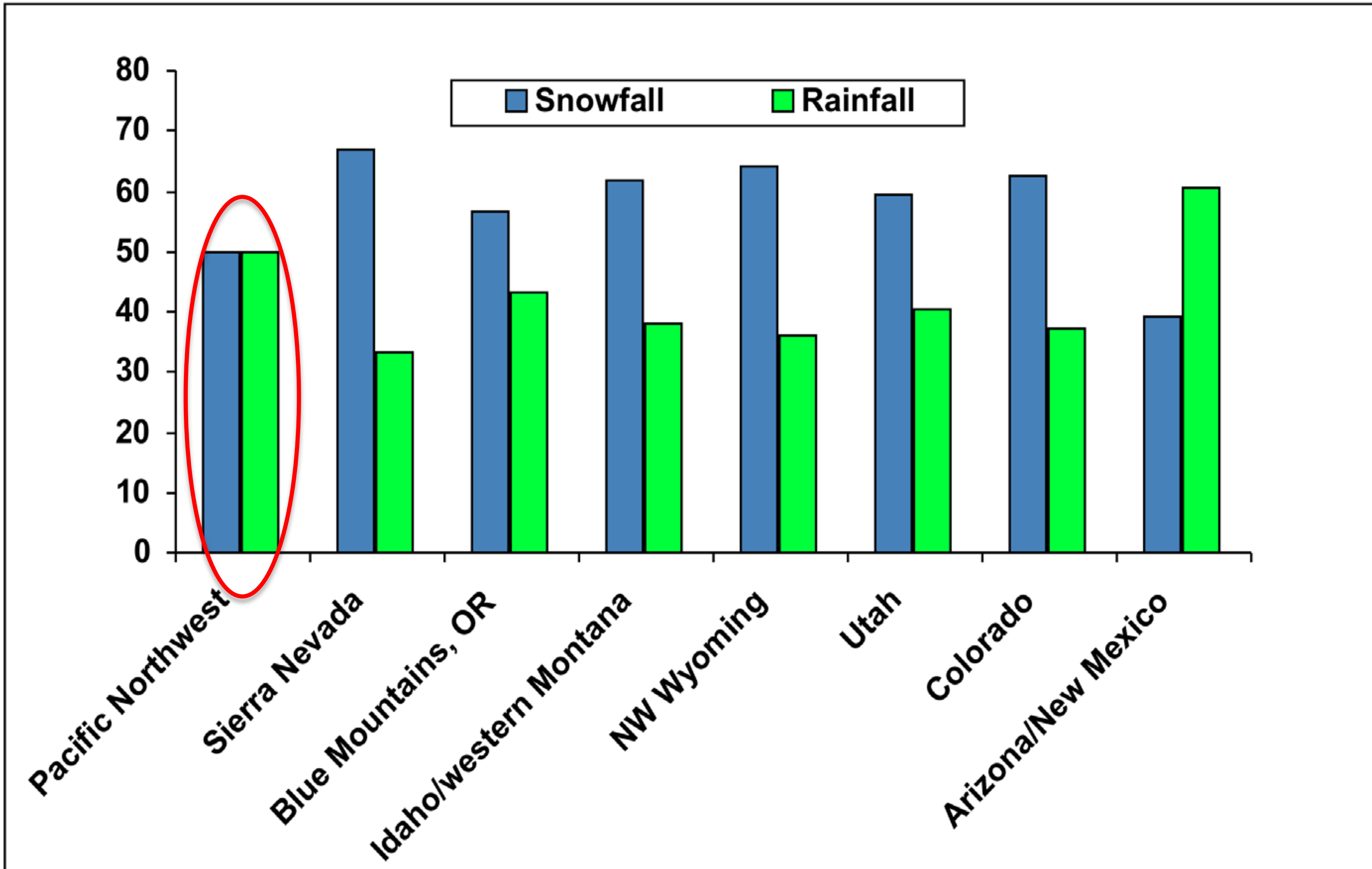
HJ Andrews Long Term Ecological Research Site

Oregon State University

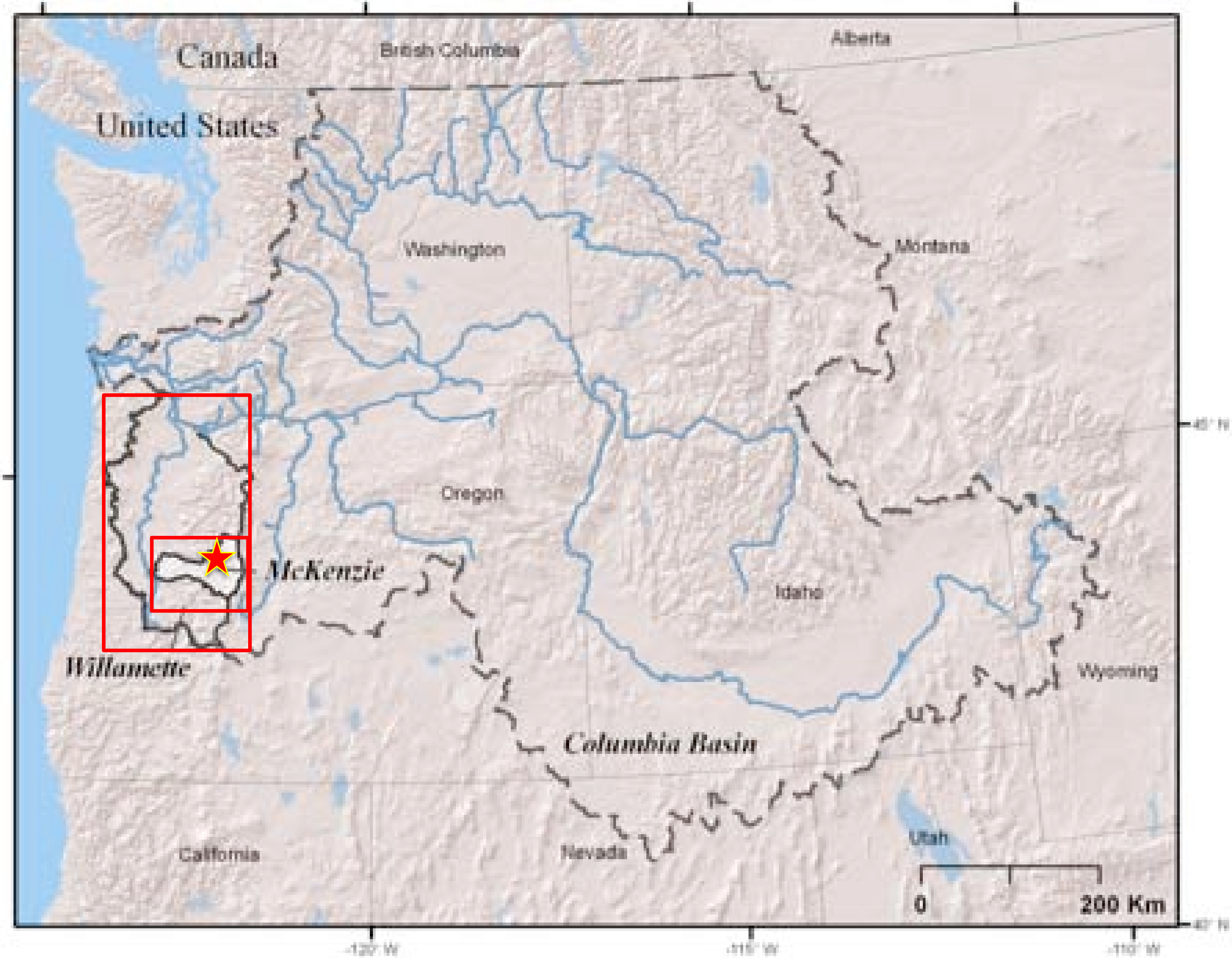
Outline

- Mountain watersheds: Highlands and lowlands
- Climate change and snow at various scales
- Temperature variability and change
- New paradigm for examining water scarcity

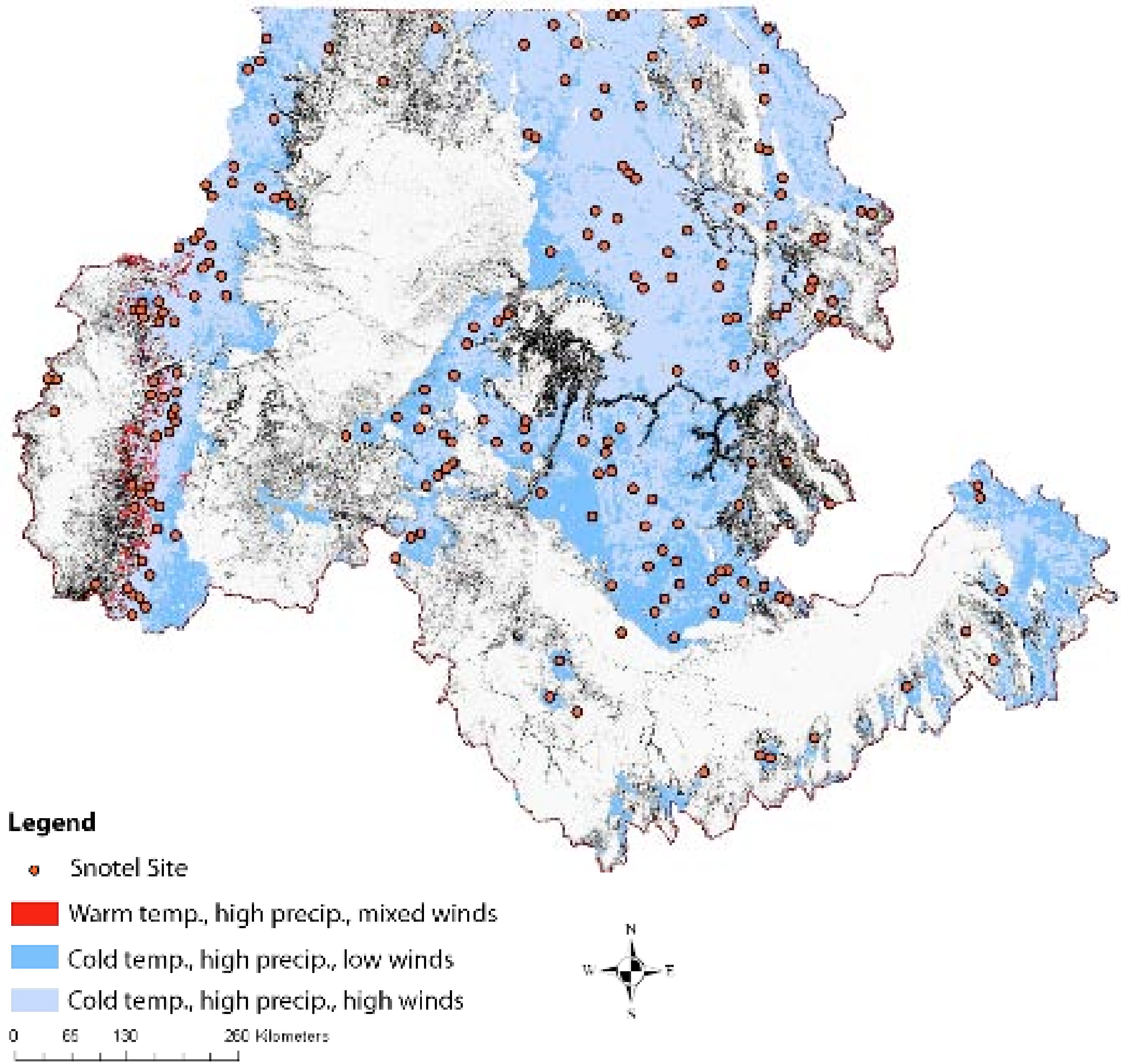
Percent Rainfall & Snowfall in Mountain Regions of the Western US



(Based on Serreze et al. 1999)


Canada
British Columbia
Alberta
United States
Washington
Montana
Oregon
McKenzie
Idaho
Willamette
Wyoming
Columbia Basin
Utah
California
Nevada
0
200 Km
-120° W
-115° W
-110° W

“At Risk” Snow in the US Columbia River Basin



“At-Risk” Snow:

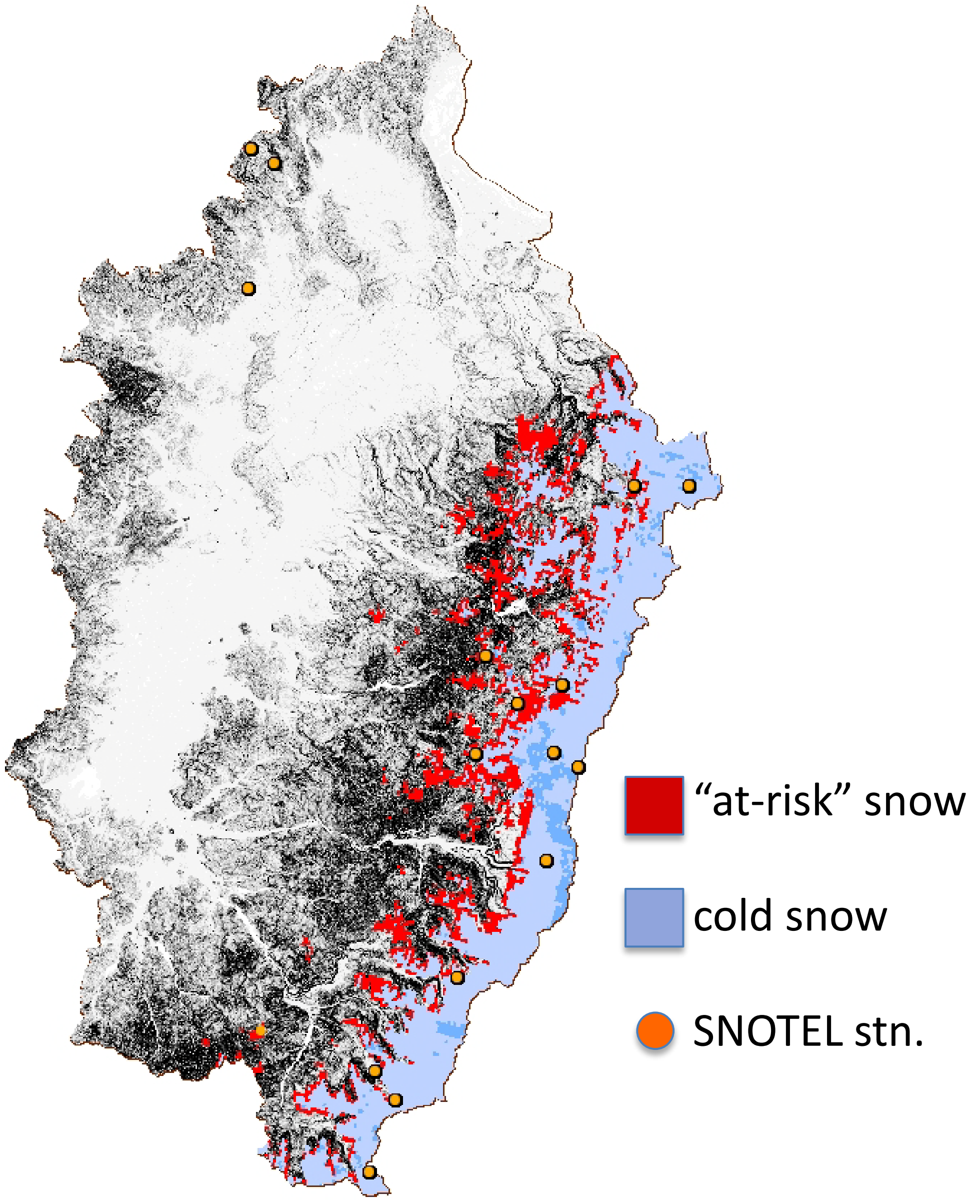
A 2°C winter warming is projected to shift mid-winter precipitation from snowfall to rainfall

Greatest impacts are for midwinter snow at lower elevations in the Western Cascades

(Nolin and Daly, 2006; Nolin et al., accepted)

Oregon State University

Willamette River Basin, Oregon



Willamette River Basin:

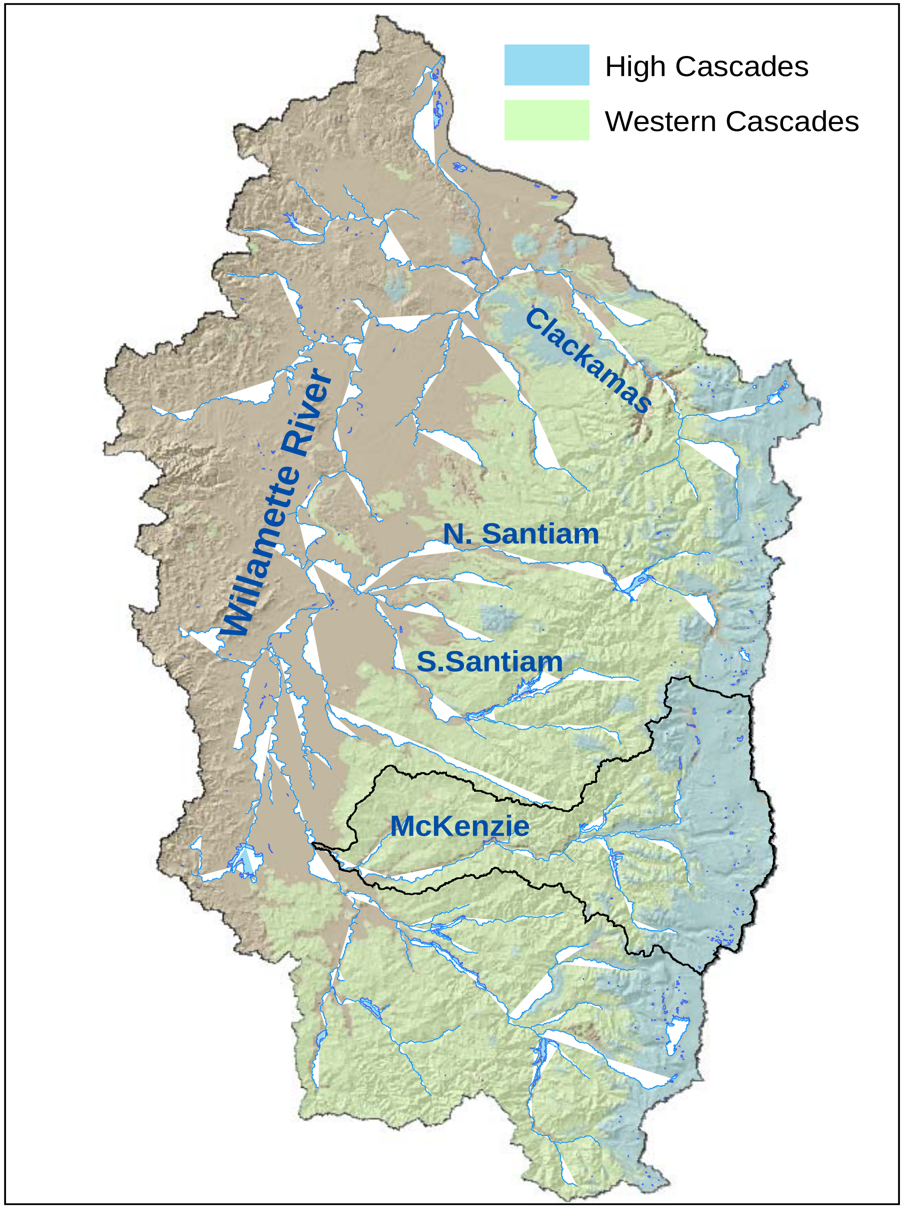
- 29,000 km^2
- 70% of Oregon's population
- Water use: hydropower, fish, irrigation, municipal

At-Risk Snow:

- For a 2°C temperature increase we project a **25% decrease in snow covered area**
- Low elevation snowfall converts to rainfall
- ~4 km^3 of water volume per year

(Nolin and Daly, 2006; Nolin et al., accepted)

Geology also Controls Streamflow Patterns



(Courtesy Gordon Grant)

High Cascades:

Young volcanic rocks

<u>Groundwater</u>-dominated

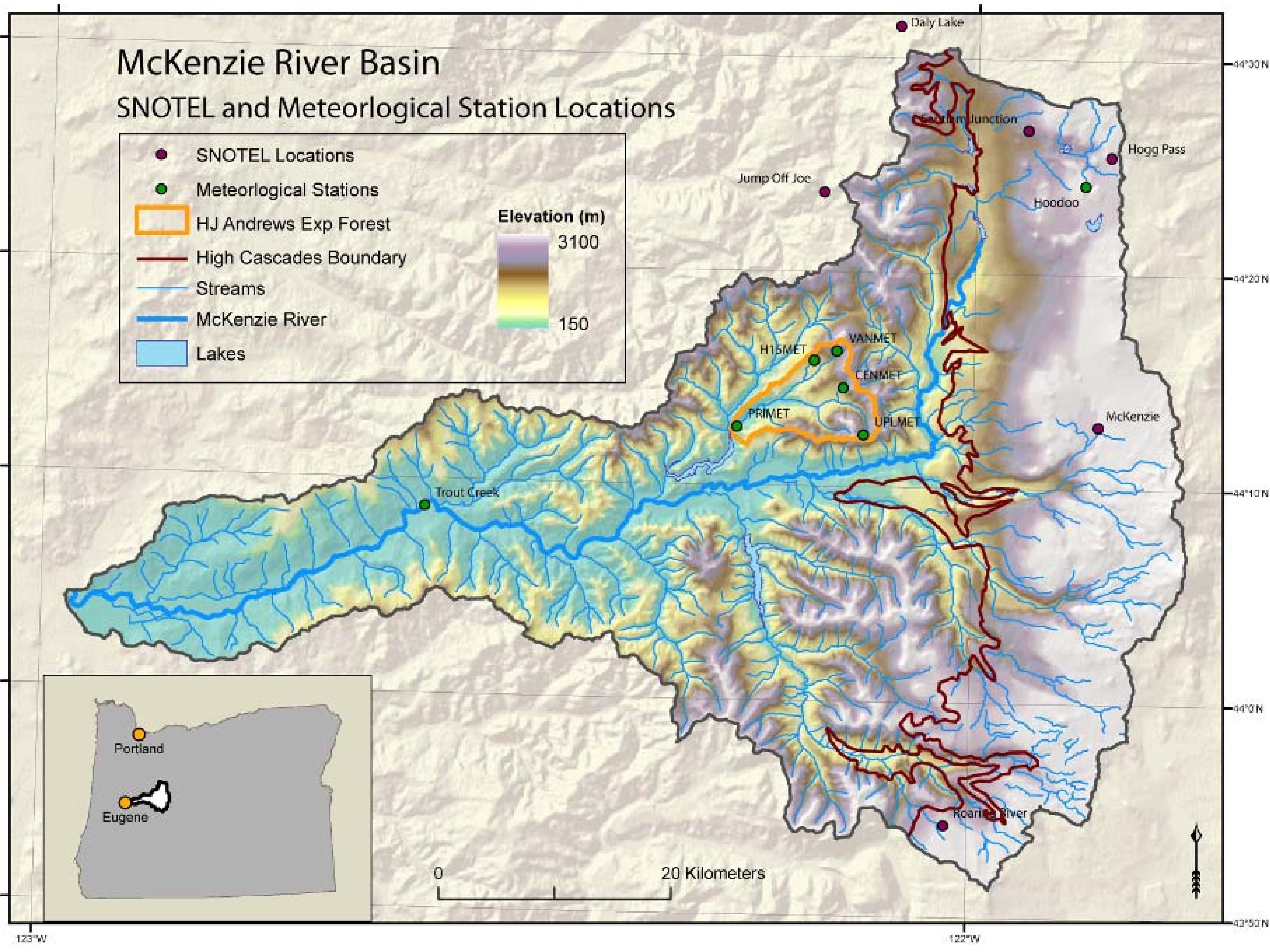
Western Cascades:

Older, weathered volcanic rocks

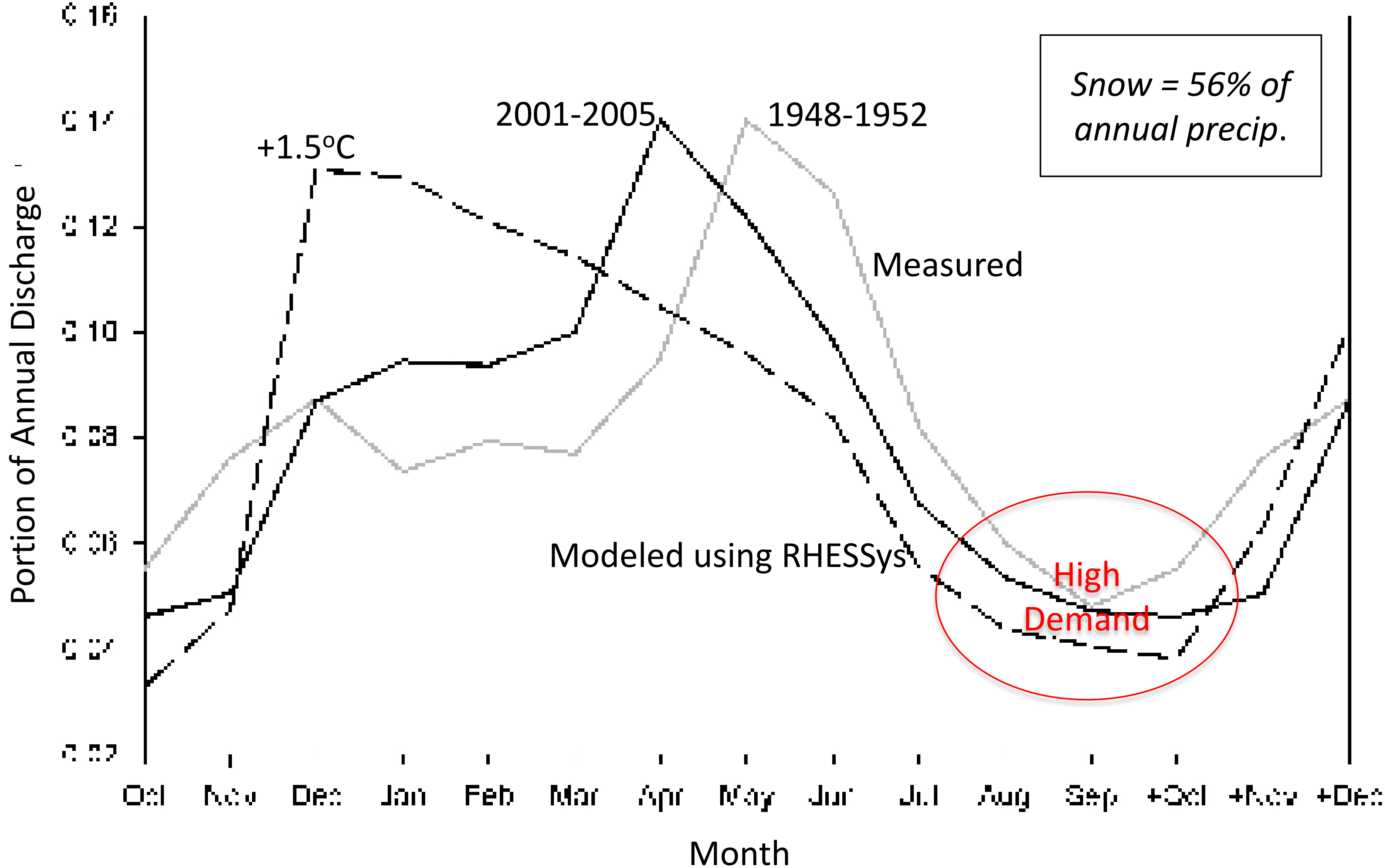
<u>Surface runoff</u>-dominated

Groundwater-dominated watersheds are more sensitive to changes in snowfall

When we make projections, we need to consider the geologic + climatic factors together

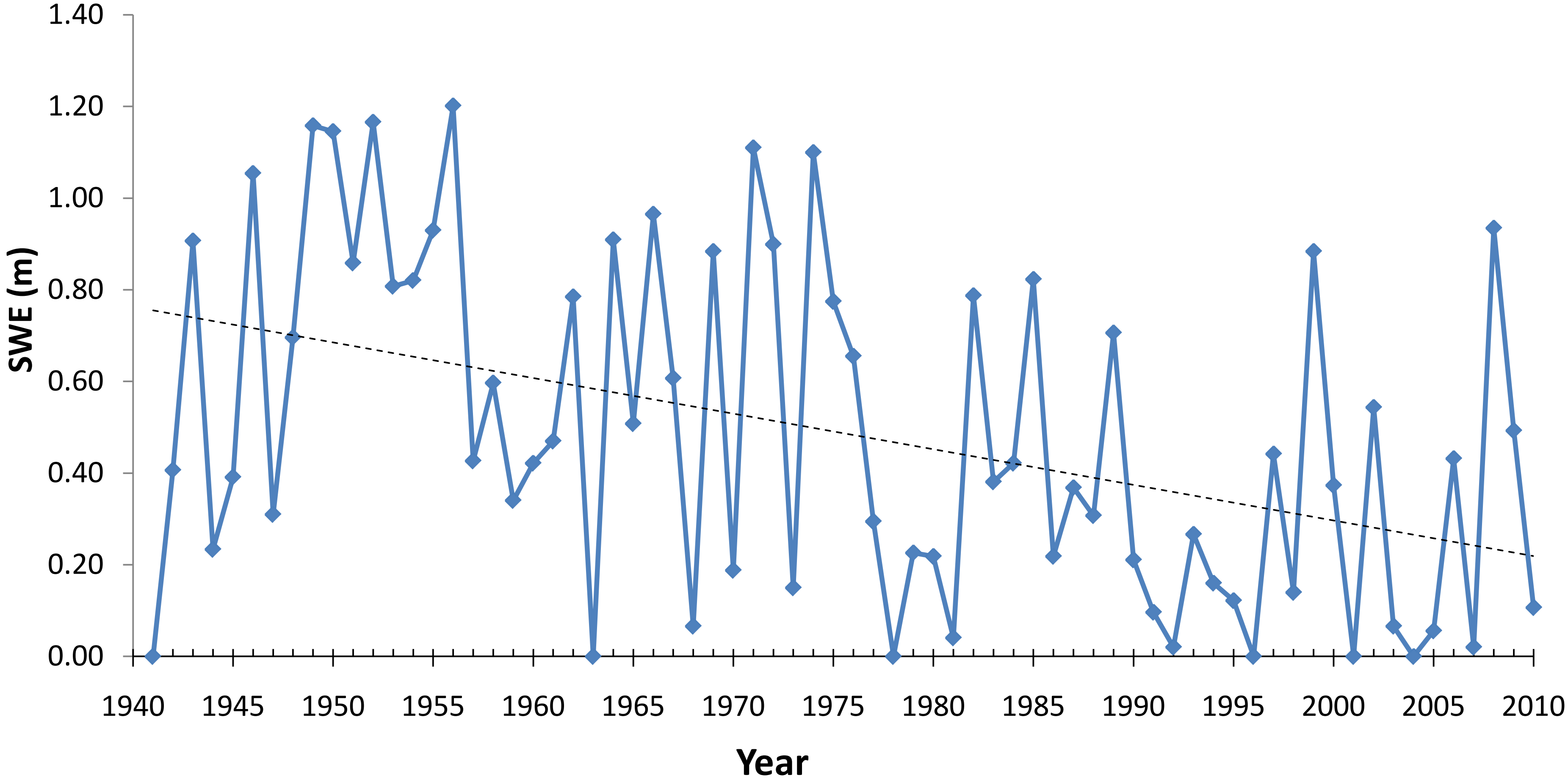

McKenzie River Basin
SNOTEL and Meteorlogical Station Locations
SNOTEL Locations
Meteorlogical Stations
HJ Andrews Exp Forest
High Cascades Boundary
Streams
McKenzie River
Lakes
Elevation (m)
3100
150
Daly Lake
Hogg Pass
Jump Off Joe
Hoodoo
VANMET
H15MET
CENMET
PRIMET
UPLMET
McKenzie
Trout Creek
Portland
Eugene
0
20 Kilometers
44°30'N
44°20'N
44°10'N
44°0'N
43°50'N
123°W
122°W

Measured and modeled flows, McKenzie River at Clear Lake, OR (elev. 918-2051) m)



From Jefferson et al., 2008; Hydrological Processes

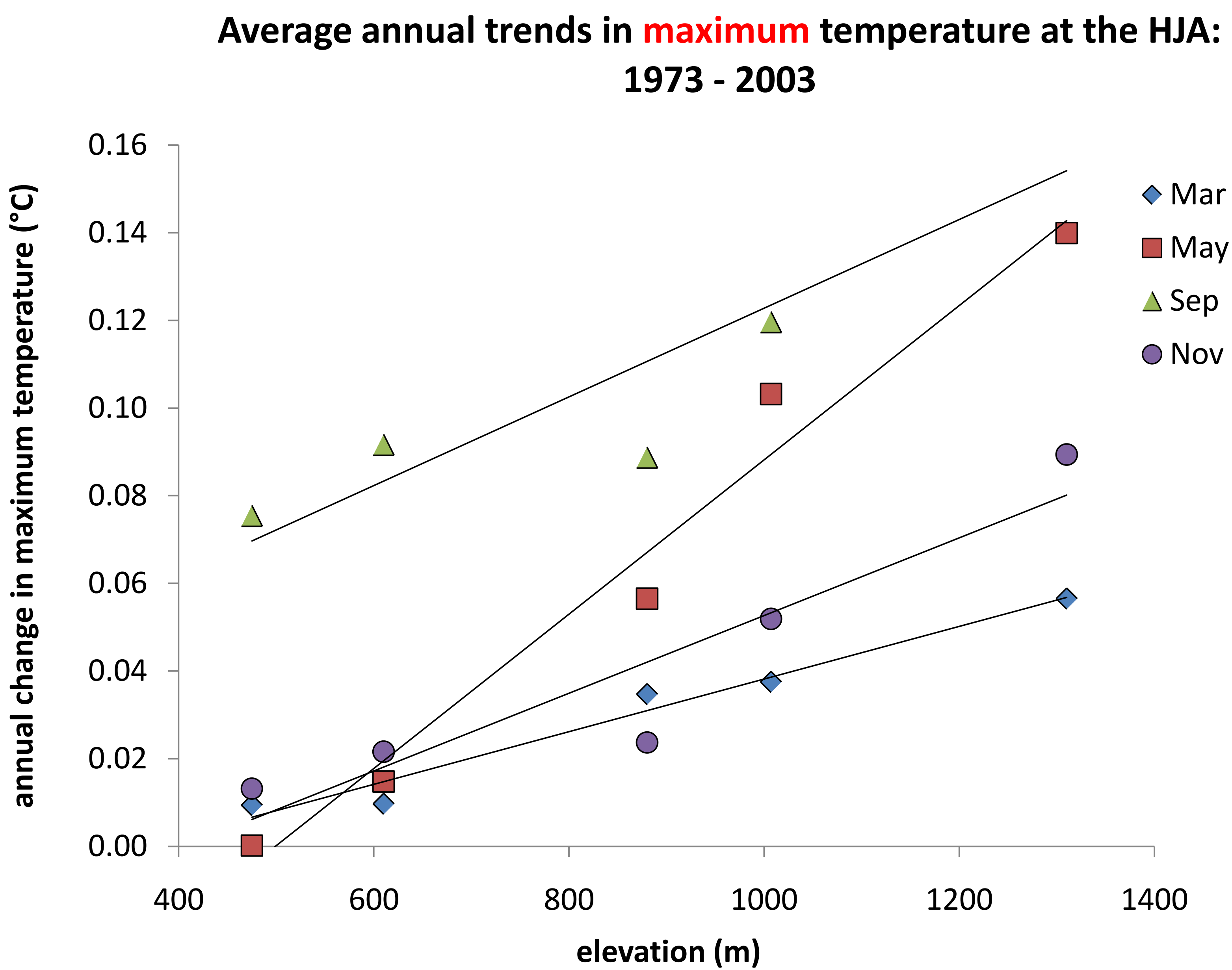
Measured SWE at Santiam Junction on April 1
(elev. 1143 m)

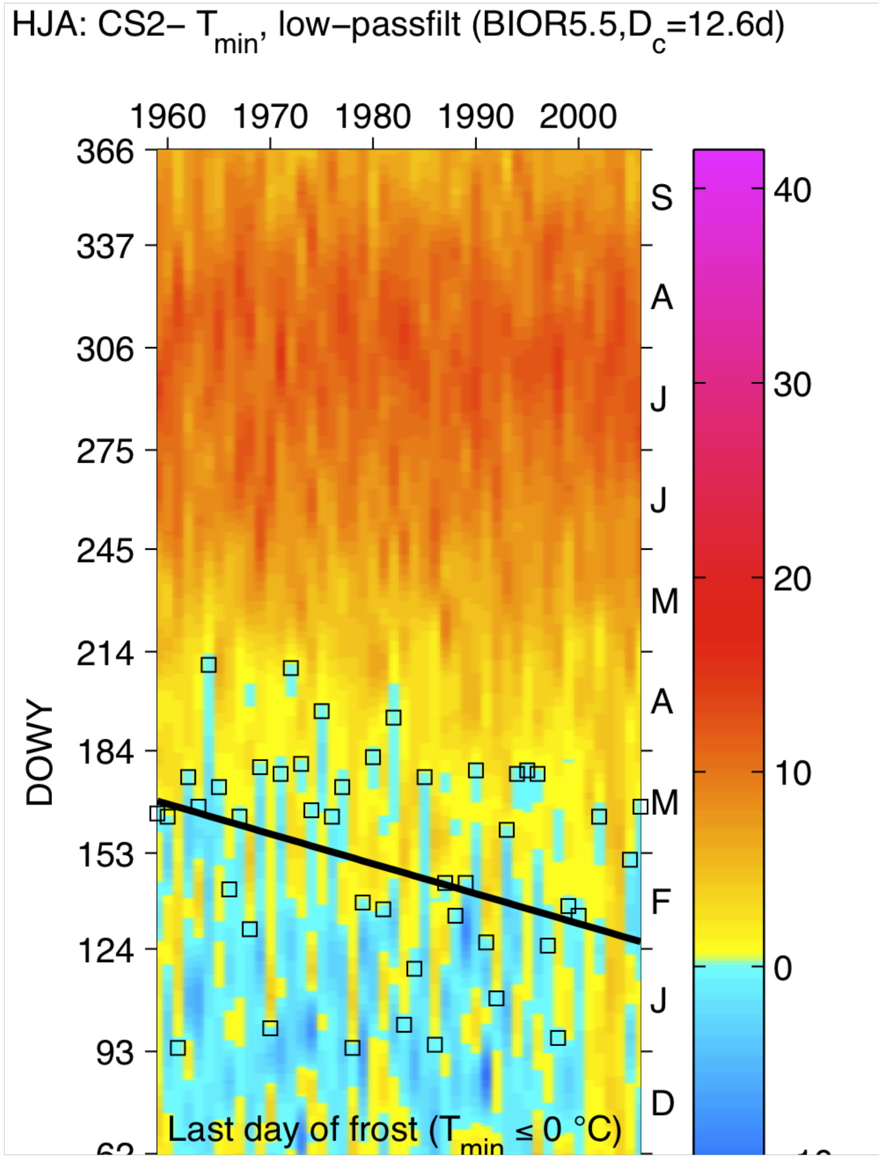


-1 cm/year

Significant at 0.99 level

Water volume loss in a 500-m elevation band = 0.5 km^3


Average annual trends in maximum temperature at the HJA:
1973 - 2003
annual change in maximum temperature (°C)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
400
600
800
1000
1200
1400
elevation (m)
Mar
May
Sep
Nov

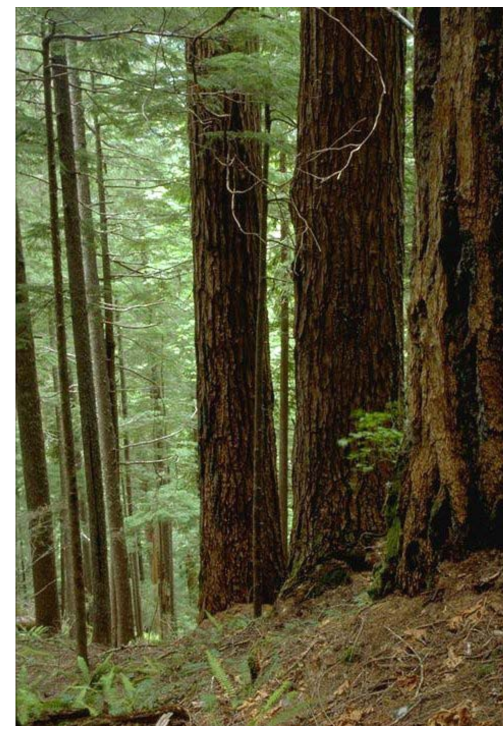


Earlier Spring at the HJA

Trend towards earlier spring at the HJA from 1958-2007

-0.9 days/year

The result? Warming allow trees to use water from the soil earlier in the year



Courtesy C. Thomas, Oregon State University

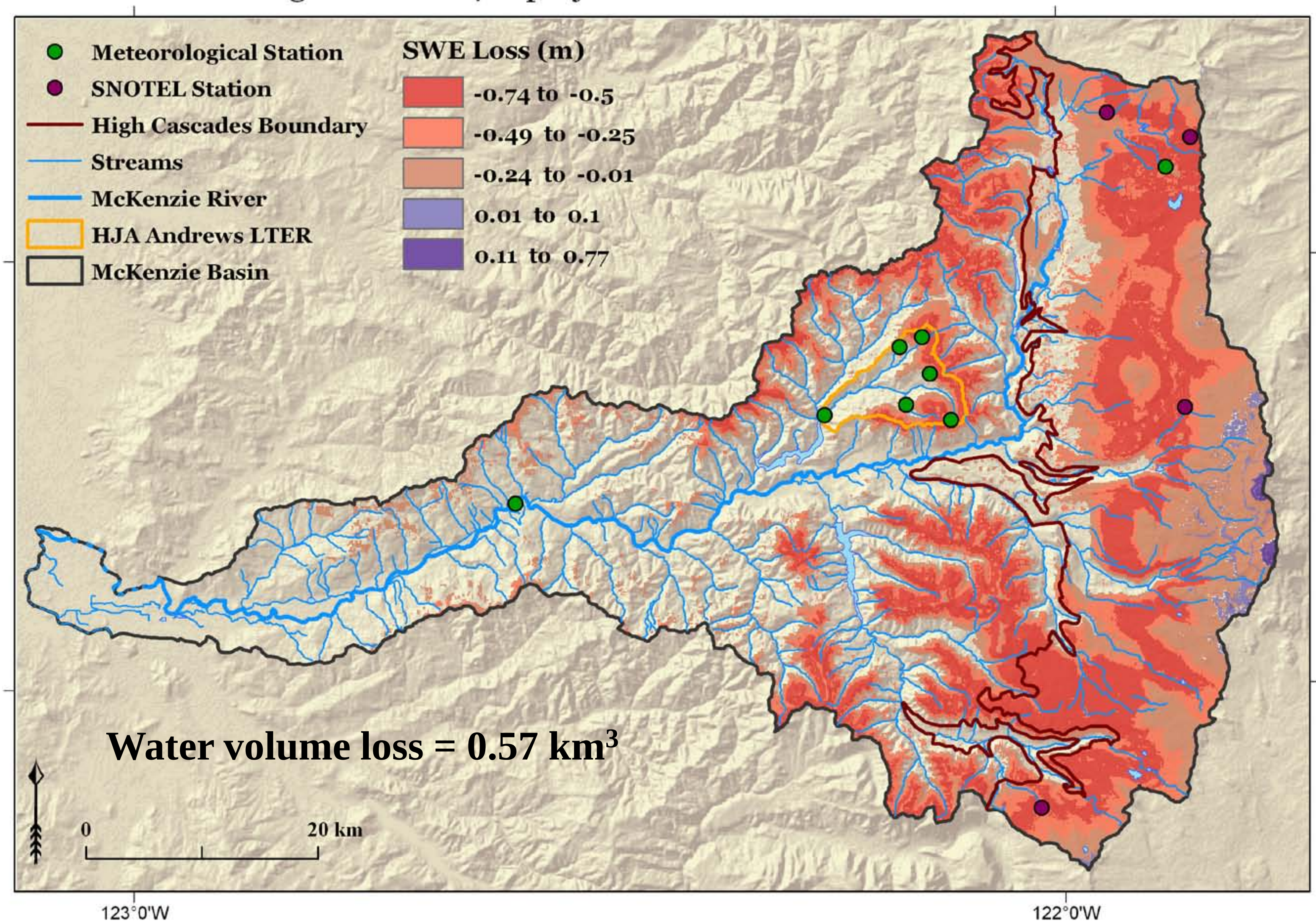
Trends in Seasonal Streamflow at the HJ Andrews LTER

Runoff Ratio (Streamflow/Precipitation) at forested “control watersheds (all values shown are statistically significant)					
	Average runoff ratio	WS02 1958-05	WS08 1963-05	WS09 1968-05	Mack 1980-05
Yr	0.6-0.8		-0.13	-0.11	-0.19
MAM	0.7-1.2	-0.19	-0.40	-0.21	
SON	0.2-0.4			-0.04	
DJF	0.6-0.8		-0.09	-0.12	-0.25

Courtesy K. Miles, J. Jones, Oregon State University

Modeled Loss of Snow Water Equivalent (April 1)

Winter with Average SWE - 2040s projected climate



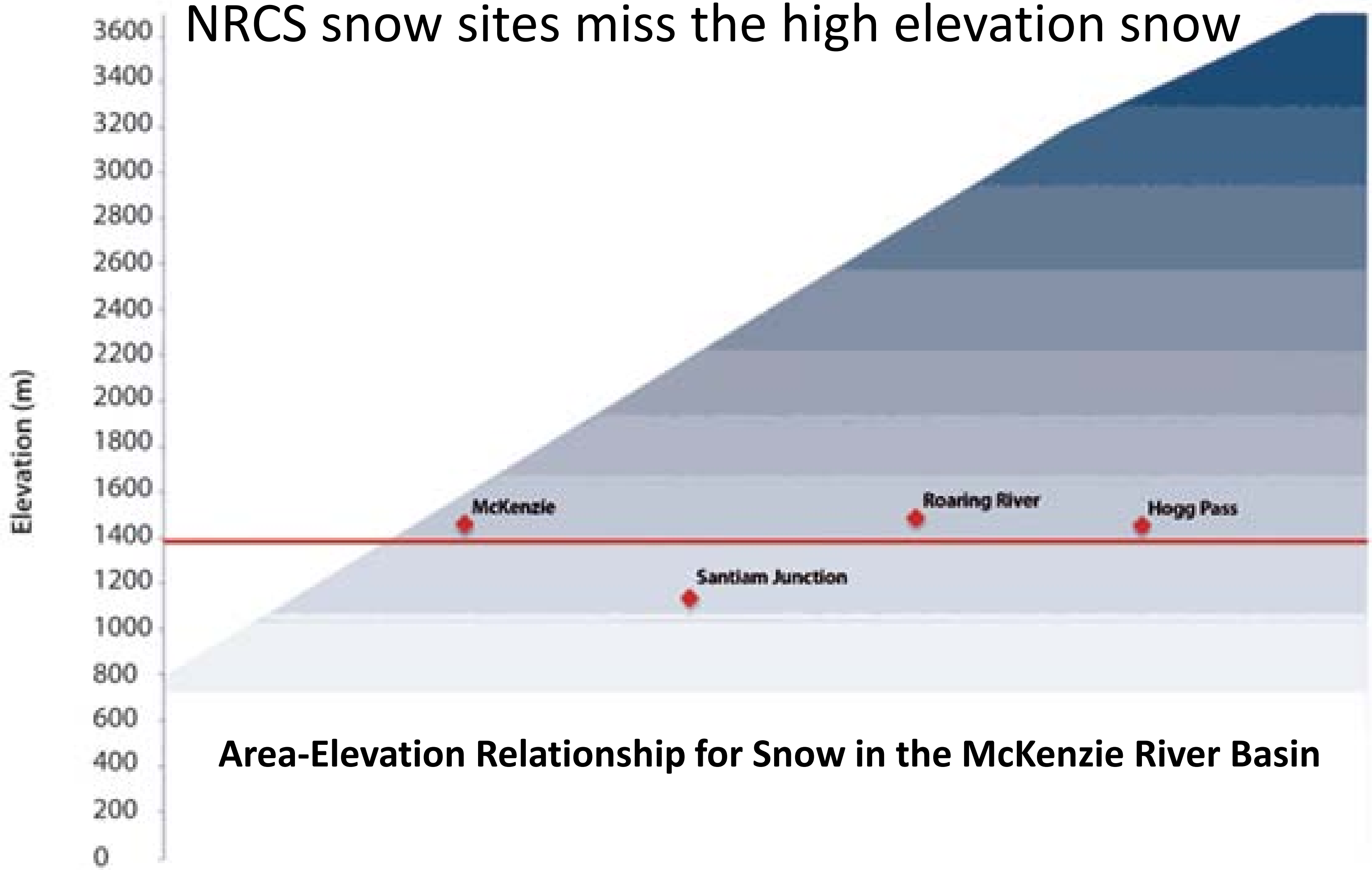
Water volume loss = 0.57 km^3

Observations and models help us conceptualize and quantify connections and feedbacks

Two major challenges:

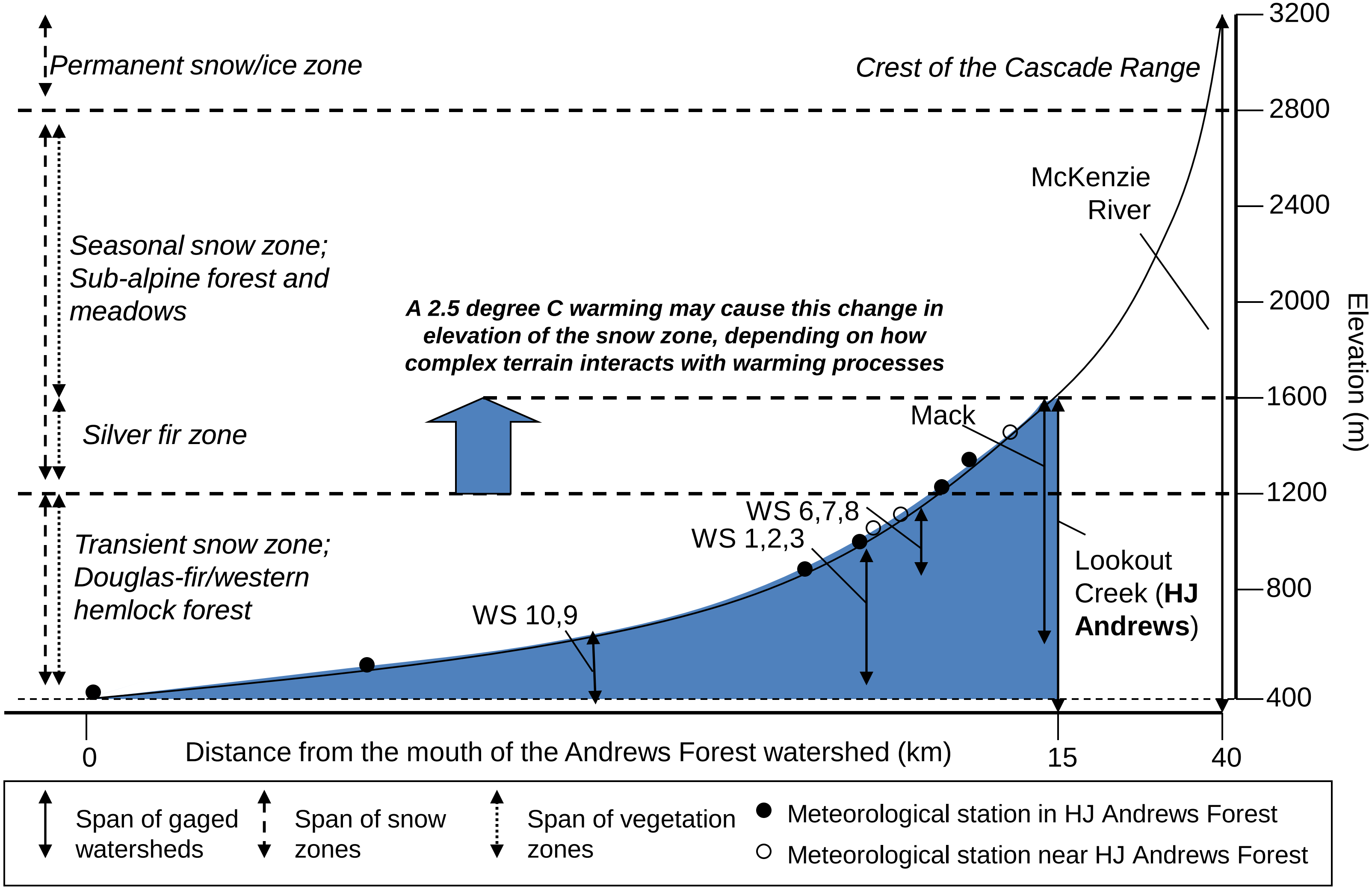
- Monitoring systems are sparse, inadequate
- Integrated conceptual framework is needed

NRCS snow sites miss the high elevation snow

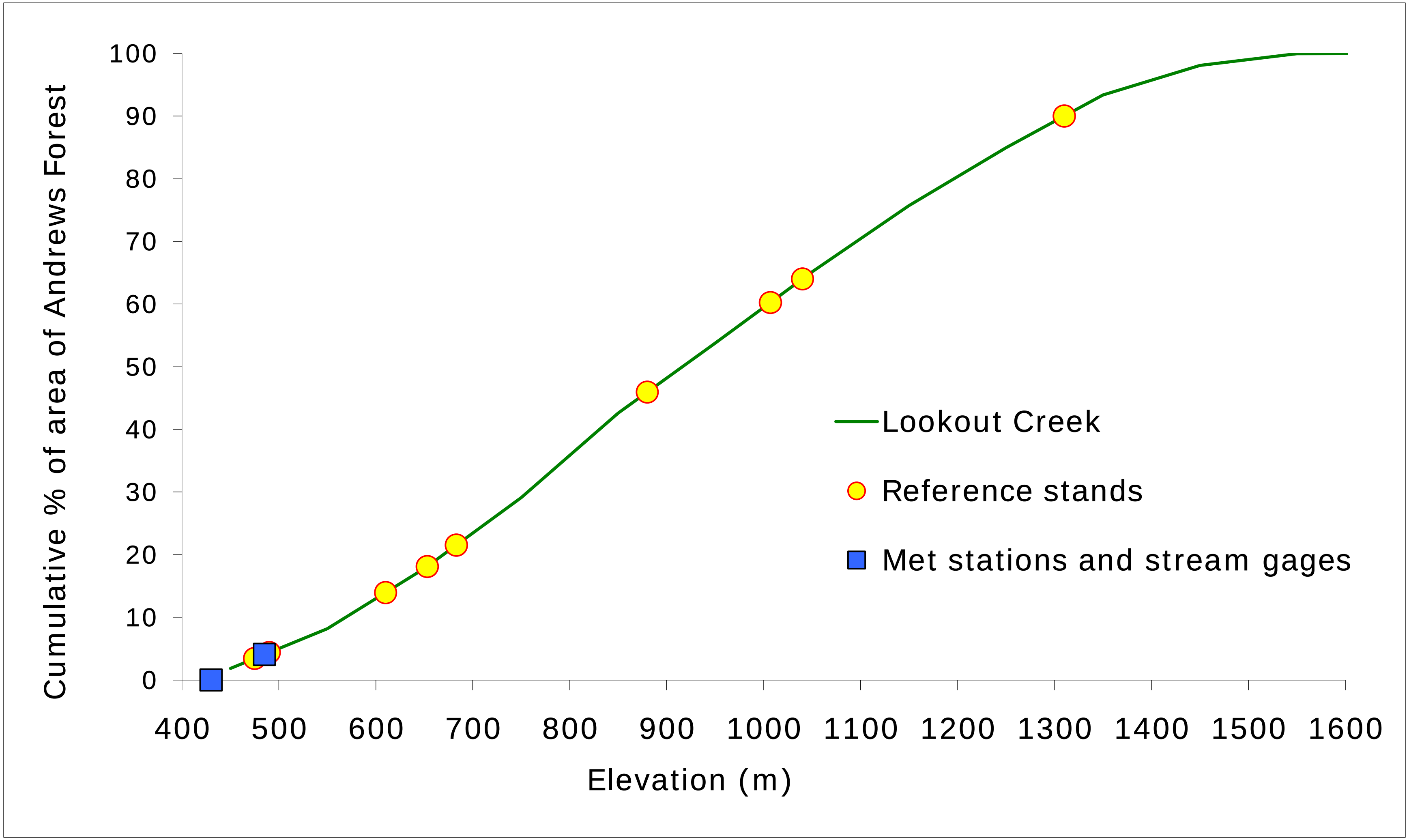


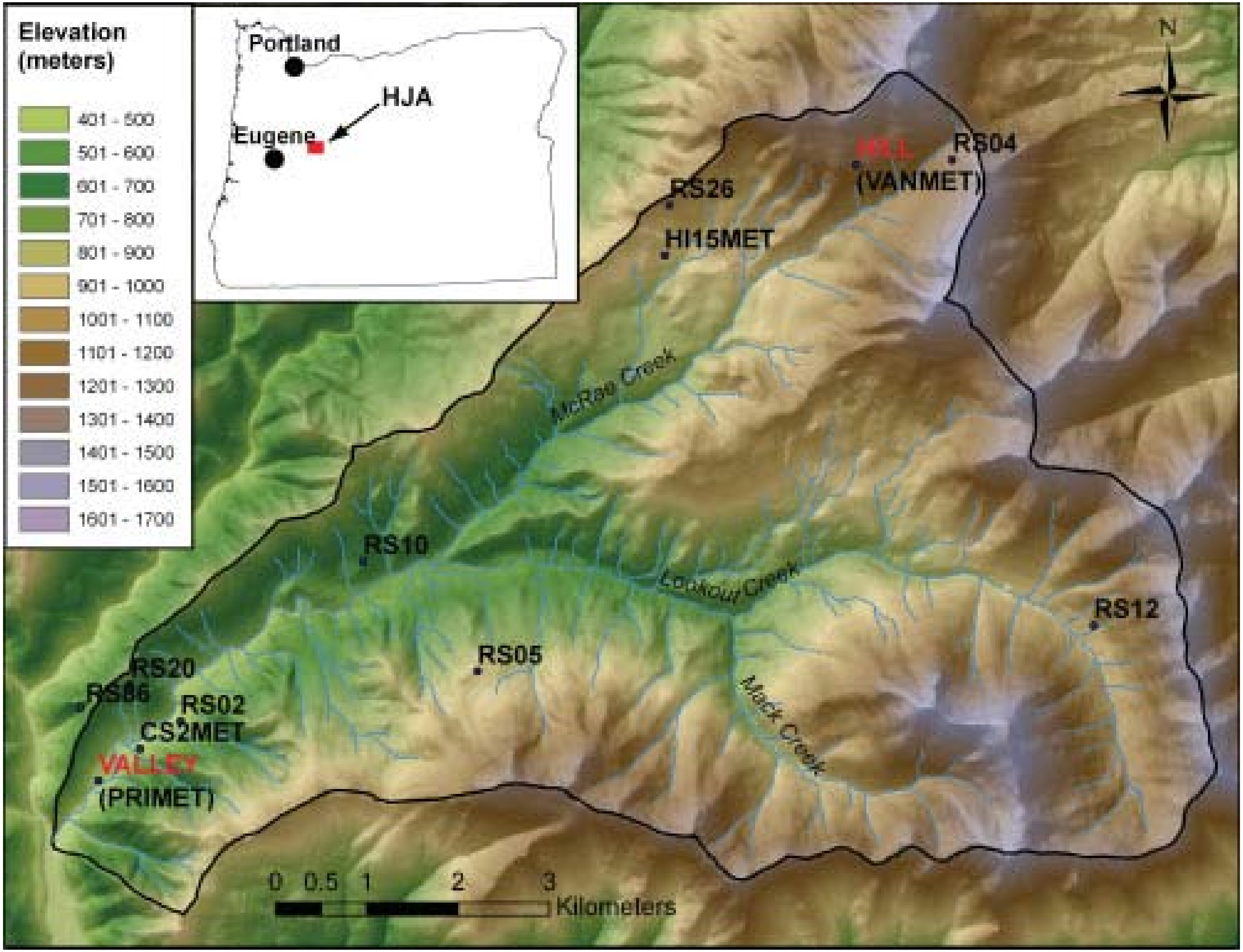
Area-Elevation Relationship for Snow in the McKenzie River Basin

Elevation Distribution and Location of Measurement Sites

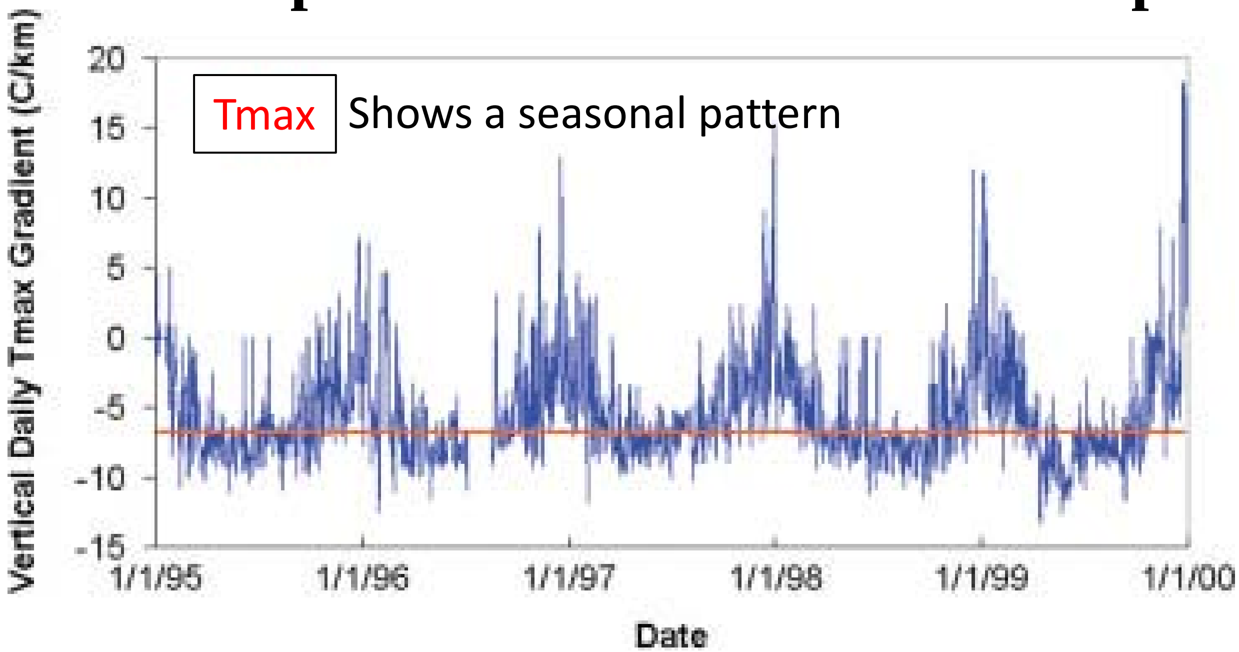


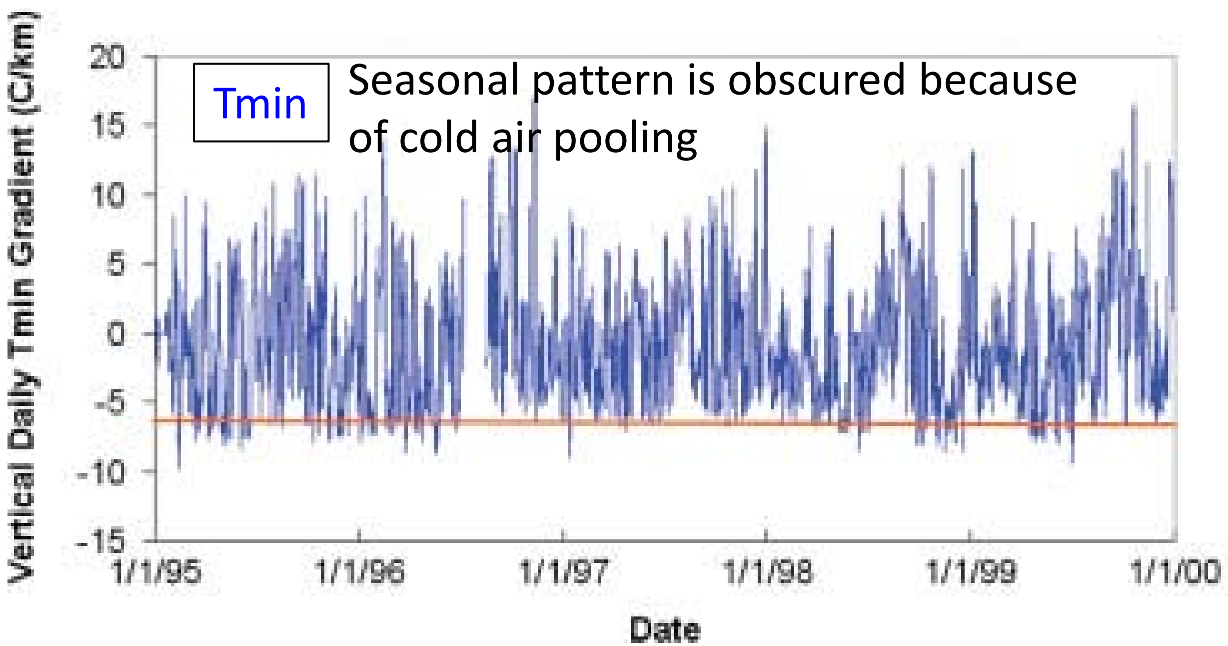
Elevation distribution of HJA sites with records longer than 30 years




Elevation (meters)
401 - 500
501 - 600
601 - 700
701 - 800
801 - 900
901 - 1000
1001 - 1100
1101 - 1200
1201 - 1300
1301 - 1400
1401 - 1500
1501 - 1600
1601 - 1700
Portland
HJA
Eugene
N
RS04
(VANMET)
RS26
HI15MET
McRae Creek
RS10
Lookout Creek
RS12
RS05
RS20
RS86
RS02
CS2MET
VALLEY
(PRIMET)
Mack Creek
0 0.5 1 2 3
Kilometers

Temperature differences between uplands and valleys

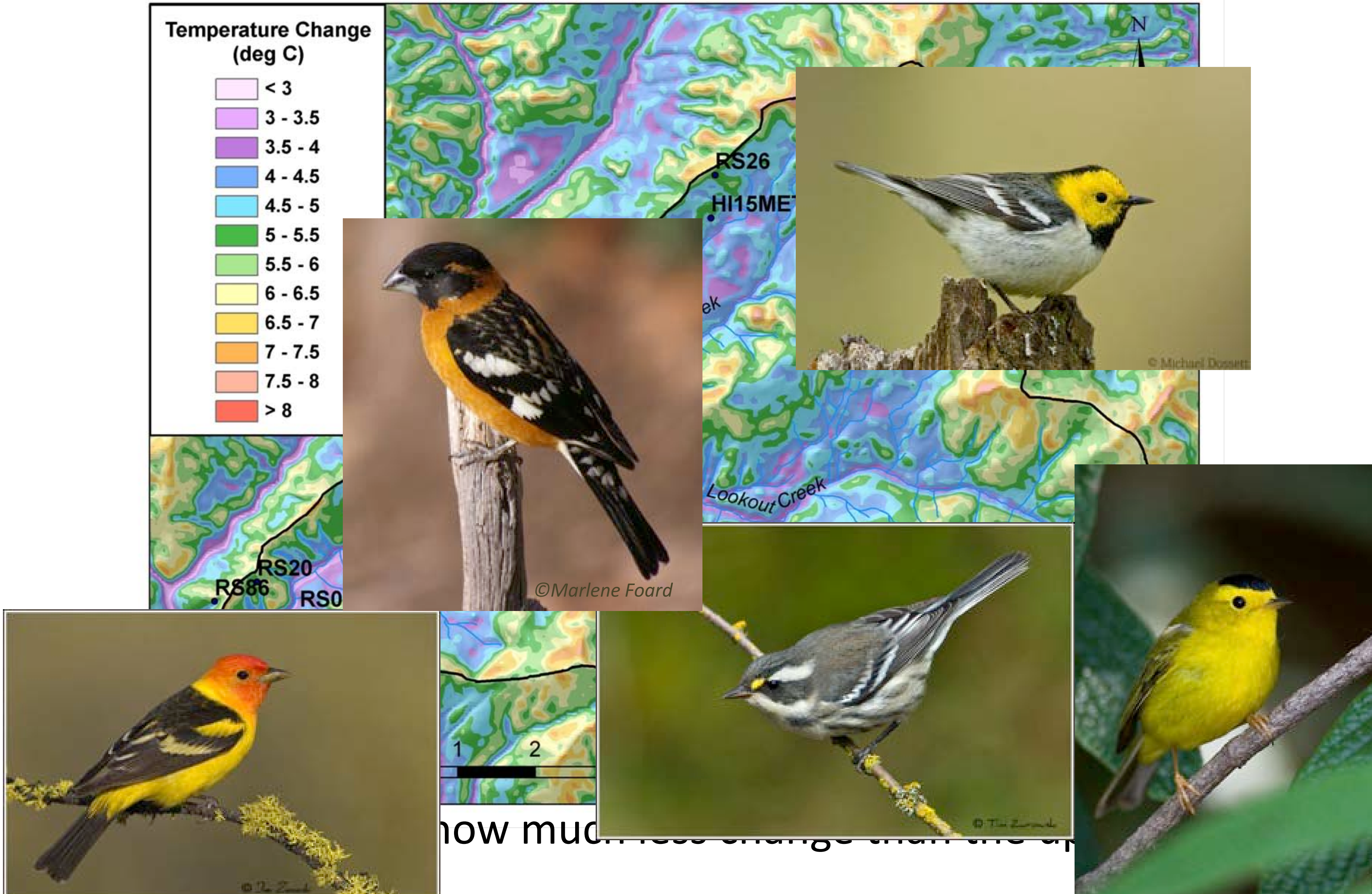




During "stable" atmospheric conditions, cold air flows downslope and pools in the valleys

The valleys become decoupled from the uplands

HJ Andrews Temperature Map for Projected Warming



how much less change than the up

Changes in Land Cover and Land Use Modify Streamflow

But how much, when?

Fire

Beetle Kill

$$I^* = \overline{S}\left(0.27 + \frac{46}{\rho_s}\right)LAI$$

Timber Harvest

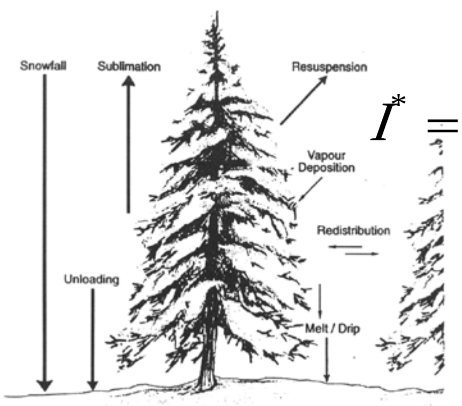
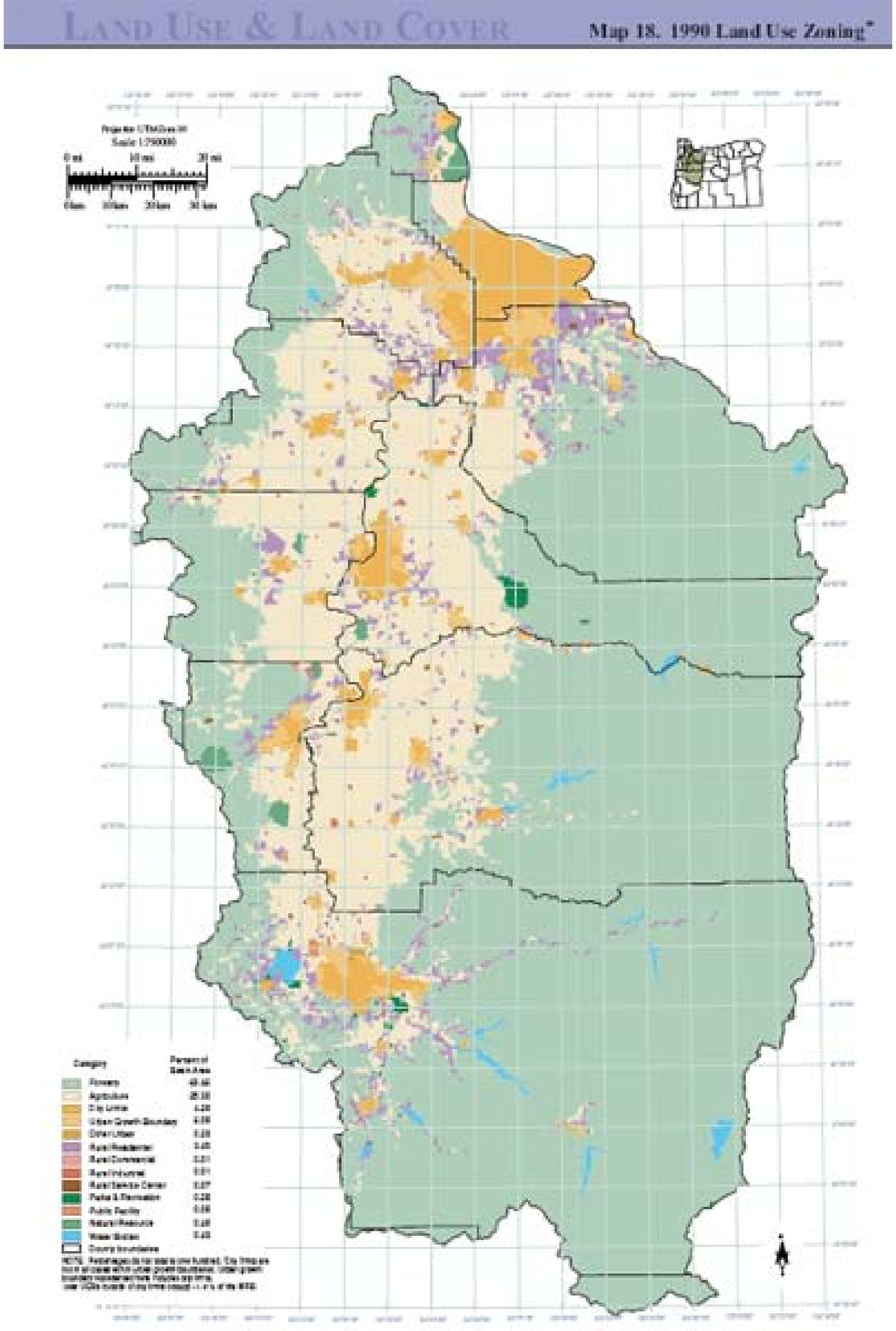


Figure 2.11. Mass fluxes associated with the disposition of winter snowfall in a boreal forest (after Pomeroy and Schmidt, 1993).

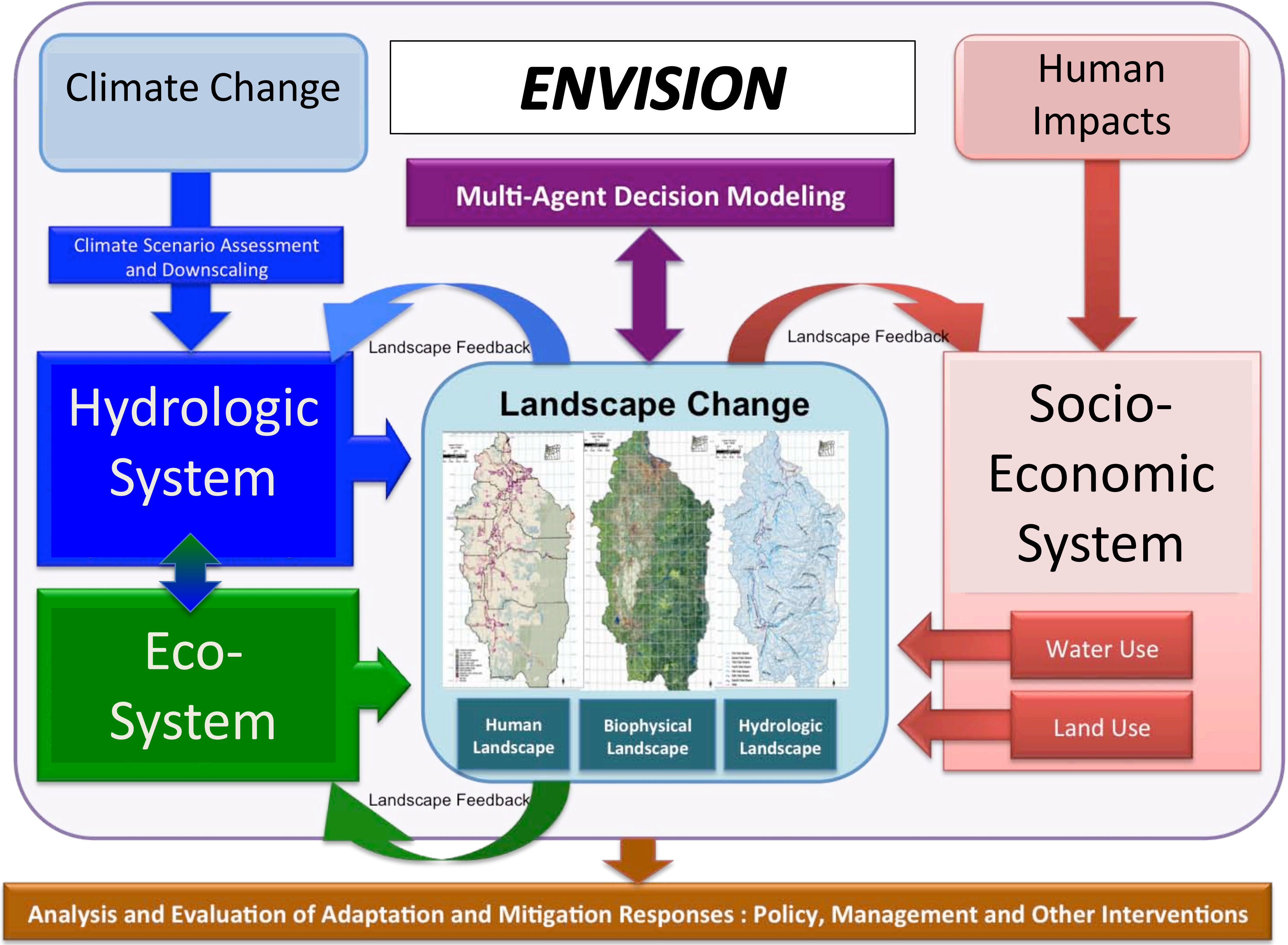
$$I^* = \overline{S}\left(0.27 + \frac{46}{\rho_s}\right)LAI$$



Water flows downhill but policy and population pressures flow uphill

Water scarcity is the relationship between supply and demand

- **Annual vs. seasonal scarcity**
- **Local vs. regional**



Courtesy OSU **Willamette Water 2100** team (McDonnell, PI; NSF Hydrologic Sciences)

In summary:

- Snowpack is changing and long records are key
- Complex topography creates complex temperature patterns
- Measurement systems should be adapted so that they measure patterns of change
- Integrated modeling framework is needed to address issues of water scarcity

Water connects all

Hearty thanks to my many collaborators and contributors:

- Eric Sproles
- Barb Bond
- Chris Thomas
- Chris Daly
- Julia Jones
- Kathleen Miles
- Sarah Frey
- Matt Betts
- Phil Mote
- Jeff McDonnell, John Bolte and the WSC team
- Jim Wigington and Scott Leibowitz
- Christina Tague
- Gordon Grant
- Sarah Lewis
- Aimee Brown