Sustainability of Western Water, Water Storage as Snow, and Trans-Basin Diversions

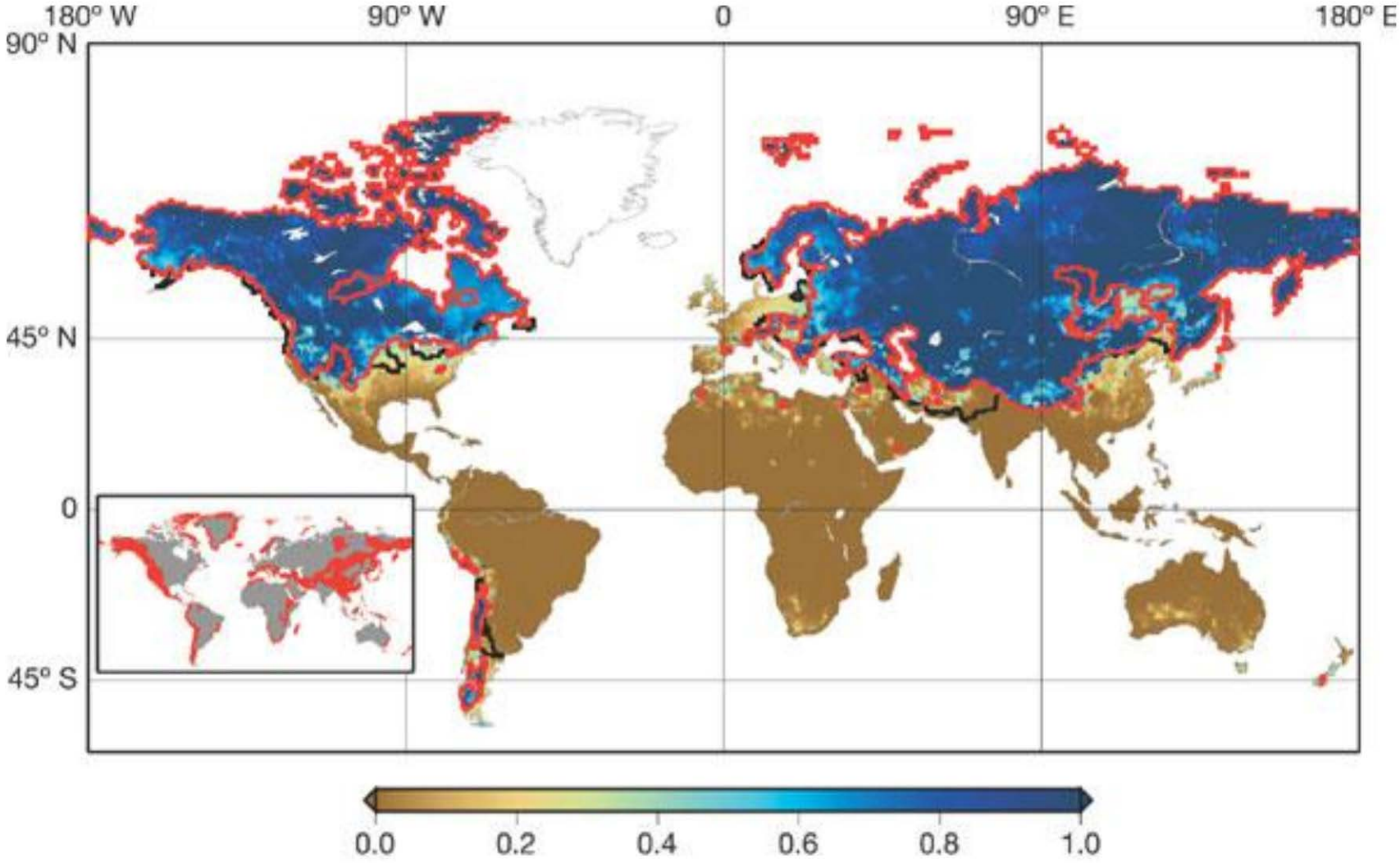
Organizations: US LTER, ILTER, MRI, LTER Europe, GBMA, USAID

Outline

- Overview of mountain hydrology
- NWT LTER basic research results
  - The new normal?
  - Non-stationarity world
- Colorado headwaters research: USDA/NSF
  - Suits in the beltway get it
- Himalaya's: USAID
  - Water problems are global

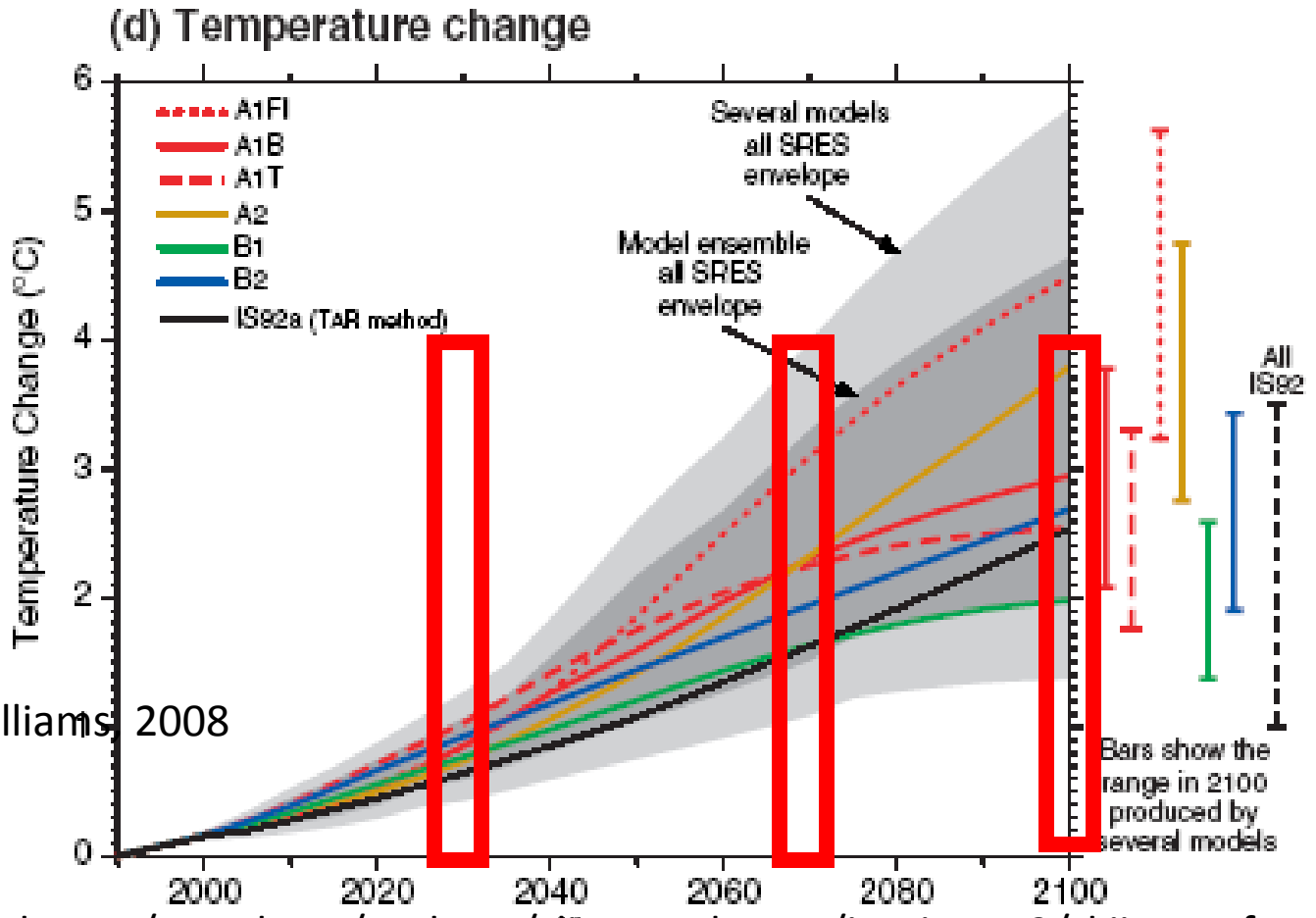
Water Sustainability & Snowmelt

1/6th of the population and 1/4th of GDP



Barnett et al., 2005 - Nature

Rising CO_2 Will Lead to Accelerated Rise in Air Temperature



Lazar and Williams 2008

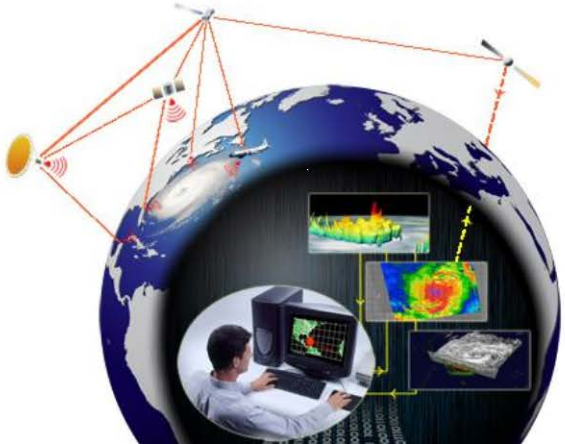
http://www.pbs.org/newshour/updates/climate-change/jan-june13/skiingprefont_02-27.html

Making a water-secure world – the three I's

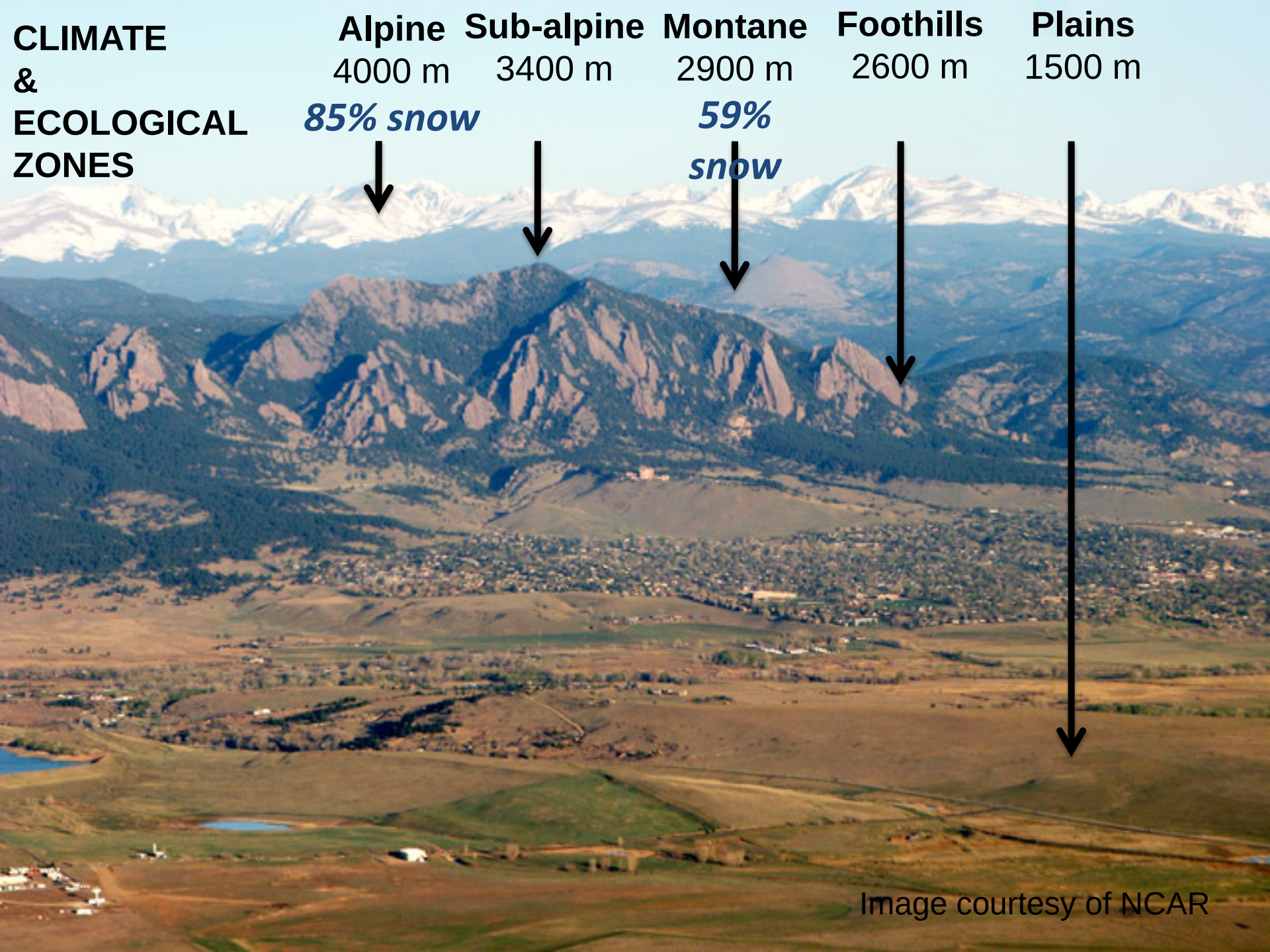
INFRASTRUCTURE
to store, transport
& treat water

Stronger & more-adaptable
INSTITUTIONS

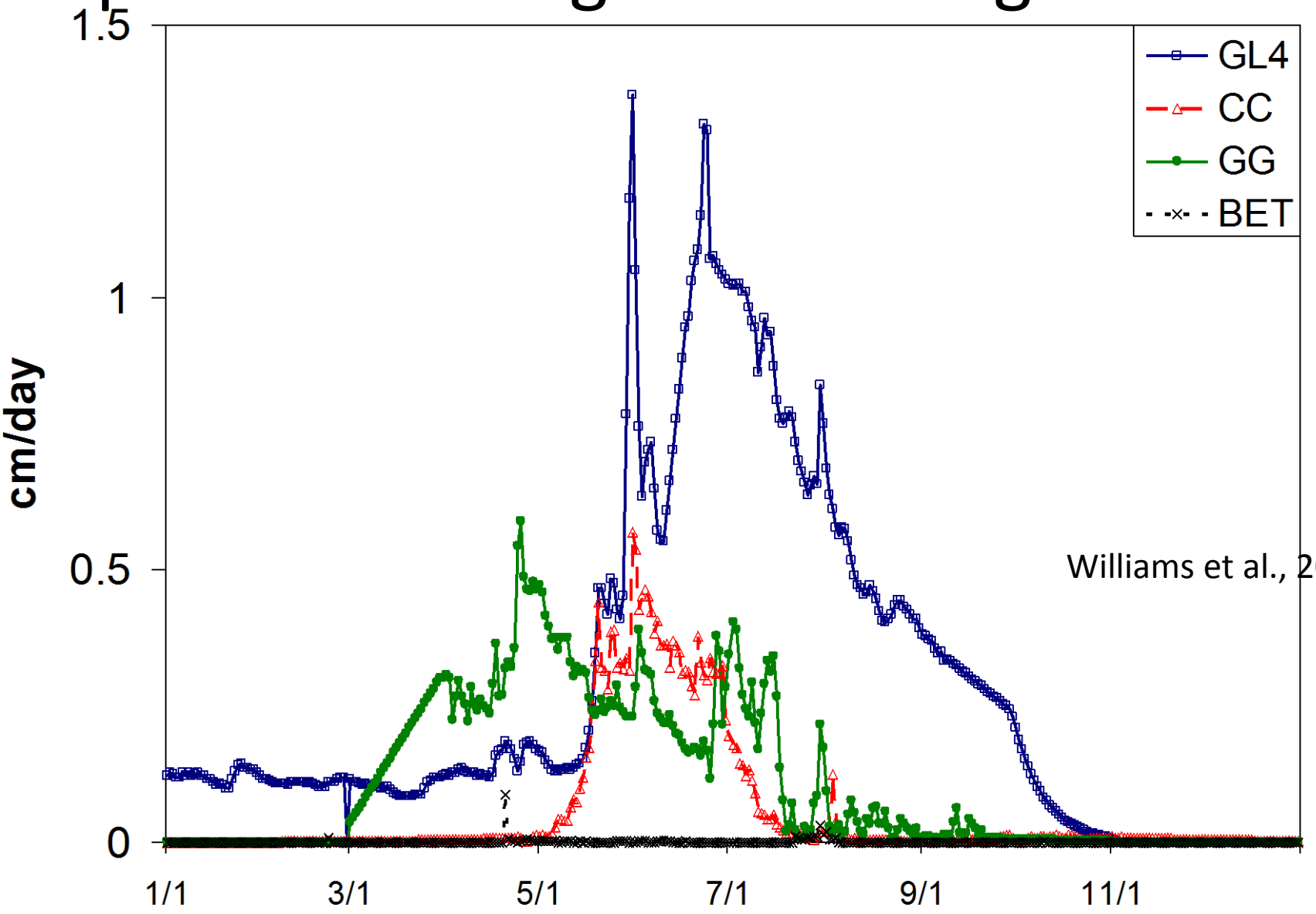
Better & more-accessible
INFORMATION



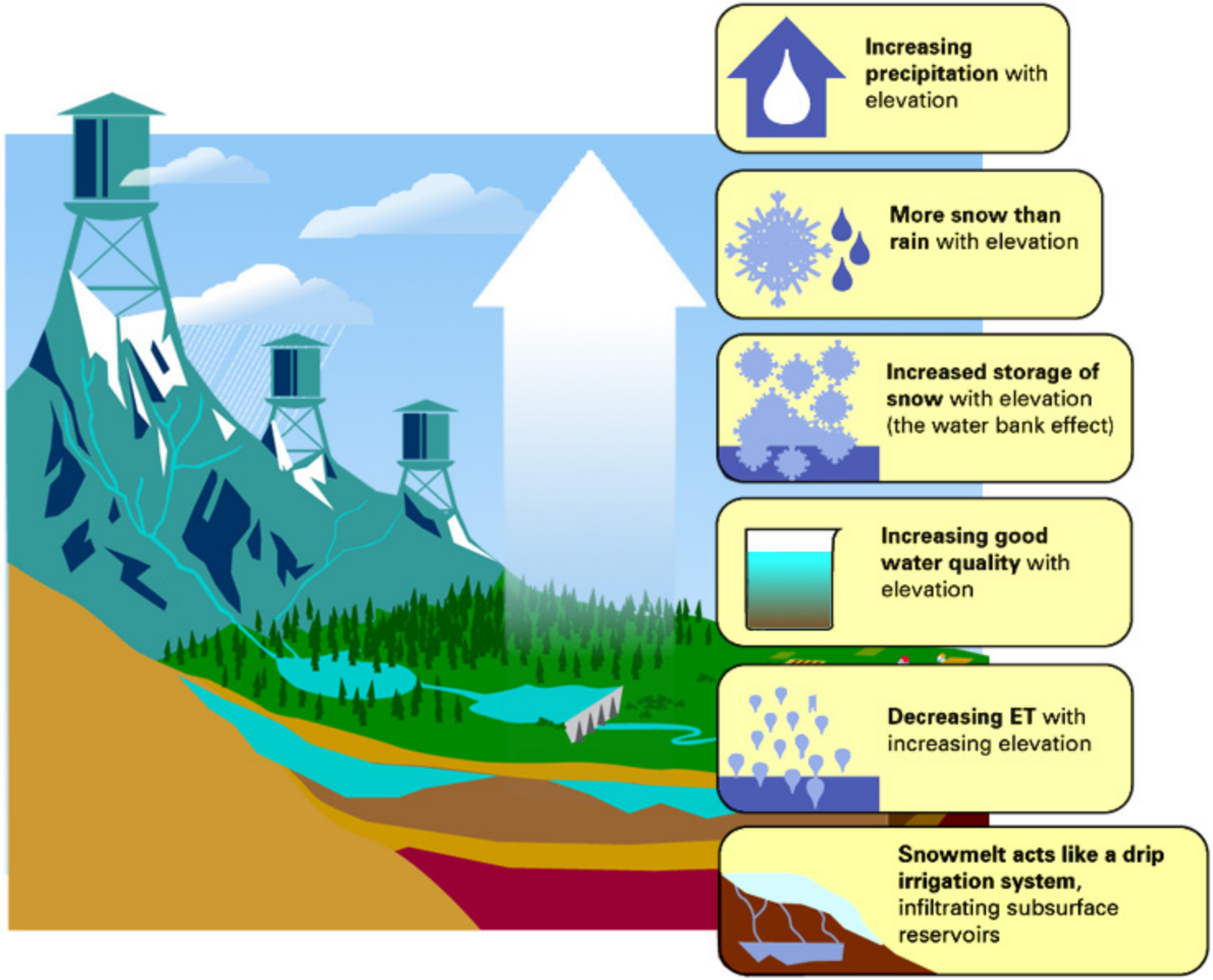
Niwot Ridge
Long-Term Ecological Research Site


CLIMATE
&
ECOLOGICAL
ZONES
Alpine
4000 m
85% snow
Sub-alpine
3400 m
Montane
2900 m
59%
snow
Foothills
2600 m
Plains
1500 m
Image courtesy of NCAR

Specific discharge elevation gradient

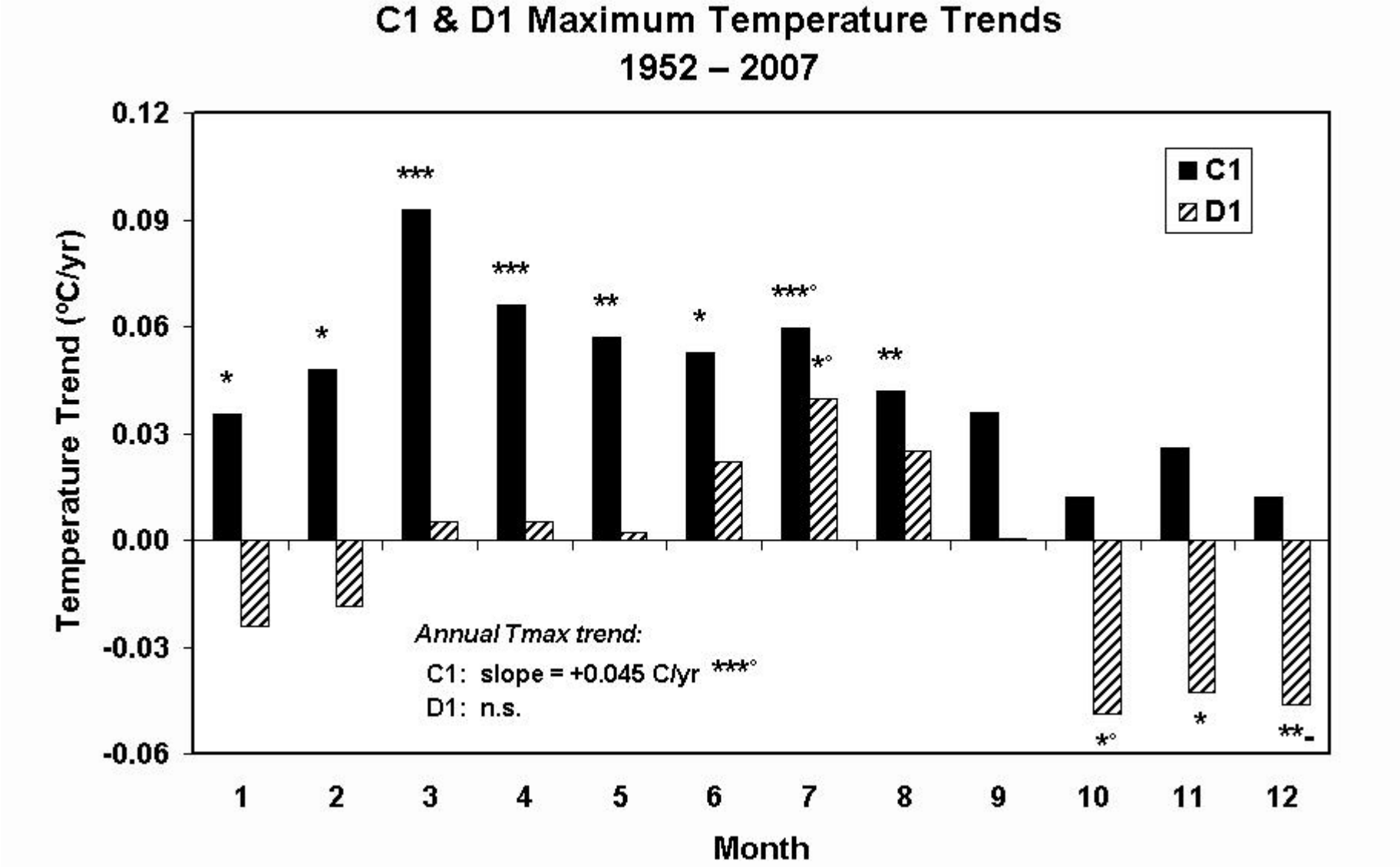


Williams et al., 2011



Mountains are water towers

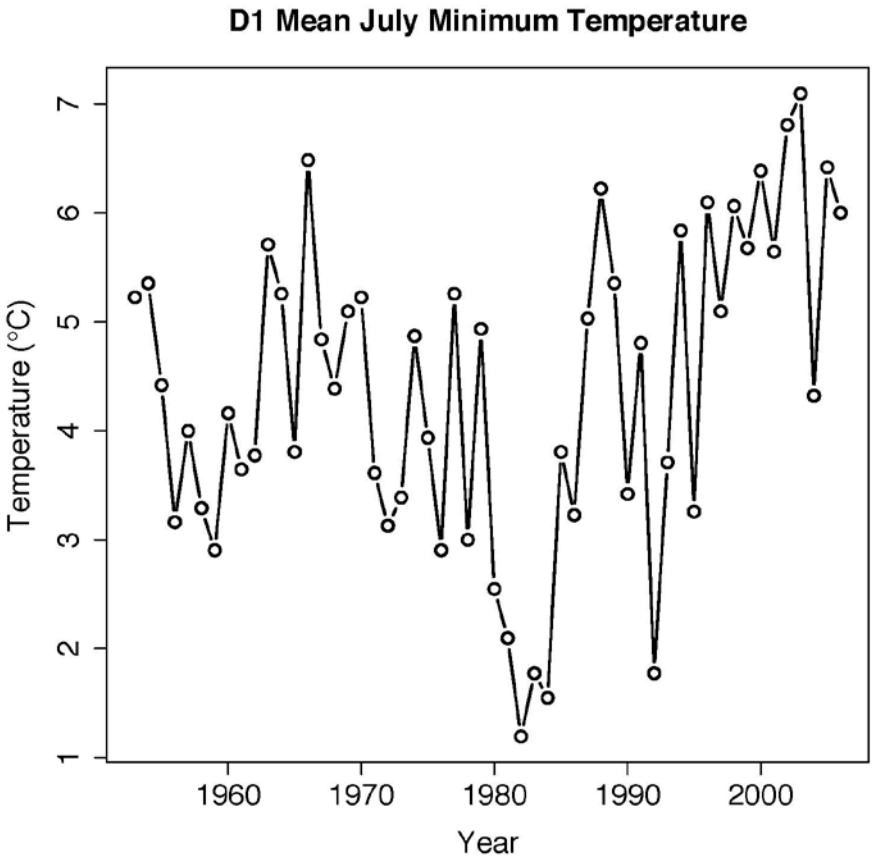
Niwot Ridge
Long-Term Ecological Research Site



Warmer in subalpine, colder during winter in alpine. Albedo effect

High-Elevation Air Temperature

- Increasing air temperature since early 1980's
- Summer air temps warming fastest
- Earlier lake ice-out dates



5ºC increase in 25 years

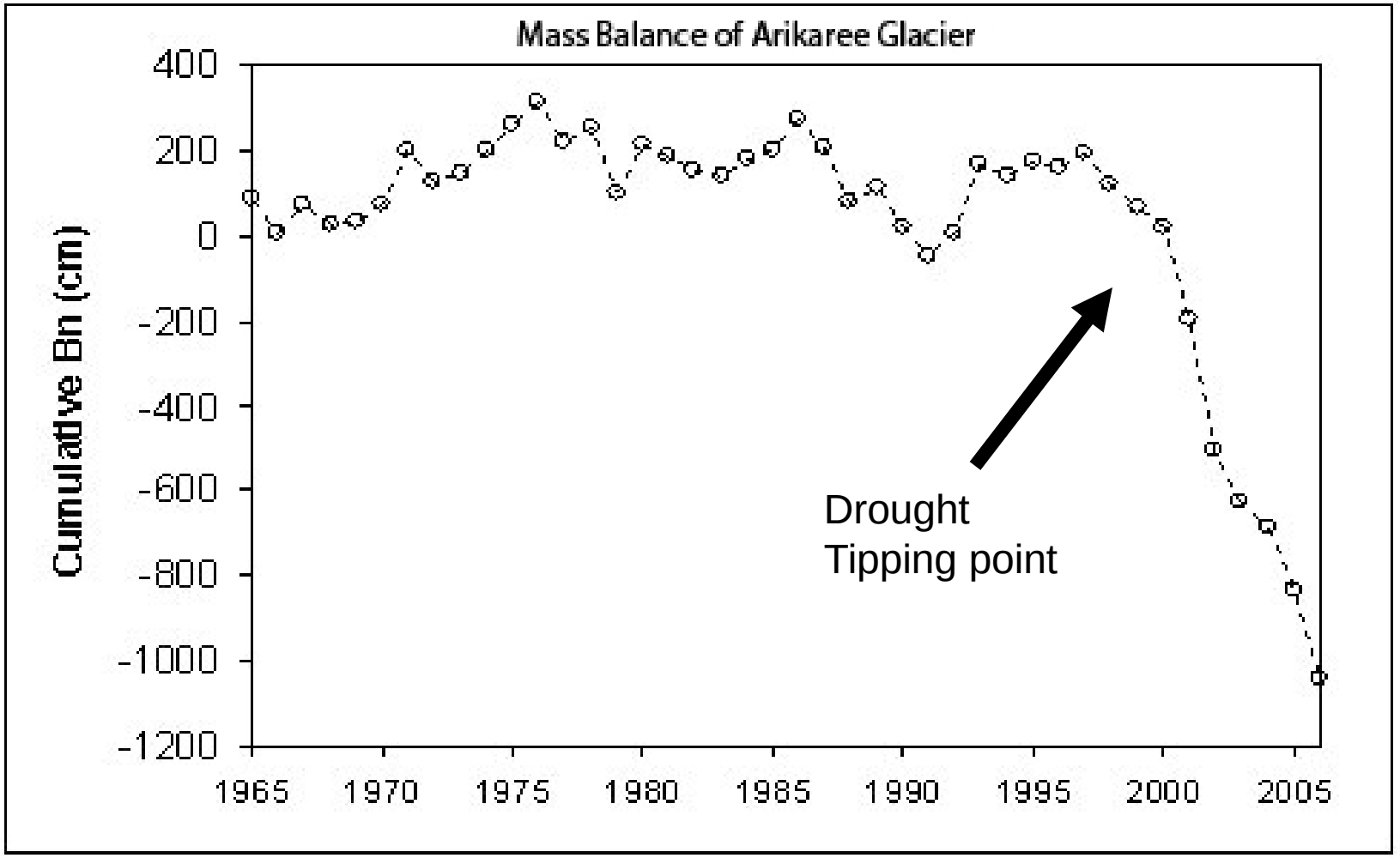
Mountain Pine Beetle

Changes in veg affect pika's?

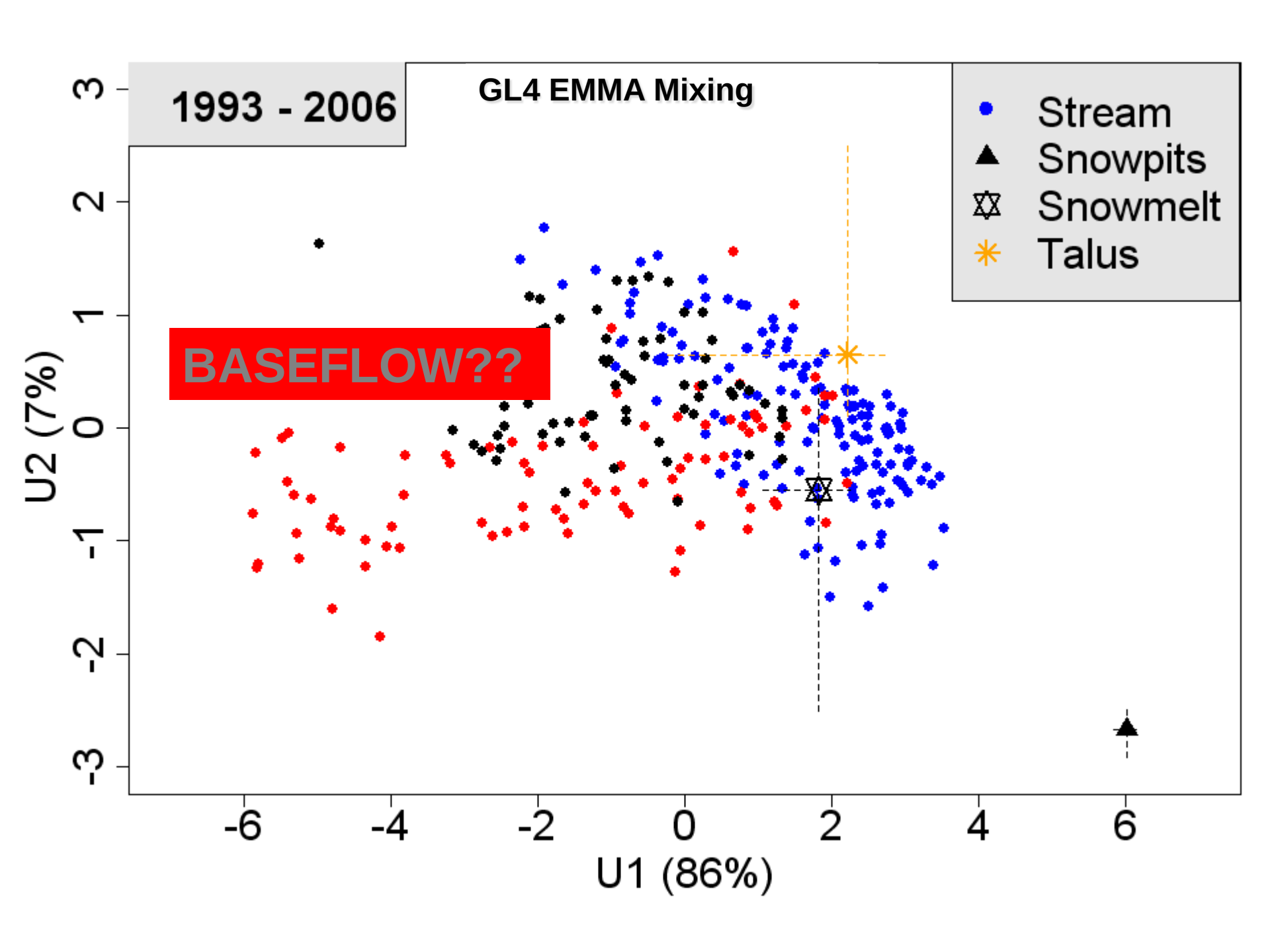
Pika's: alpine
Polar bears: Arctic
Penguins: Antarctic

Iconic species and P

Arikaree glacier is dying

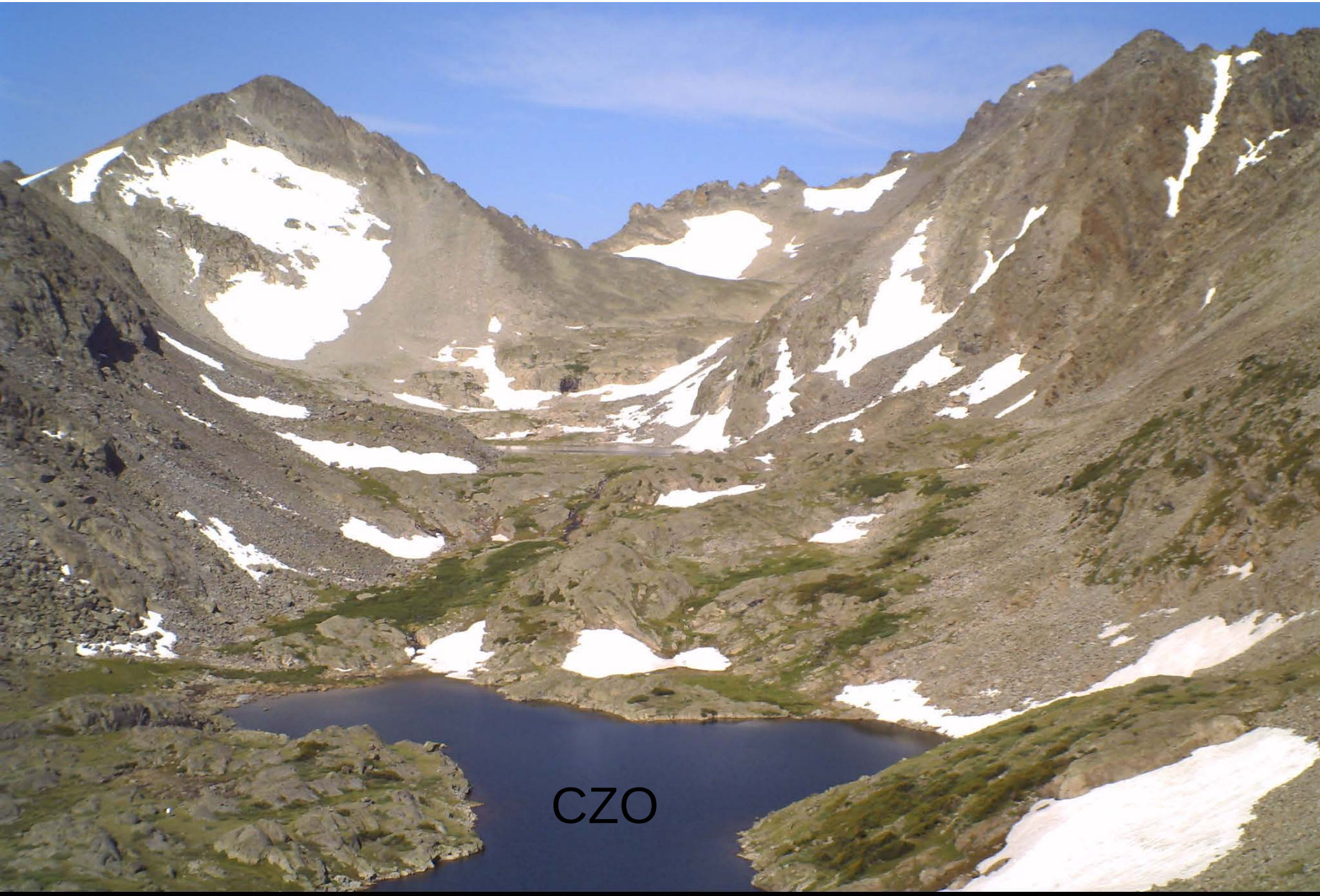


Arikaree Glacier: Mass balance (Bn), cm water equivalent.

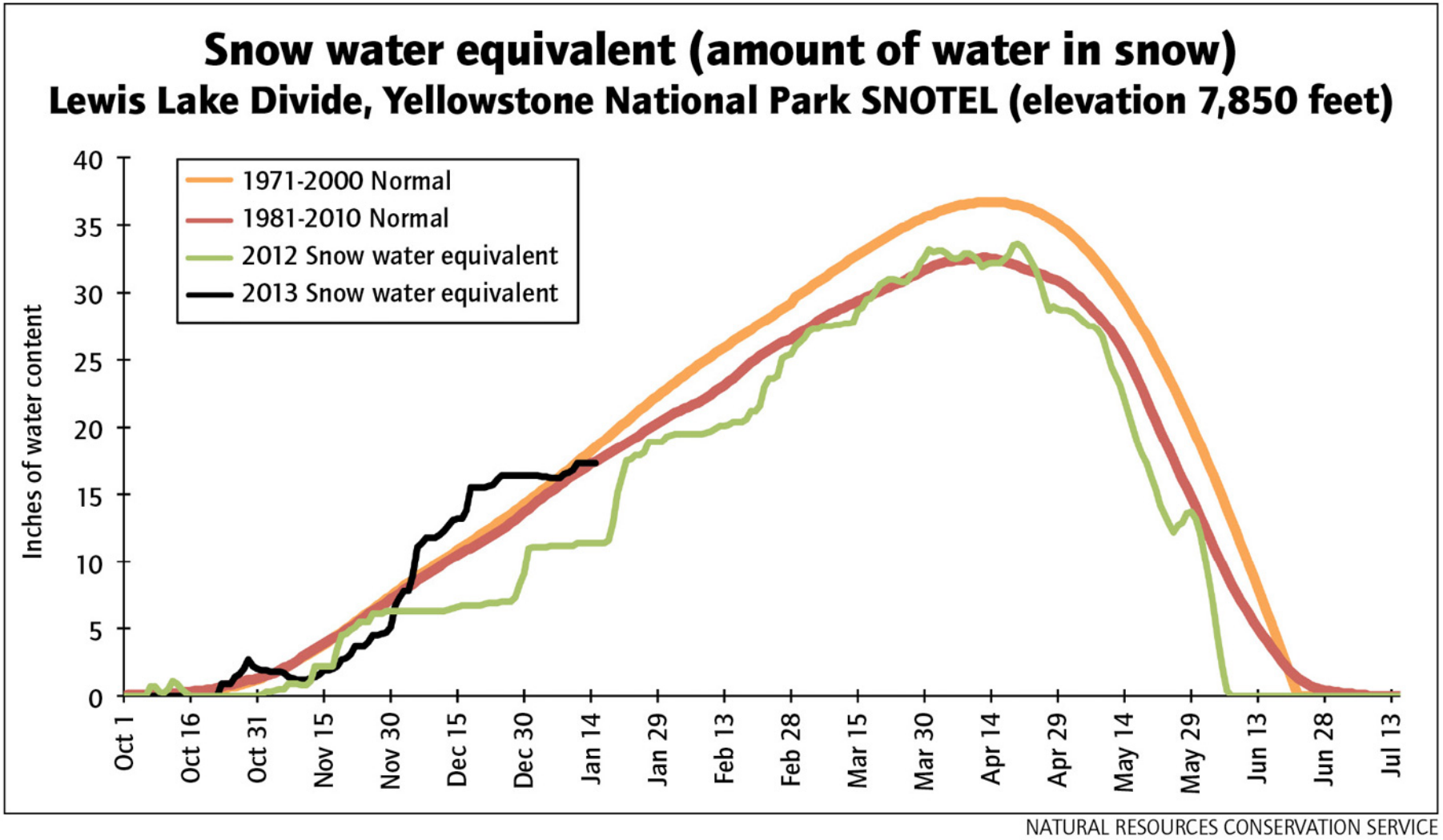

1993 - 2006
GL4 EMMA Mixing
Stream
Snowpits
Snowmelt
Talus
BASEFLOW??
U2 (7%)
U1 (86%)
3
2
1
0
-1
-2
-3
-6
-4
-2
0
2
4
6

Green Lakes Valley June 22, 2011

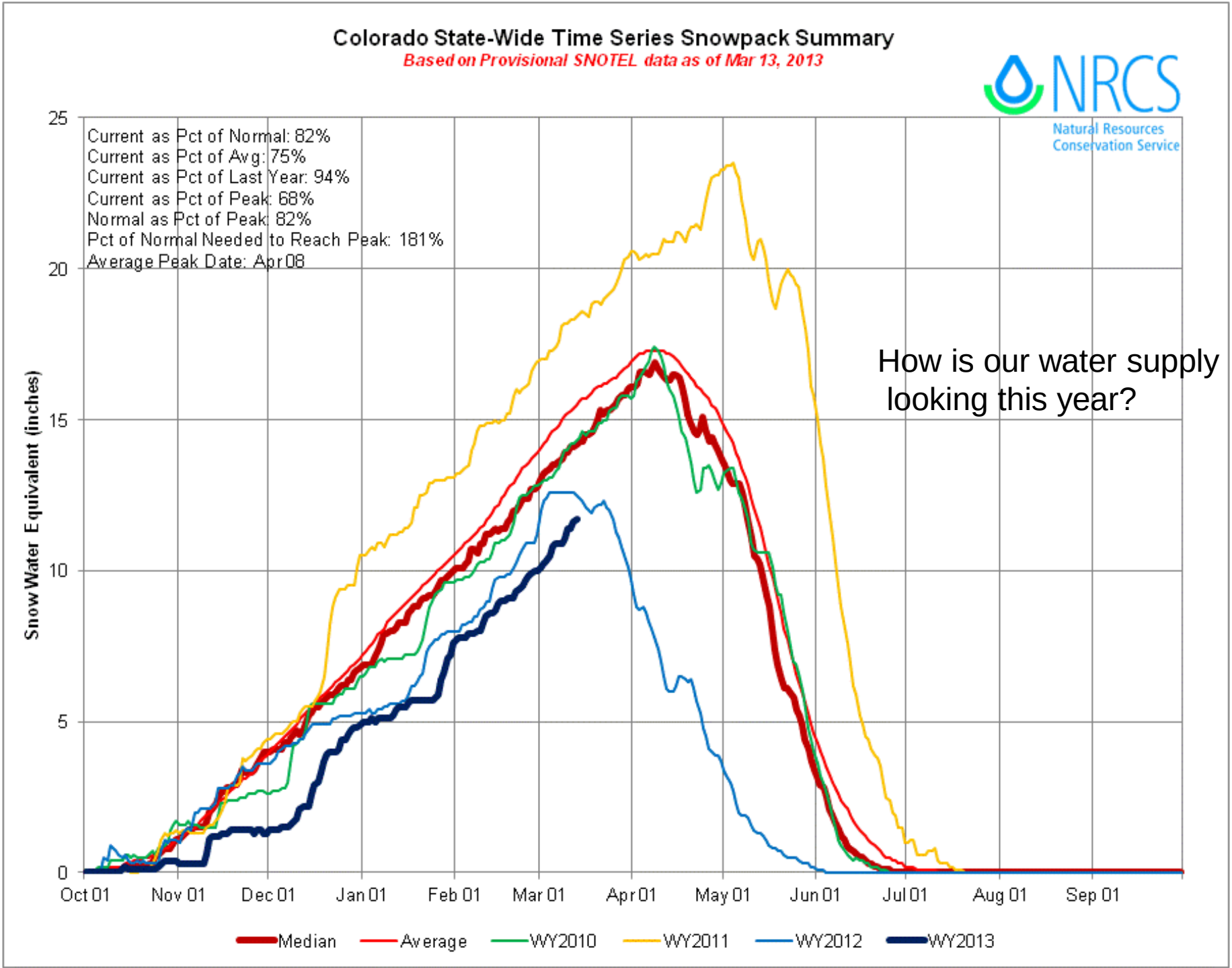
Green Lakes valley June 22, 2012



The new normal



"Normal" is now about 10% less snow compared to 10 years ago.

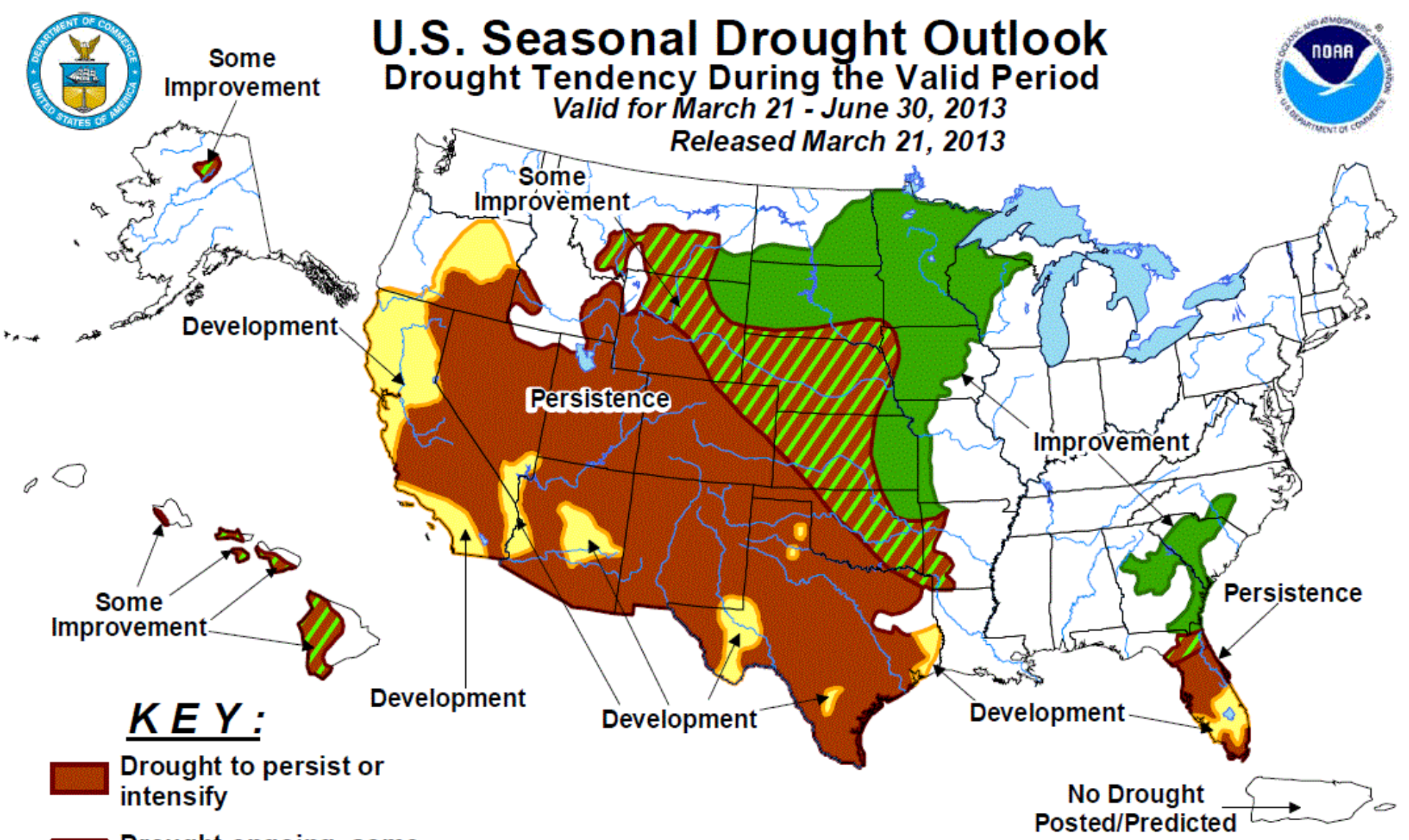

Colorado State-Wide Time Series Snowpack Summary
Based on Provisional SNOTEL data as of Mar 13, 2013
NRCS
Natural Resources Conservation Service
Current as Pct of Normal: 82%
Current as Pct of Avg: 75%
Current as Pct of Last Year: 94%
Current as Pct of Peak: 68%
Normal as Pct of Peak: 82%
Pct of Normal Needed to Reach Peak: 181%
Average Peak Date: Apr 08
Snow Water Equivalent (inches)
25
20
15
10
5
0
Oct 01
Nov 01
Dec 01
Jan 01
Feb 01
Mar 01
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Median
Average
WY2010
WY2011
WY2012
WY2013
How is our water supply looking this year?

U.S. Seasonal Drought Outlook

Drought Tendency During the Valid Period

Valid for March 21 - June 30, 2013

Released March 21, 2013



K E Y :

- Drought to persist or intensify
- Drought ongoing, some improvement
- Drought likely to improve, impacts ease
- Drought development likely

Depicts large-scale trends based on subjectively derived probabilities guided by short- and long-range statistical and dynamical forecasts. Short-term events -- such as individual storms -- cannot be accurately forecast more than a few days in advance. Use caution for applications -- such as crops -- that can be affected by such events. "Ongoing" drought areas are approximated from the Drought Monitor (D1 to D4 intensity). For weekly drought updates, see the latest U.S. Drought Monitor. NOTE: the green improvement areas imply at least a 1-category improvement in the Drought Monitor intensity levels, but do not necessarily imply drought elimination.

Ecohydrological vulnerability to changes in climate and land use in the Colorado River Basin headwaters: implications for water policy and management

Noah Molotch (PI)

Patrick Bourgeron

Mark Williams

Leanne Lestak

David Gochis

Kathleen Miller

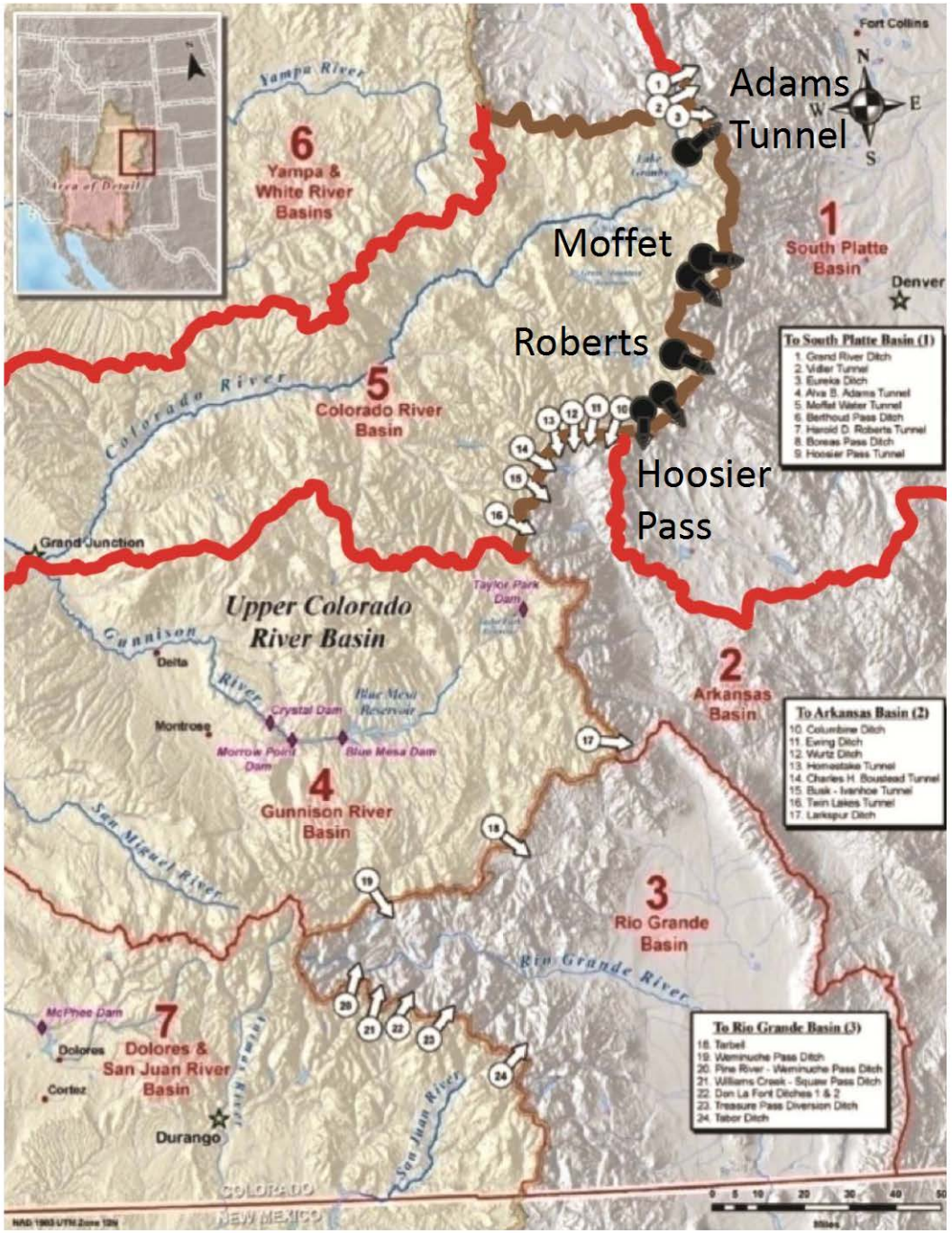
Olga Wilhelmi

David Yates

Colorado Transbasin Diversions:

24 major transbasin diversions

Approx. 560,000+ AFY moved from Colorado River Basin to E. Slope (Roughly 20-25% of in-state consumptive use of CO River)

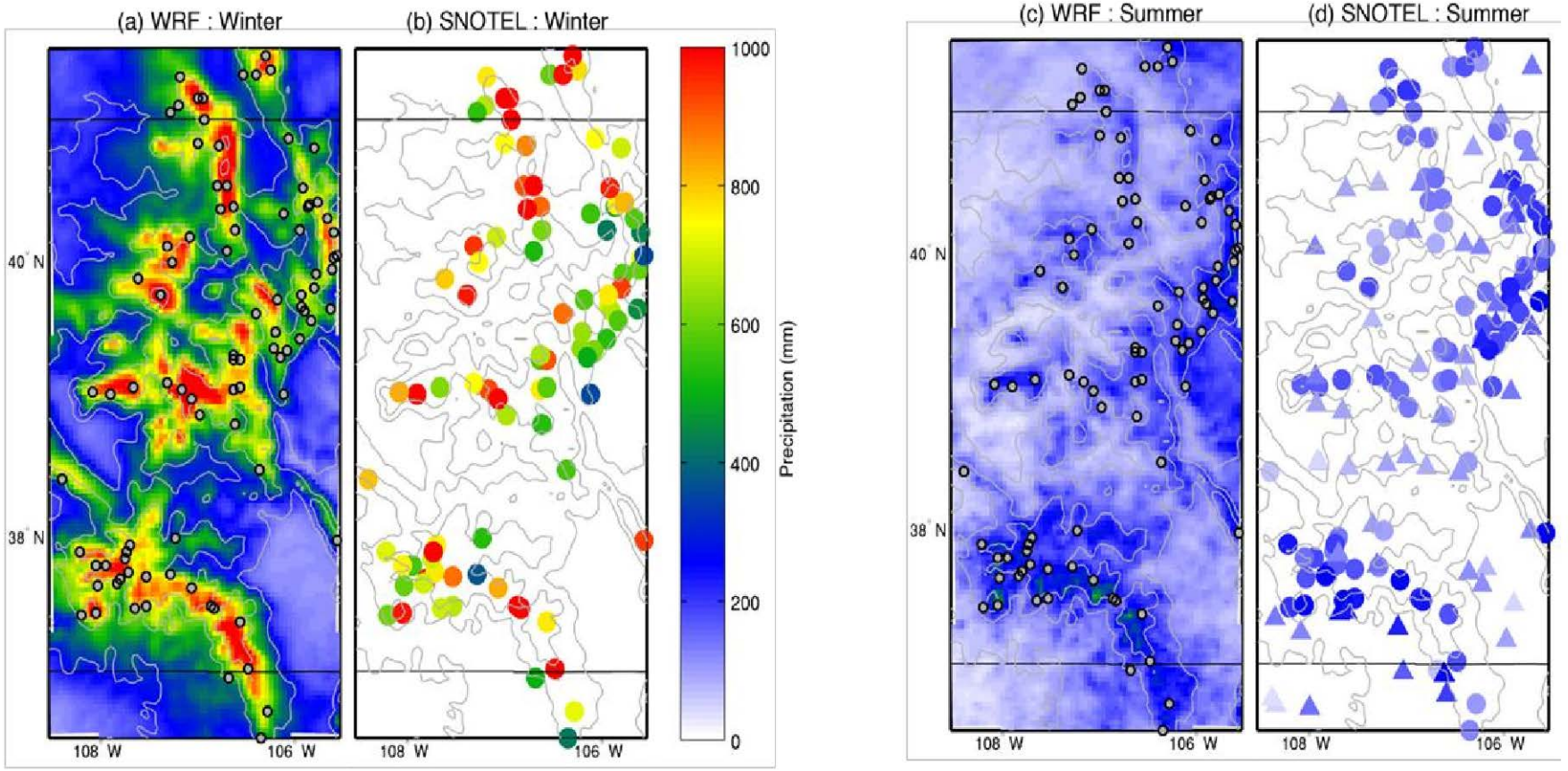


Science Questions

- Q1: How will climate-related changes in snowmelt timing and magnitude alter the partitioning of the water balance?
- Q2: How will alterations in snowmelt timing and landscape disturbances interact to influence ecosystem structure, function, and streamflow?
- Q3: How will stakeholders be affected by different scenarios of climate / land-scape change associated with changes in snowmelt partitioning and the fulfillment of inter-basin water transfers?
- Q4: How could improved information regarding future snowmelt timing contribute to more effective long-range multi-stakeholder water and forest planning within the current policy and legal institution framework?

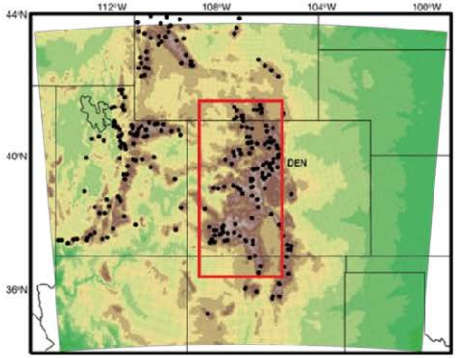
Q1

Regional Climate Modeling: Precipitation



Regional Climate Modeling using WRF-NOAH

Activity Lead: Gochis, NCAR



Rasmussen et al., 2012
J. Climate

Q1

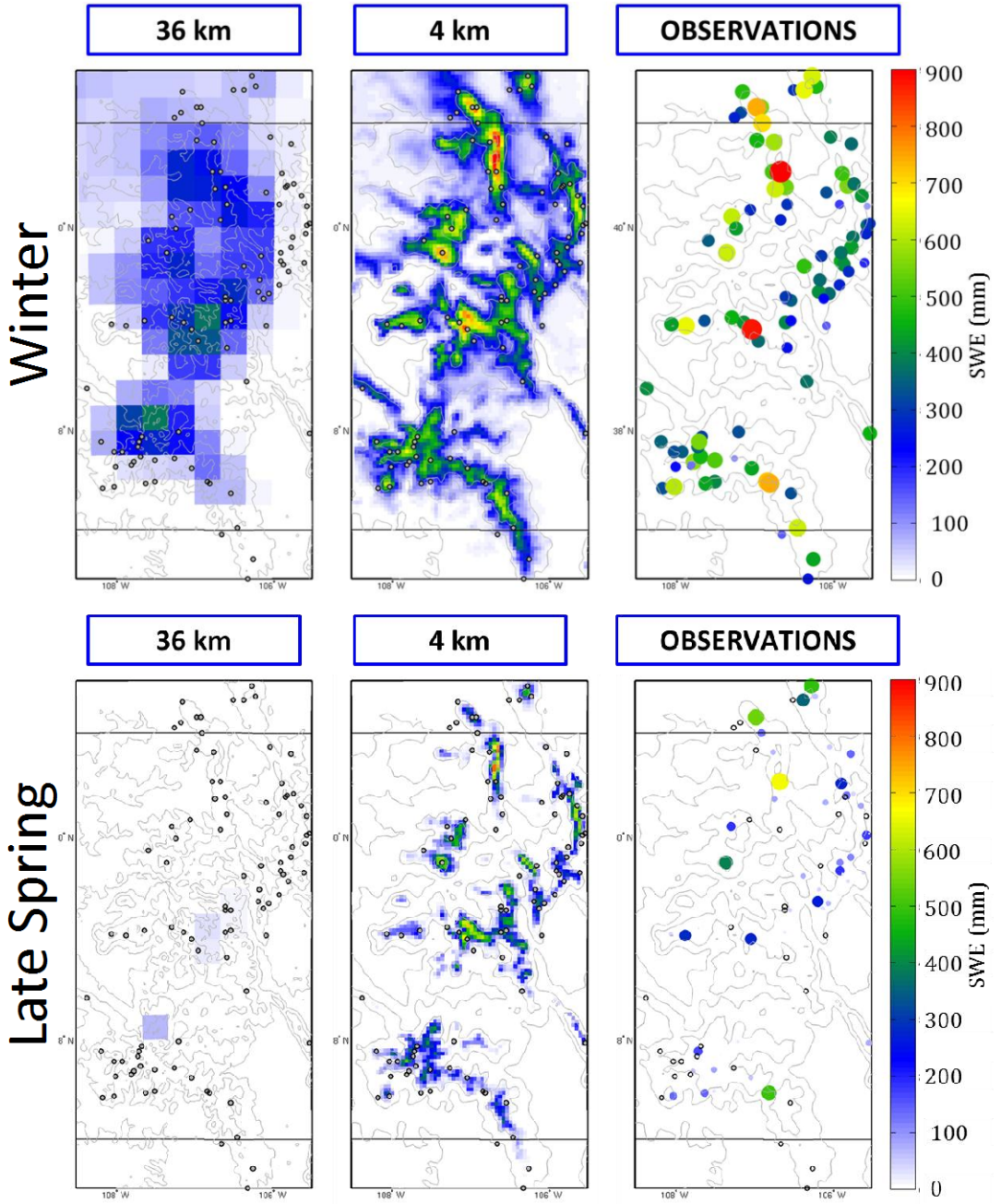
Regional Climate Modeling: Snowpack

Scale Dependent Snowpack Behavior

- Errors reduced at higher resolution.
- Spring snowpack conditions poorly resolved at coarser scale.

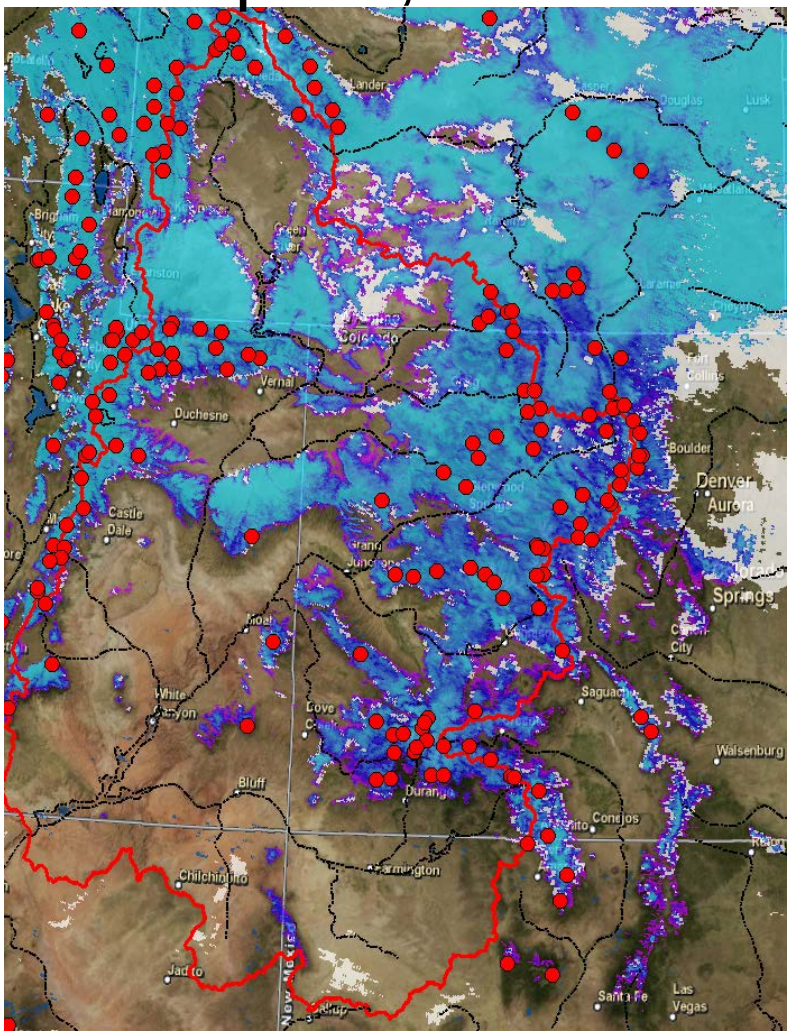
Future:

- Perform historical spatially explicit evaluations (2000 – 2008).
- Predictions (2045 – 2053) with dynamic land cover.

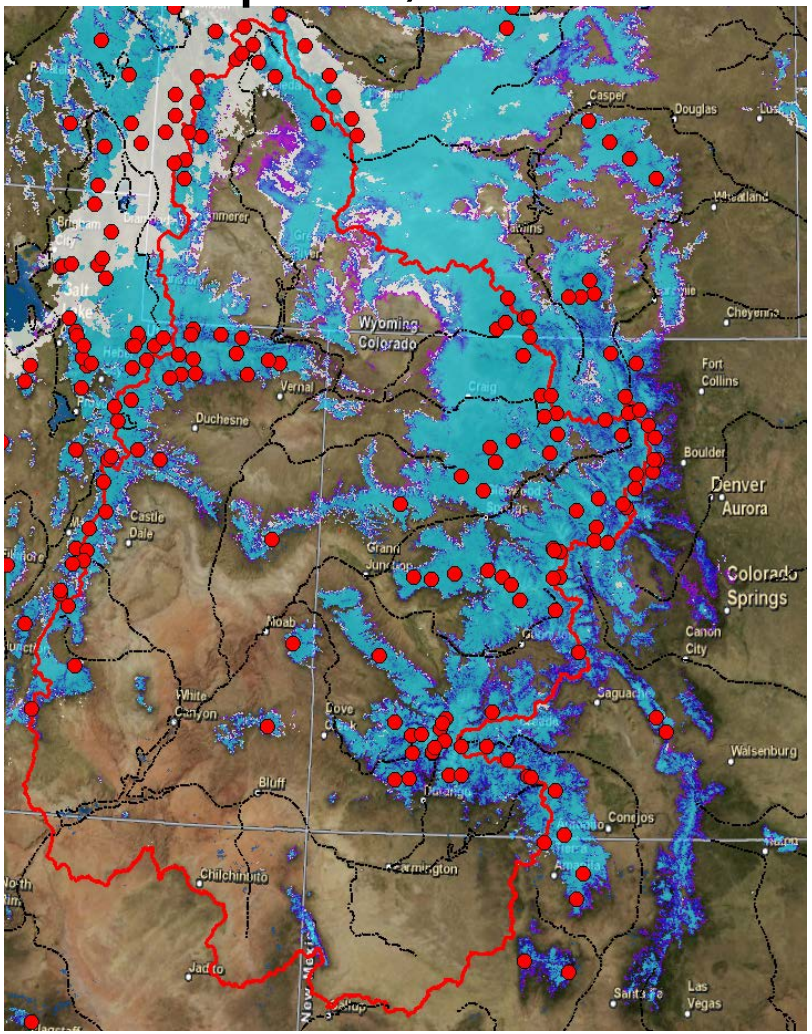


Snow Extent in the Colorado River Basin from MODIS

April 6, 2009



April 8, 2010



Q2

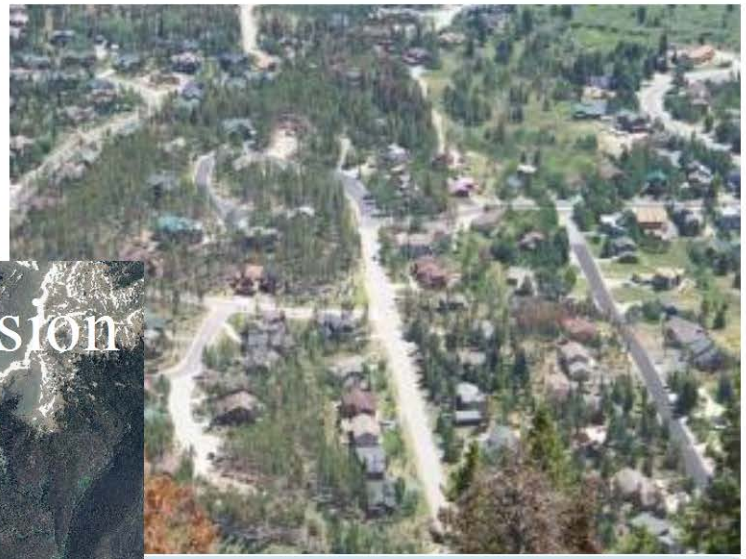
Ecosystem Sensitivity to Ex-Urban Population Growth

Summit County

Historical populations

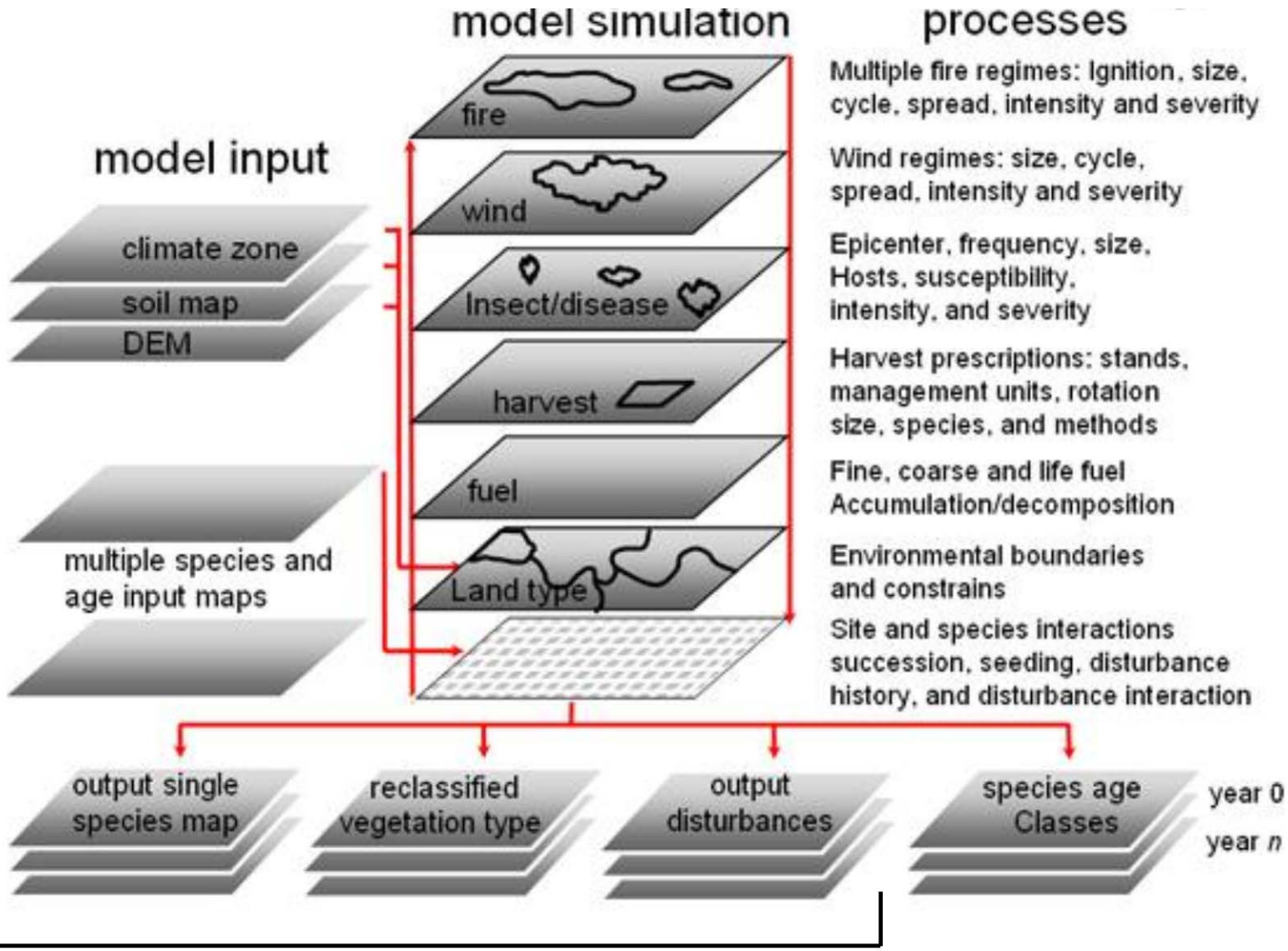
Census	Pop.	%±
1900	2,744	—
1910	2,003	−27.0%
1920	1,724	−13.9%
1930	987	−42.7%
1940	1,754	77.7%
1950	1,135	−35.3%
1960	2,073	82.6%
1970	2,665	28.6%
1980	8,848	232.0%
1990	12,281	38.8%
2000	23,548	91.7%
2010	27,994	18.9%

Fire Protection



Q2

Ecosystem Sensitivity: LANDIS Model



Derive LAI and Forest Cover Fraction for RCM Simulations

Activity Lead: Bourgeron, CU

Q3

Modeling the Built Environment with the Water Evaluation And Planning (WEAP) Model

Upper Colorado Water System "Objects" in WEAP:

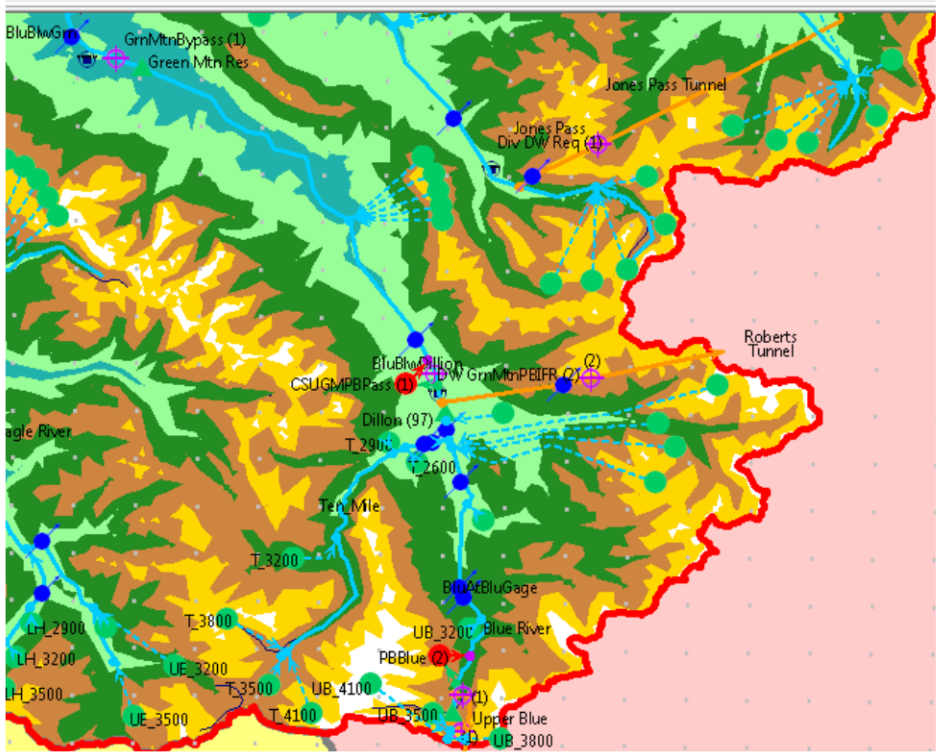
18 Rivers – linked to catchments
- Blue
- Snake
- Ten Mile
- Fraser
- Williams Fork
- …
- Colorado

15 Diversions
- Hoosier
- Homestake (Fry Ark)
- Boustead (Fry Ark)
- Roberts Tunnel
- Alva B. Adams (CBT)
- Windy Gap (CBT)

13 Reservoirs
- Dillion
- Green Mtn
- Granby-Grand Lake

6 Demands
- Domestic
- Agriculture
- Environmental/Instream flows

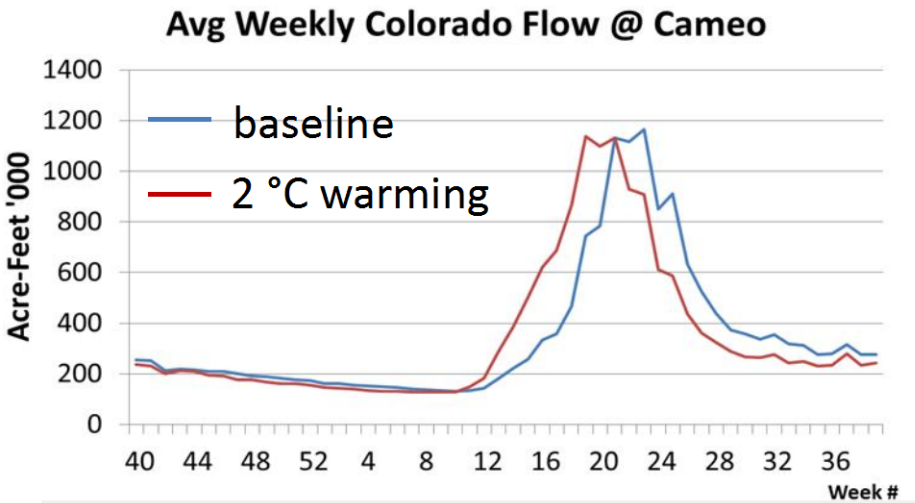
Example:
WEAP Model Implementation for Denver Water for the Upper Blue River and Associated Trans-basin Diversions

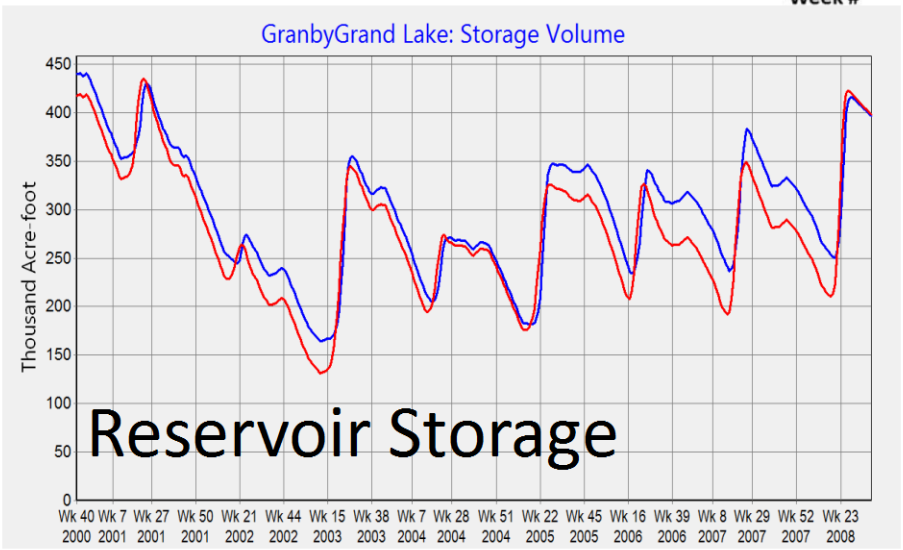


Q3

Sustainability: Modeling climate change impacts on the built environment with WRF & WEAP

- 4km WRF simulations forcing WEAP model
- Includes infrastructure and water rights requirements.
- Shift to reduced summertime and autumn flows.
- reservoir storage is reduced during most years

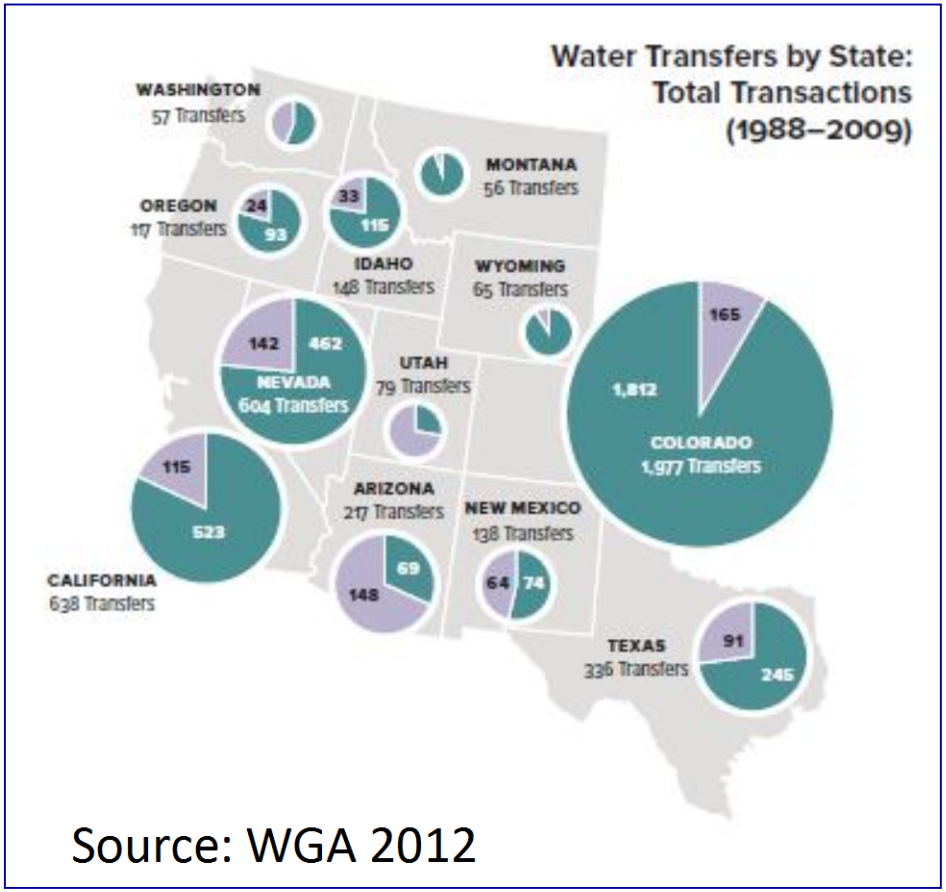




Q4

Socioeconomic Analysis

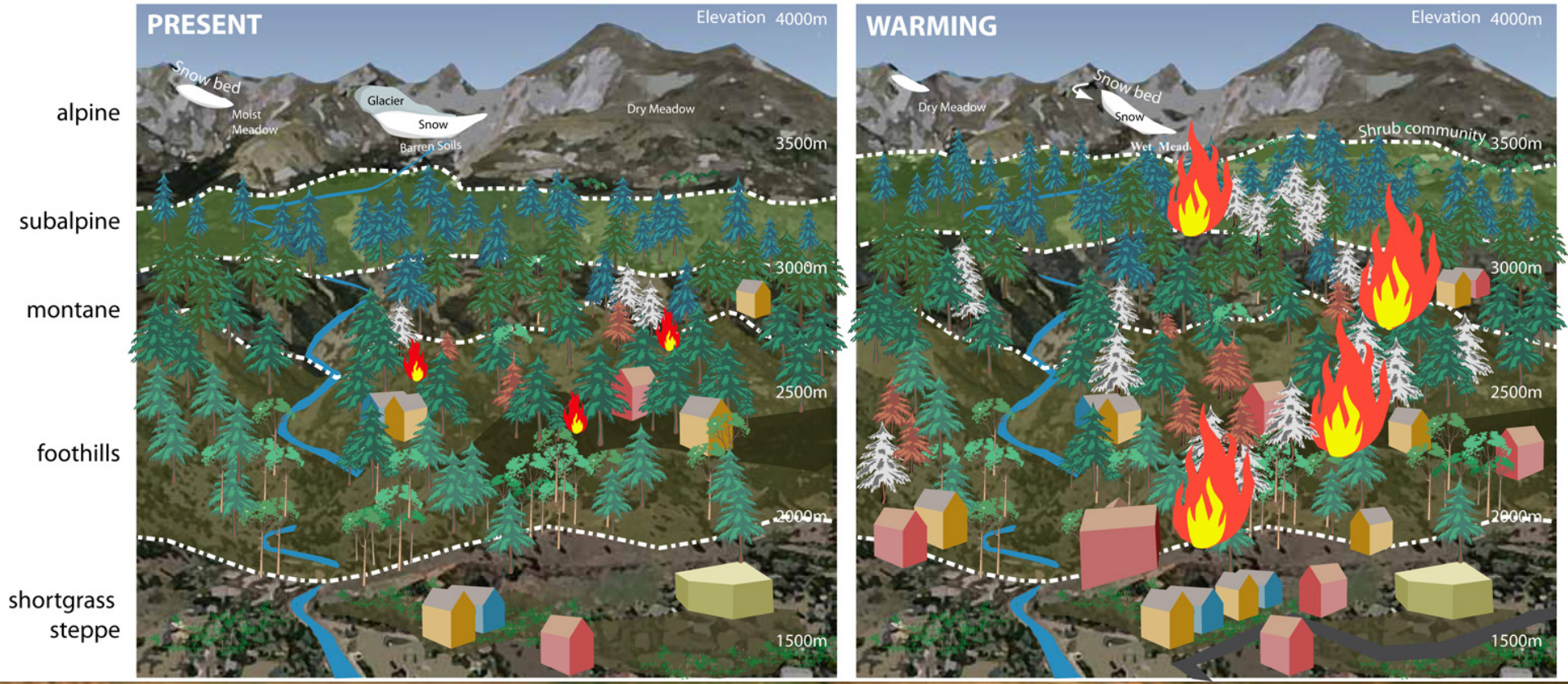
- Colorado has the most active water market in the nation.
- Transfers: tight water supplies result in third party impacts.
- Water markets: need augmentation (e.g. Basin Roundtable and Inter-basin Commission Process).
- The effectiveness of coordination depends on decision-making dynamics and information use.



Source: WGA 2012

Activity Lead: Miller, NCAR

Expected Changes In Connectivity Among Elevation Zones and Disturbance Regimes Related To Climate And Land Use Change

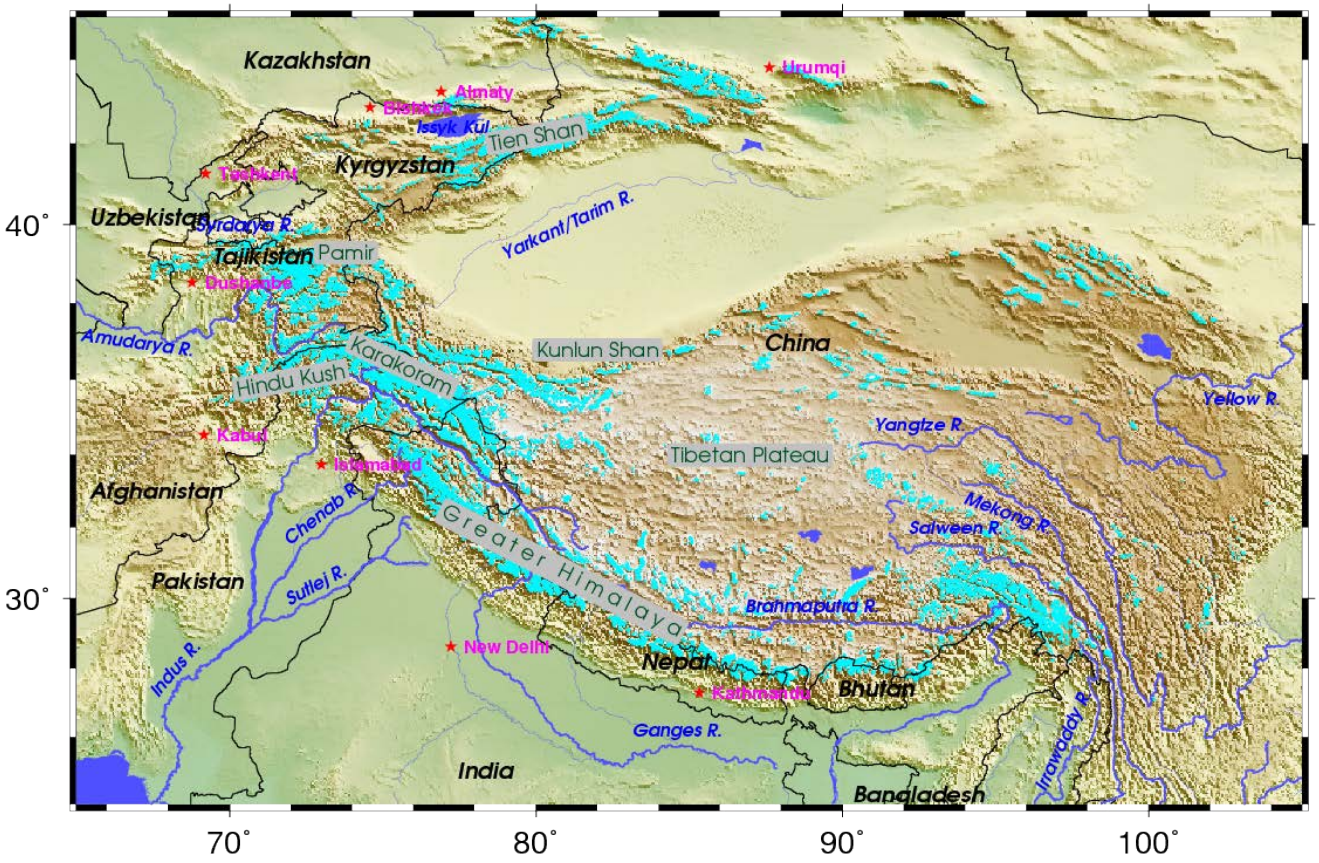


CHARIS - Contribution to High Asia Runoff of Ice and Snow

The CHARIS project began in 2011 with funding from USAID to the University of Colorado

PI:
Richard Armstrong, NSIDC

Co-I:
Mark Williams, INSTAAR



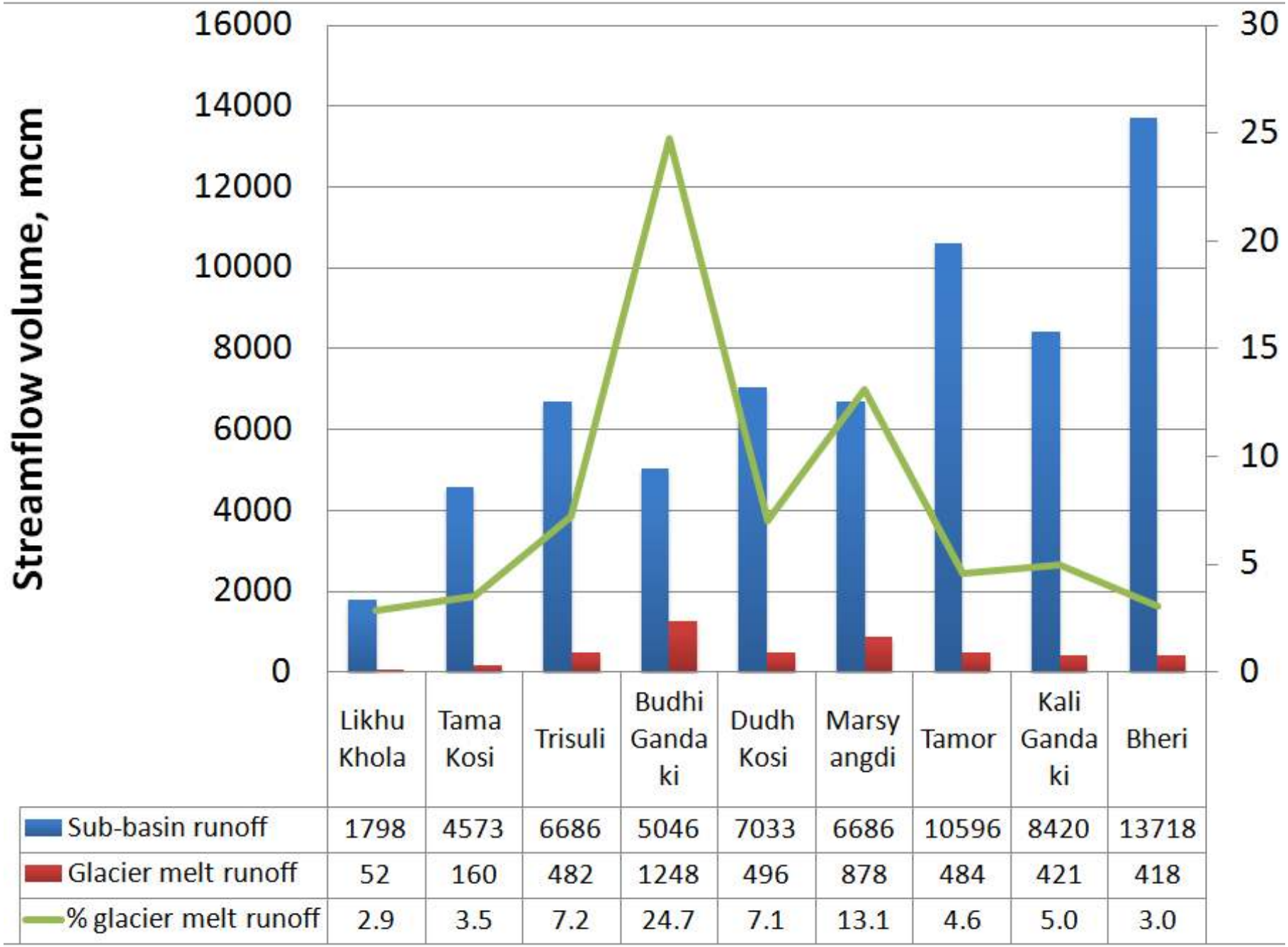
Map courtesy B. Raup. Glacier coverage from the RGI and GLIMS is in cyan light blue color (See http://www.glims.org/ for information on RGI and other glacier outline data)

Our study region includes the Amu Darya, Syr Darya, Indus, Ganges, and Brahmaputra river basins

http://nsidc.org/charis/


Pyramid field station, Khumbu Nepal, 5,000 m


Precip bucket KalaPatthar Everest in back



	Likhu Khola	Tama Kosi	Trisuli	Budhi Gandaki	Dudh Kosi	Marsyangdi	Tamor	Kali Gandaki	Bheri
Sub-basin runoff	1798	4573	6686	5046	7033	6686	10596	8420	13718
Glacier melt runoff	52	160	482	1248	496	878	484	421	418
% glacier melt runoff	2.9	3.5	7.2	24.7	7.1	13.1	4.6	5.0	3.0

Summary

- Improve future predictions of water availability through integrated climate / snowpack / land cover / water management models.

- Identify winners and losers under future water availability scenarios.

- Identify socioeconomic pressures associated with reduced water availability & identify options for mitigation.