Mountain Watersheds: Outdoor Hydro-Climatic Laboratories for Detecting and Understanding Climate Warming

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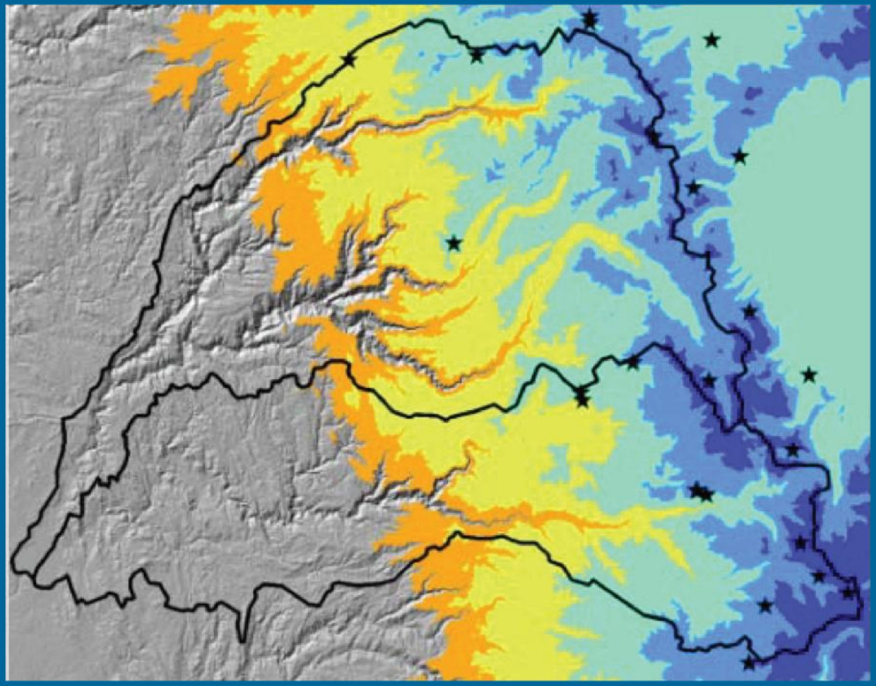
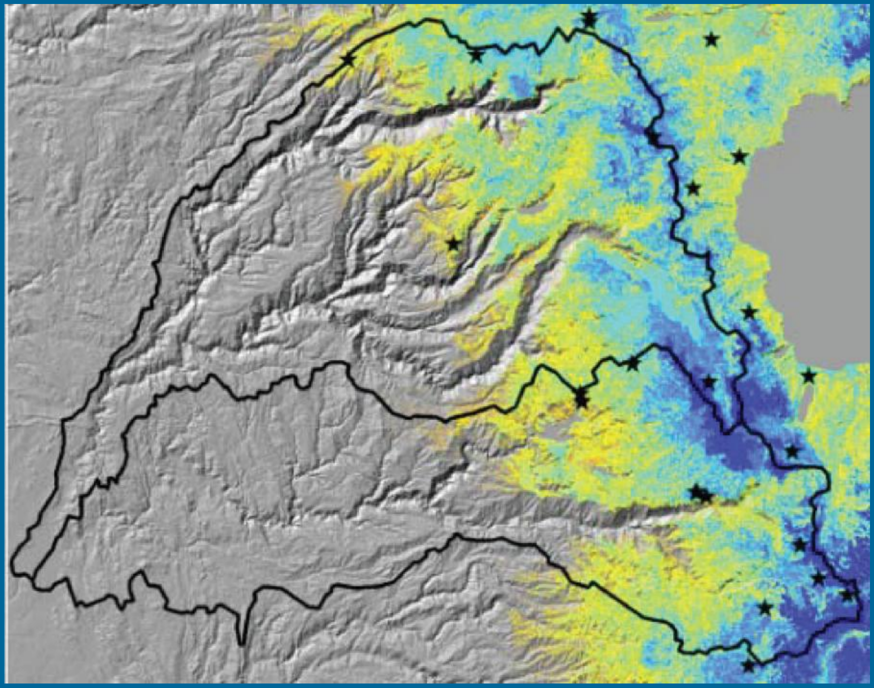
American River Basin (5400 km^2), Sierra Nevada
April 1, 2009 Estimated SWE Volume

Assumed Stationary Climate:



Historical Data Relationship:
Interpolated from SNOTEL data

Actual Warming Climate:



Satellite Estimate:
SWE Reconstruction, MODIS data

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Observatories – a decade of improvement:

* What should we measure?

* How should we measure it?

* Where should we measure it?

It all depends on:

What the observatory objectives are

Where the site is located…

GRADIENTS are Critical!

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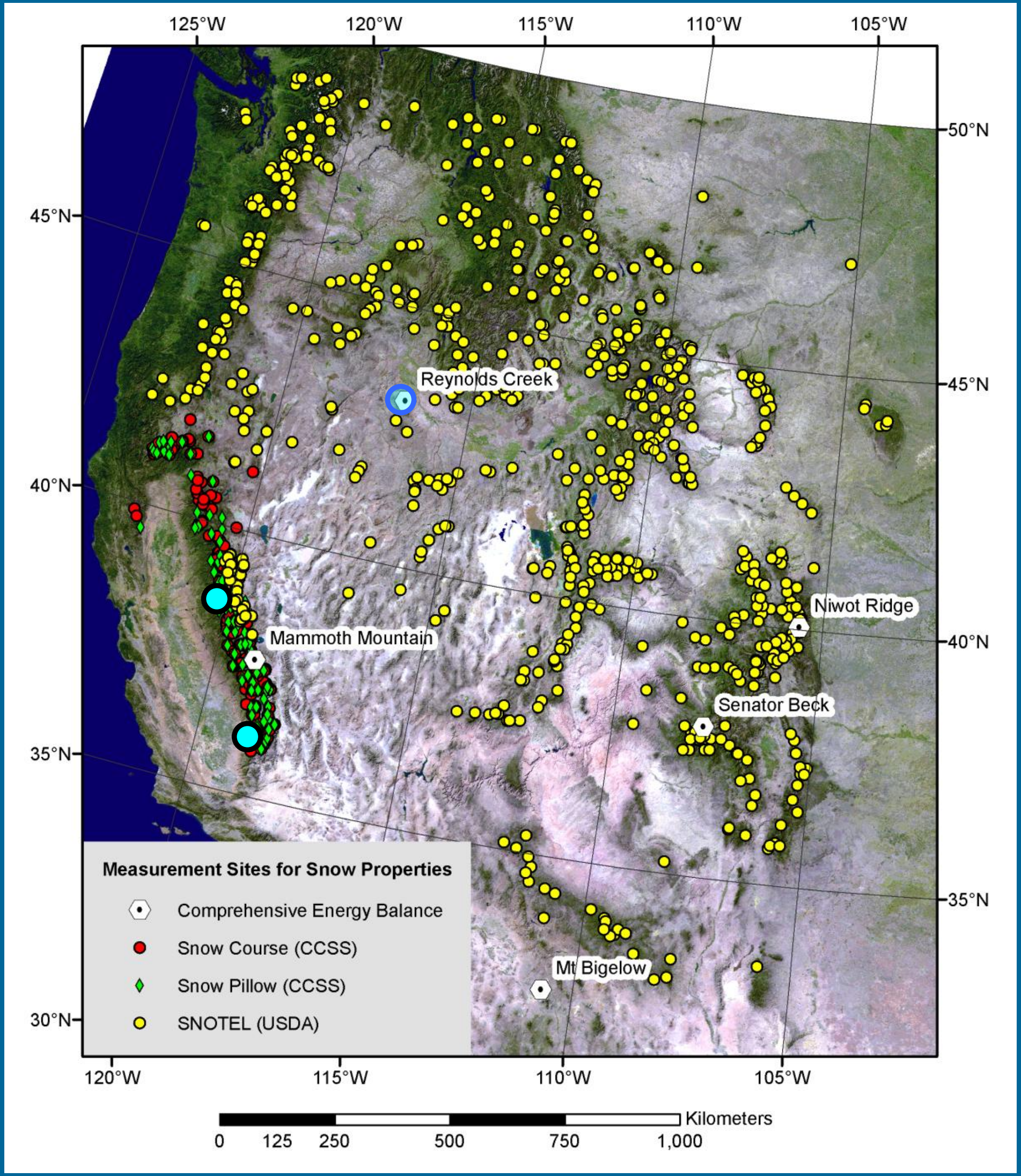
Snowcover Measurement Sites



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North American Cordilleran Transect

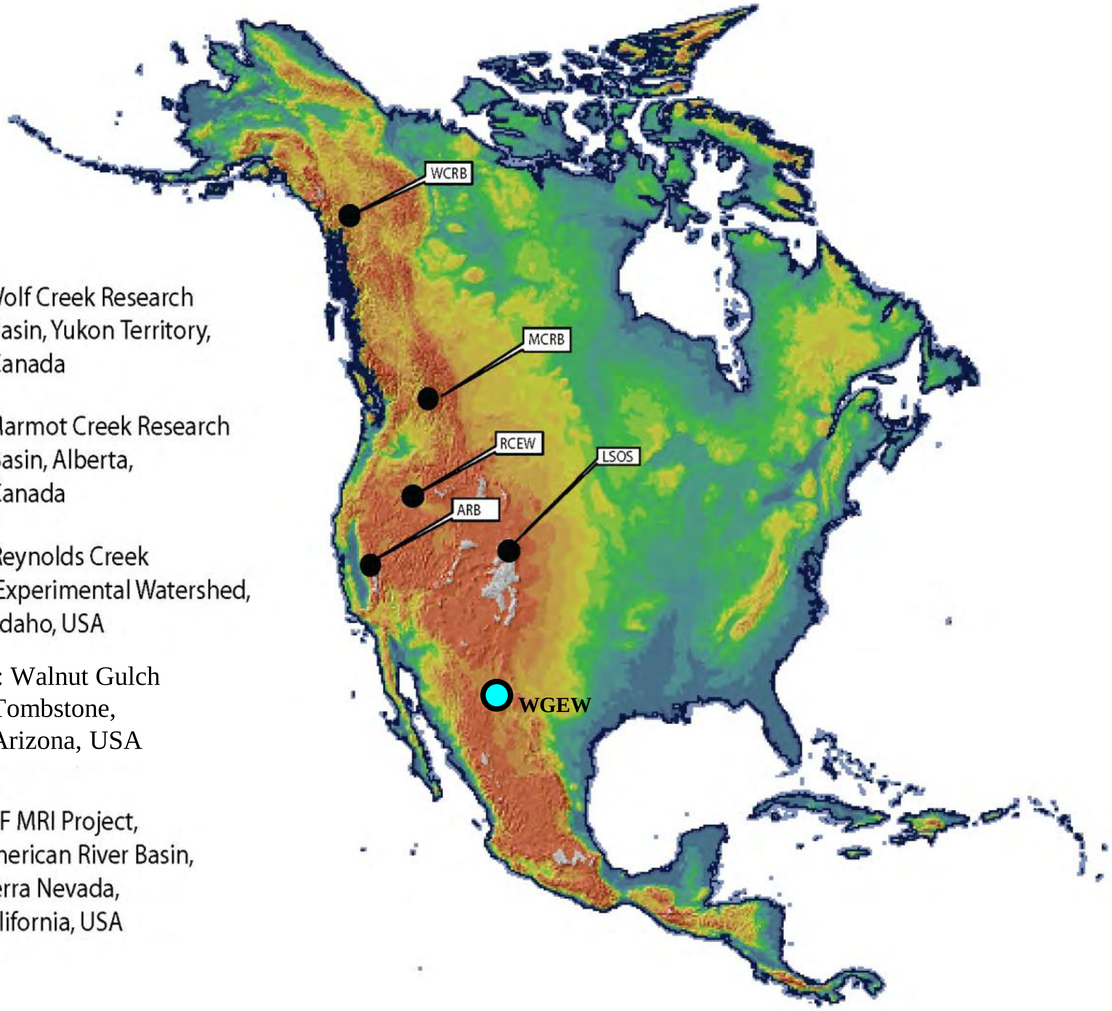
WCRB: Wolf Creek Research Basin, Yukon Territory, Canada

MCRB: Marmot Creek Research Basin, Alberta, Canada

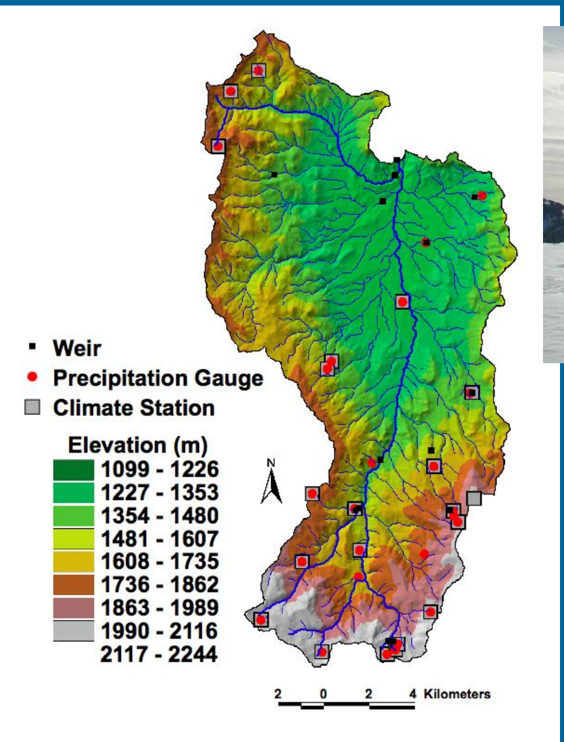
RCEW: Reynolds Creek Experimental Watershed, Idaho, USA

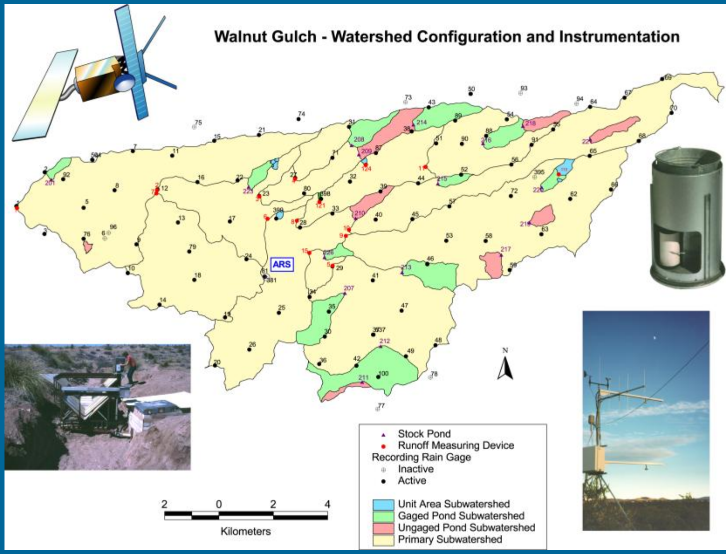
WGEW: Walnut Gulch Tombstone, Arizona, USA

ARB: NSF MRI Project, American River Basin, Sierra Nevada, California, USA



Utilizing Long-Term ARS Data to Compare and Contrast Hydro-climatic Trends from Snow and Rainfall Dominated Watersheds





D.C. Goodrich, et al.

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Very Different Hydro-Climatic Environments!

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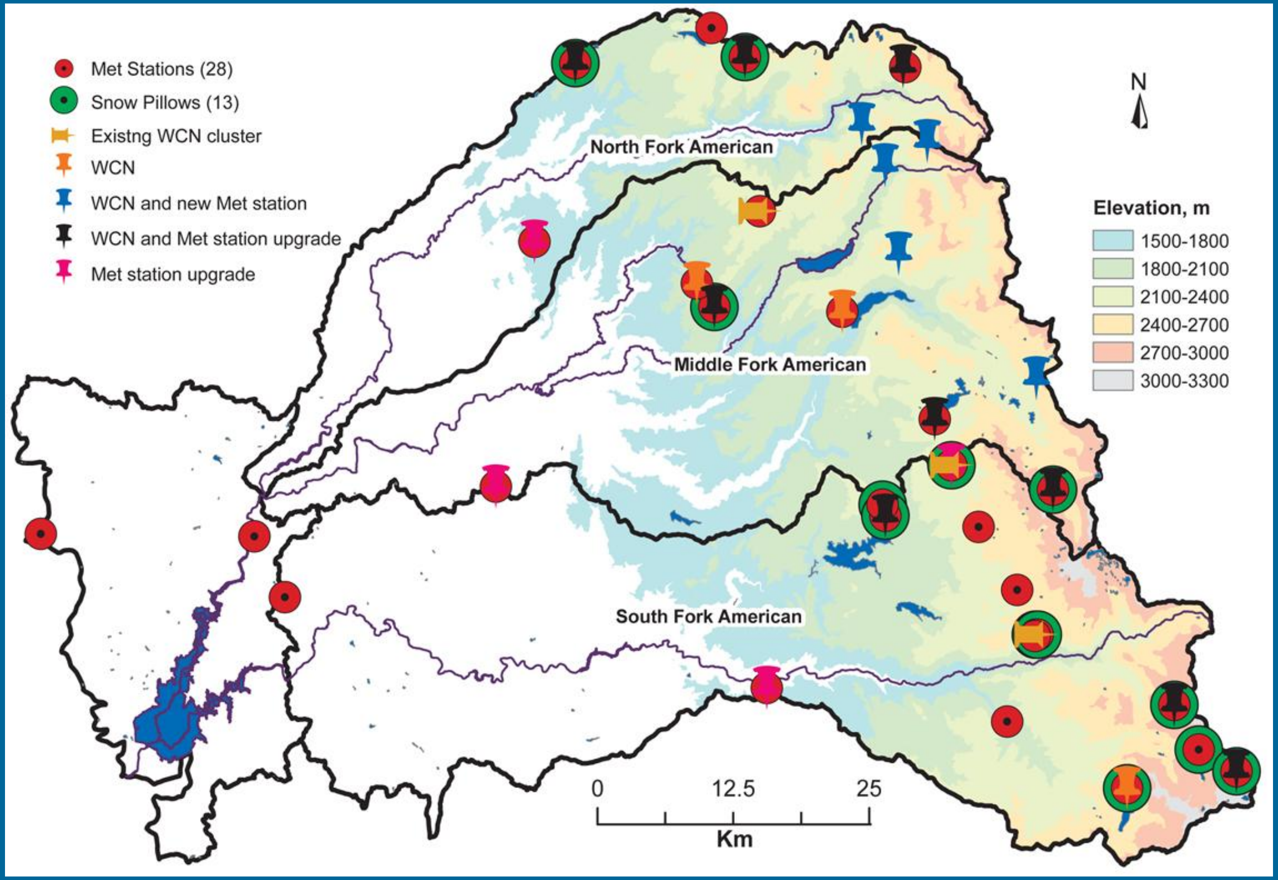
Basin-wide deployment of hydrologic instrument clusters – American R. basin



Strategically place low-cost sensors to get spatial estimates of snowcover, soil moisture & other water-balance components,

Including:

<u>Temperature,</u>
<u>Humidity,</u>
<u>Wind &</u>
<u>Precipitation</u>

Network & integrate these sensors into a single spatial instrument for water-balance measurements.

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What is Changing:

Temperature – increasing:

+2 to +2.5C over the past 50 years!

Precipitation – unclear:

- **Annual Volume Unchanged?**
- **Phase has changed**

Discharge – unclear:

- **Annual Volume Unchanged?**
- **Earlier Spring Flows**
- **Reduced Summer Flows**

Humidity – increasing during storms

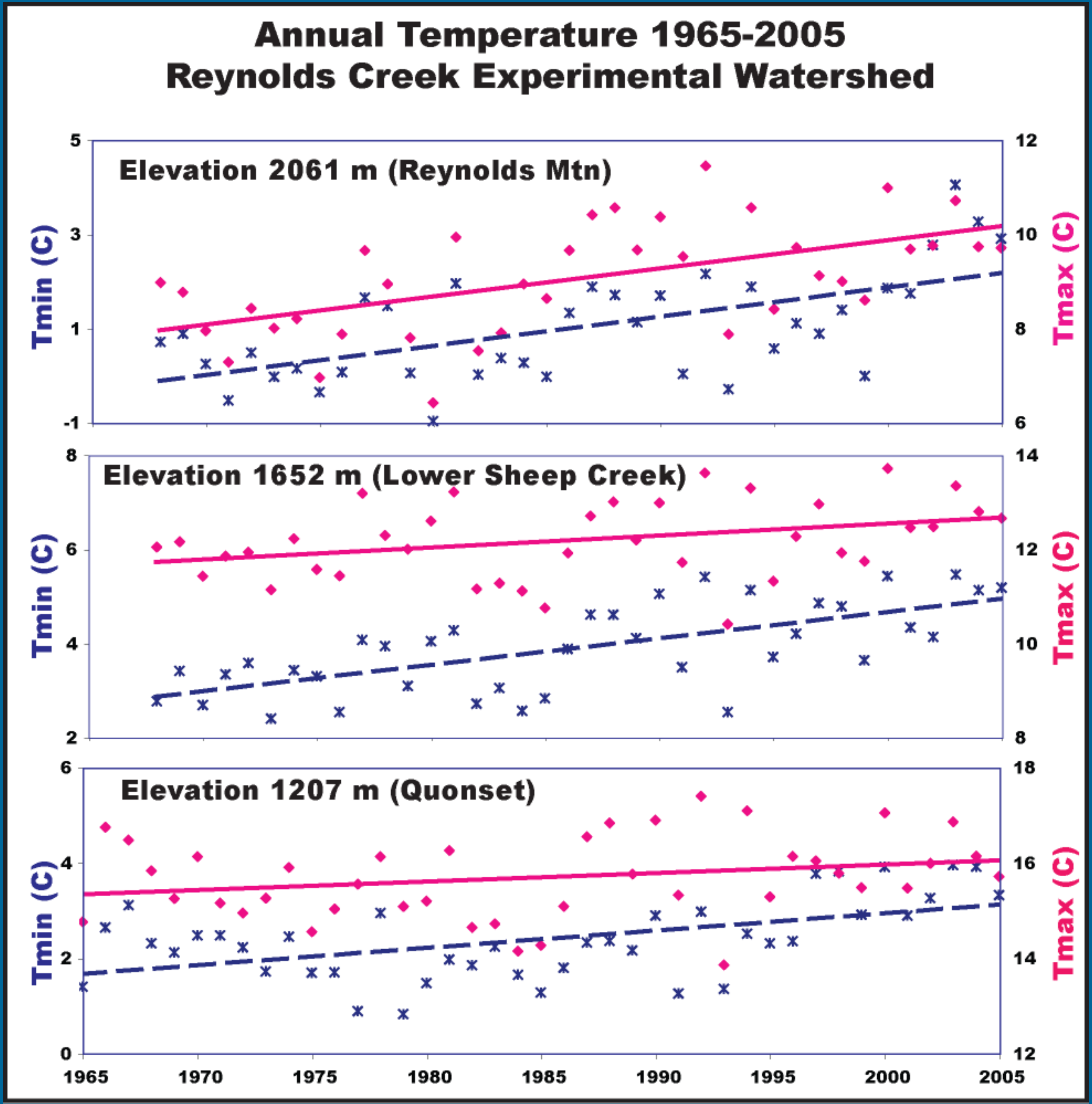
Soil Moisture – changing:

- **increase in winter**
- **decrease in summer**

+ 2.5:
-0.6 to +1.9

+ 2.7:
+2.5 to +5.2

+ 1.4:
+1.7 to +3.1



+ 2.4:
+7.9 to +10.3

+ 0.9:
+11.8 to +12.7

+ 0.9:
15.4 to 16.3

95%

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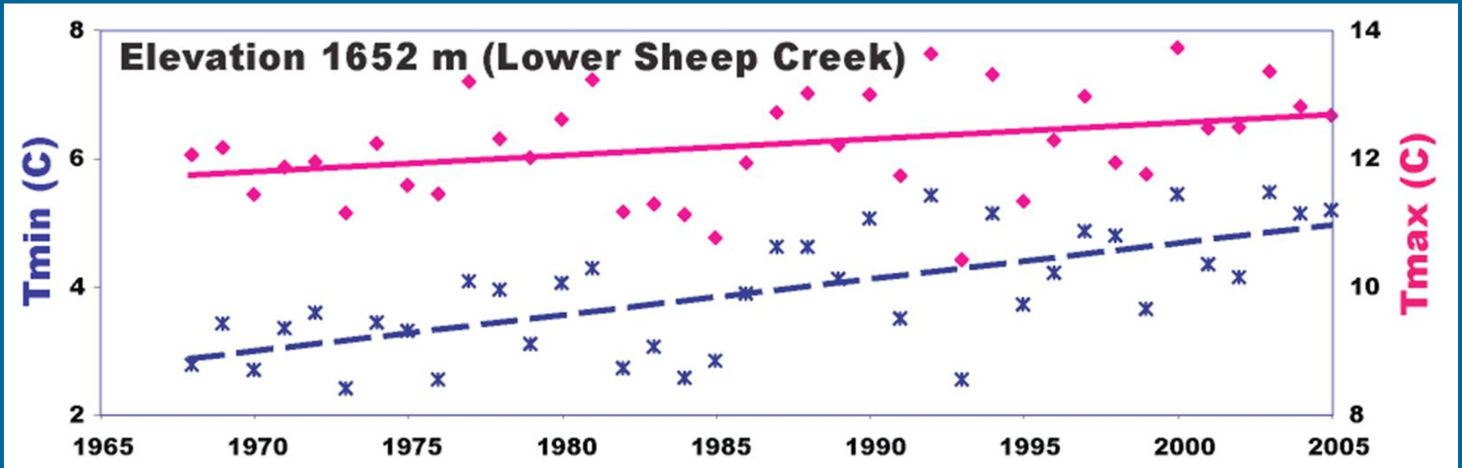
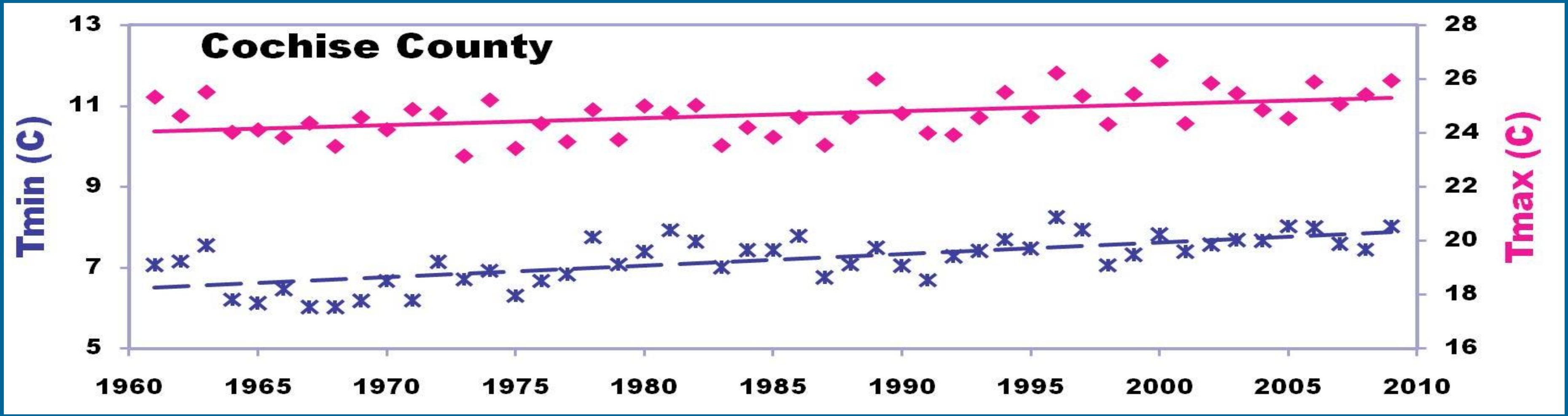
Temperature Trends at RCEW & WGEW in the US





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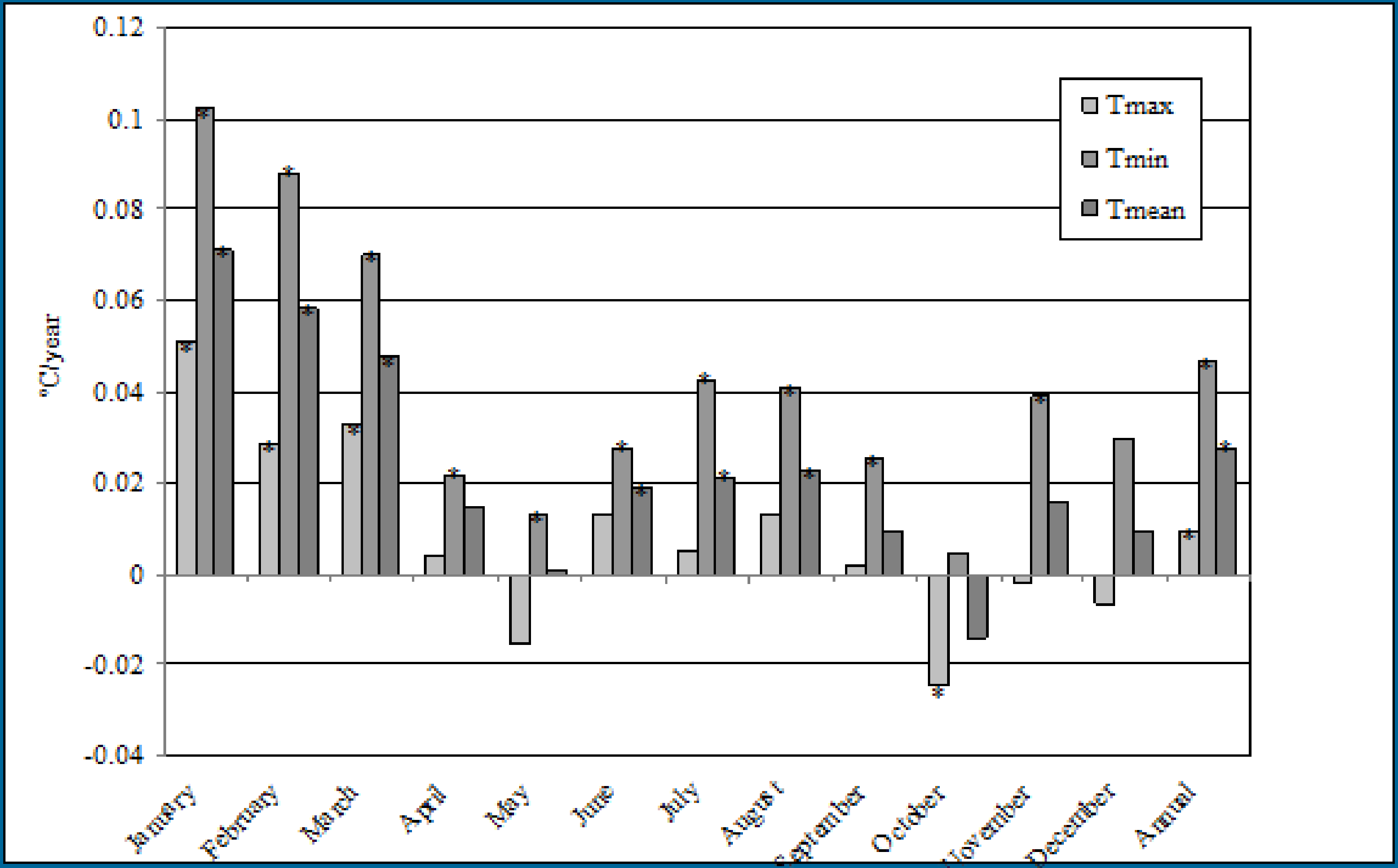
Temperature Trends at Marmot Creek in Alberta



Temperature Trends Along the North American Cordilleran Transect

		T_{min}		T_{max}	
Station	Elev. (m)	Slope (°C/dec)	Trend sig.[a]	Slope (°C/dec)	Trend sig.[a]
RC-High	2,093	0.45	**	0.35	**
RC-Mid	1,652	0.57	**	0.29	**
RC-Low	1,200	0.36	**	0.20	*
WG-CC	--	0.29	***	0.26	**
MC-UC	1777	0.42	**	0.10	*

[a] MK-TFPW test significance level:

** for α = 0.05, ** for α = 0.01, and *** for α = 0.001*

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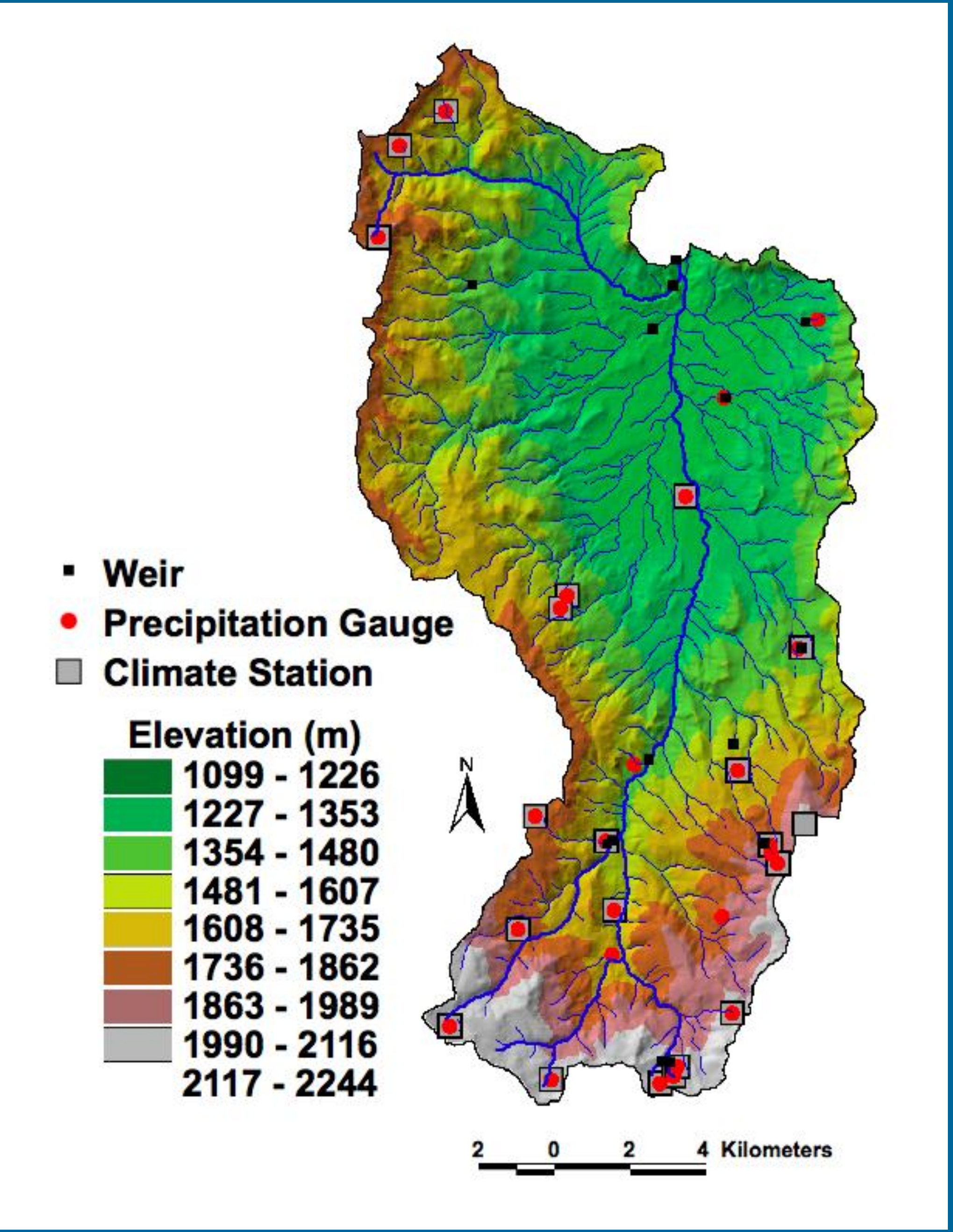
RCEW (239 km²):

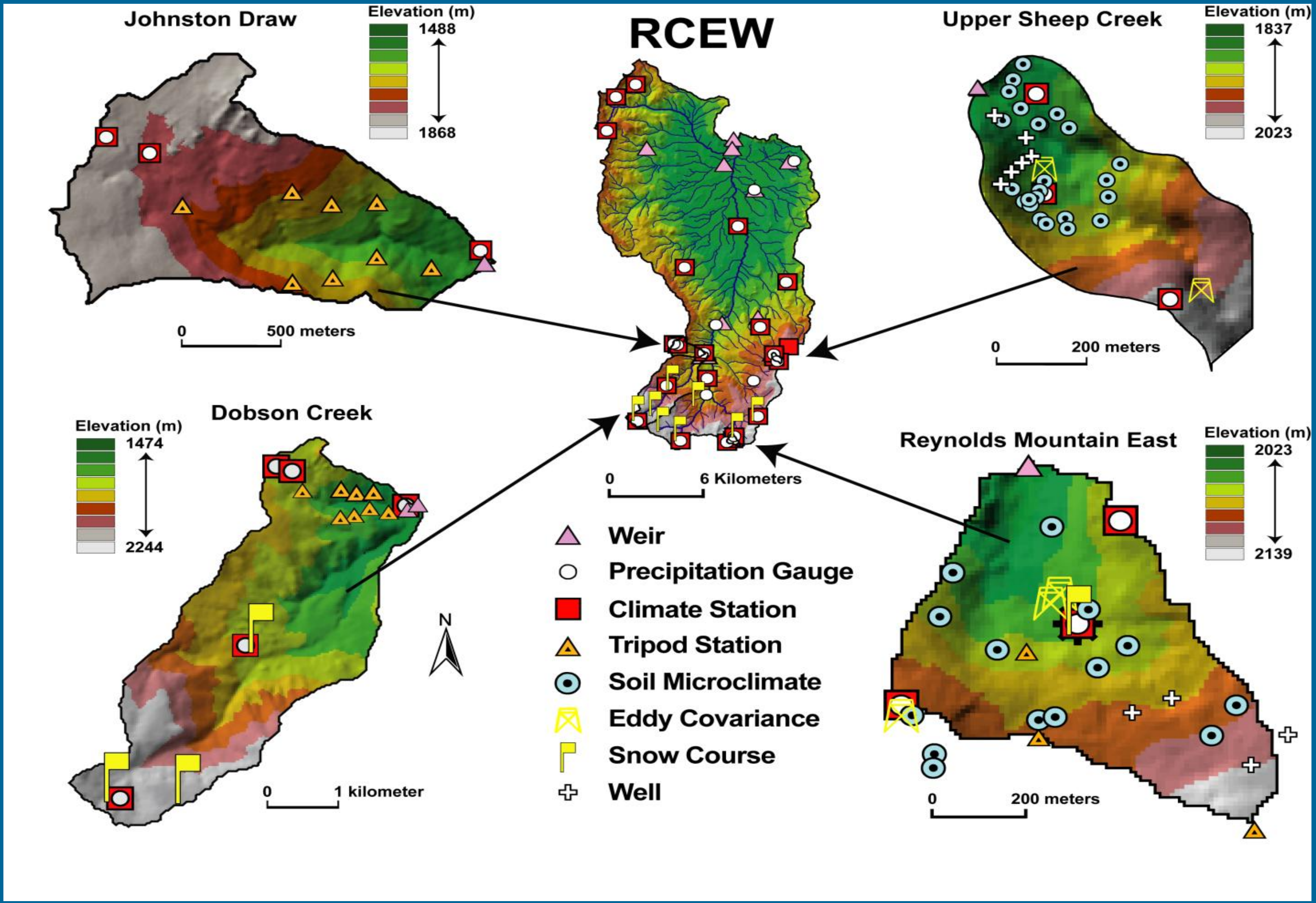
- 32 climate stations
- 36 precipitation stations
- 5 EC systems
- 14 weirs (nested)
- 6 soil microclimate stations
- 4 hill-slope hydrology sites
- 4 instrumented catchments
- 3 instrumented headwater basins:

<u>USC</u> (0.25 km², 186m relief) ephemeral, groundwater dominated, annual precipitation 300-500mm

<u>RME</u> (0.38 km², 116m relief) perennial, surface water dominated, annual precipitation 750-1000mm

<u>Johnston Draw</u> (1.8 km², 380m relief) ephemeral, rain-snow boundary, annual precipitation 500-600mm

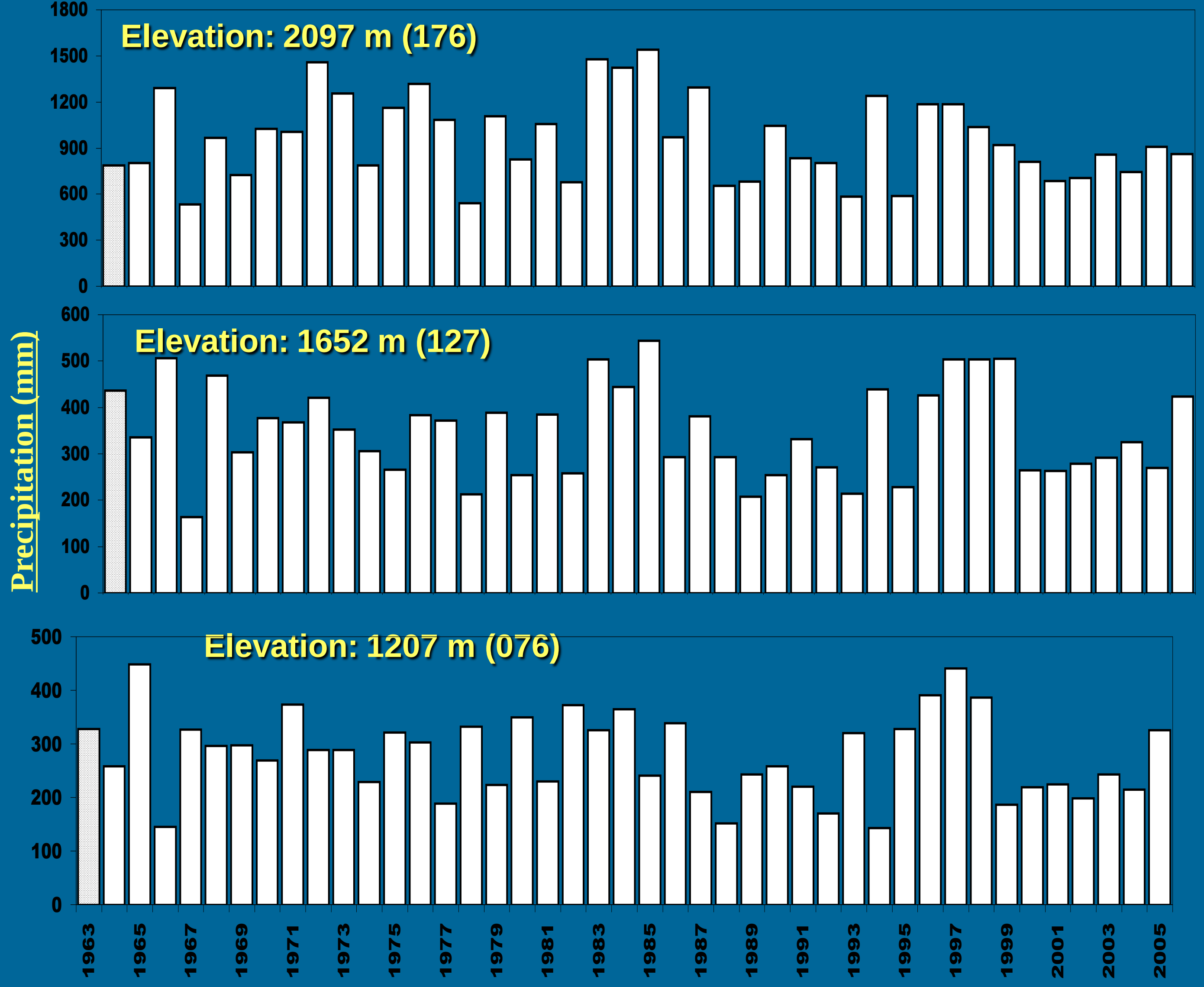




RCEW
Johnston Draw
Elevation (m)
1488
1868
500 meters
Upper Sheep Creek
Elevation (m)
1837
2023
200 meters
6 Kilometers
Dobson Creek
Elevation (m)
1474
2244
1 kilometer
N
Reynolds Mountain East
Elevation (m)
2023
2139
200 meters
Weir
Precipitation Gauge
Climate Station
Tripod Station
Soil Microclimate
Eddy Covariance
Snow Course
Well

Annual Precipitation

No Significant Trend



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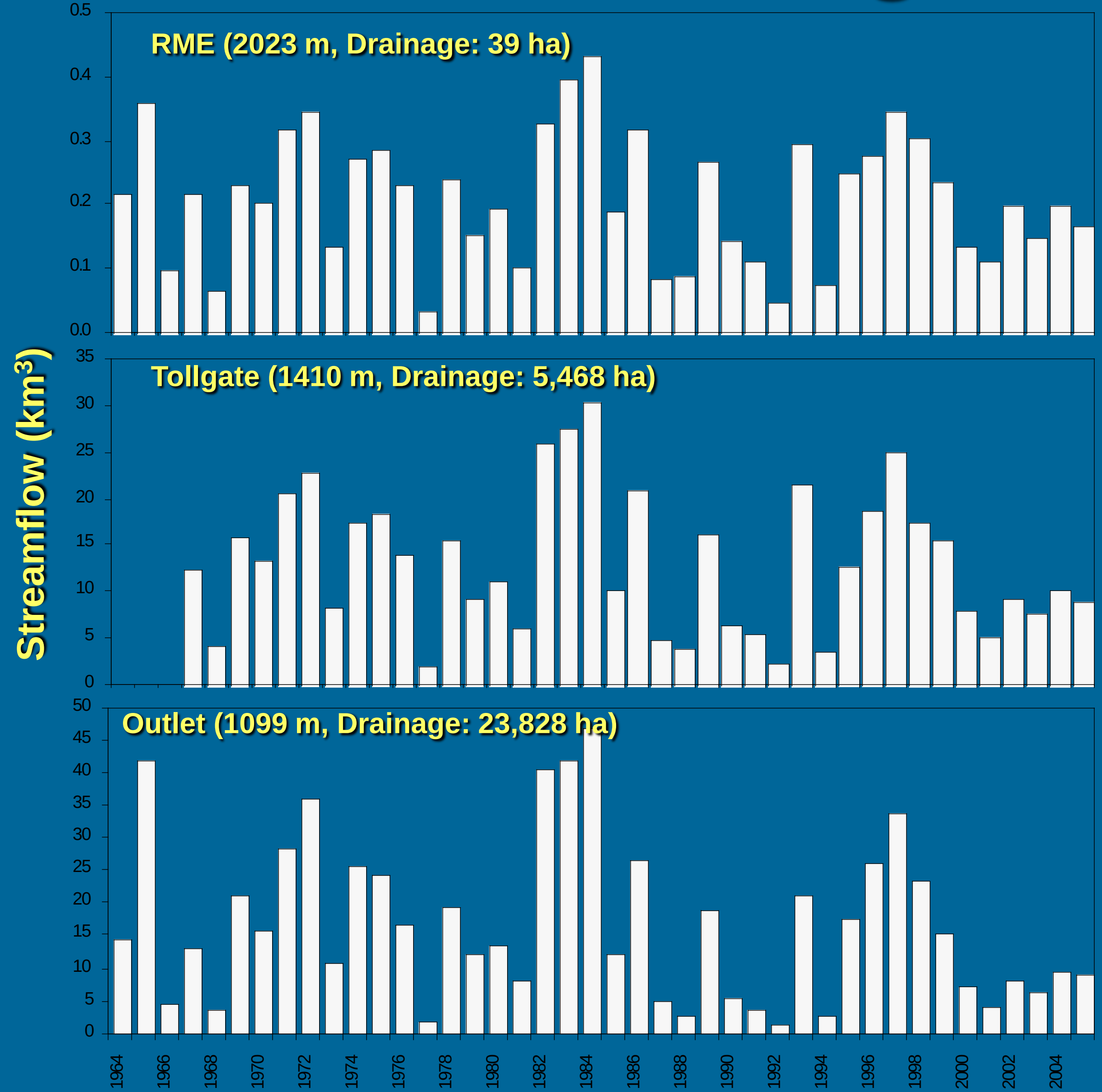
Annual Stream Discharge

No Significant Trend



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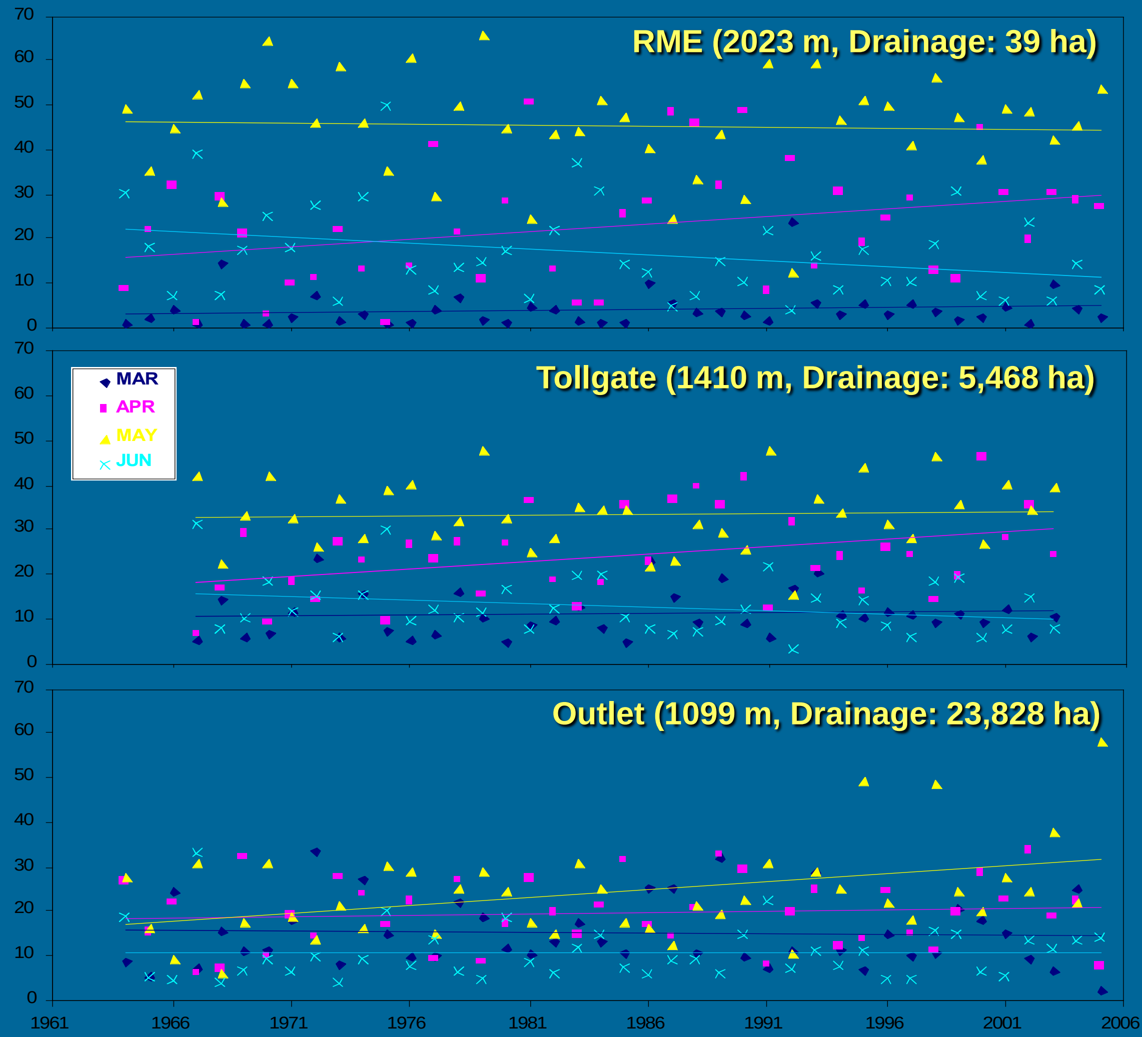
% Annual Stream Discharge, by Month

March, April, May & June (78-95% of Annual Flow)

Headwater Catchment:
March +3%
April +14%
May -------
June -13% (95%)

Mid-Elevation Drainage:
March +1%
April +12% (95%)
May +1%
June -8%

Basin Outlet:
March -------
April +4%
May +12% (95%)
June -2%



Summer Flow: Reduced from 23% to 10%

56% Reduction

Summer Flow: Reduced from 16% to 8%

51% Reduction

Summer Flow: Reduced from 11 % to 9%

19% Reduction

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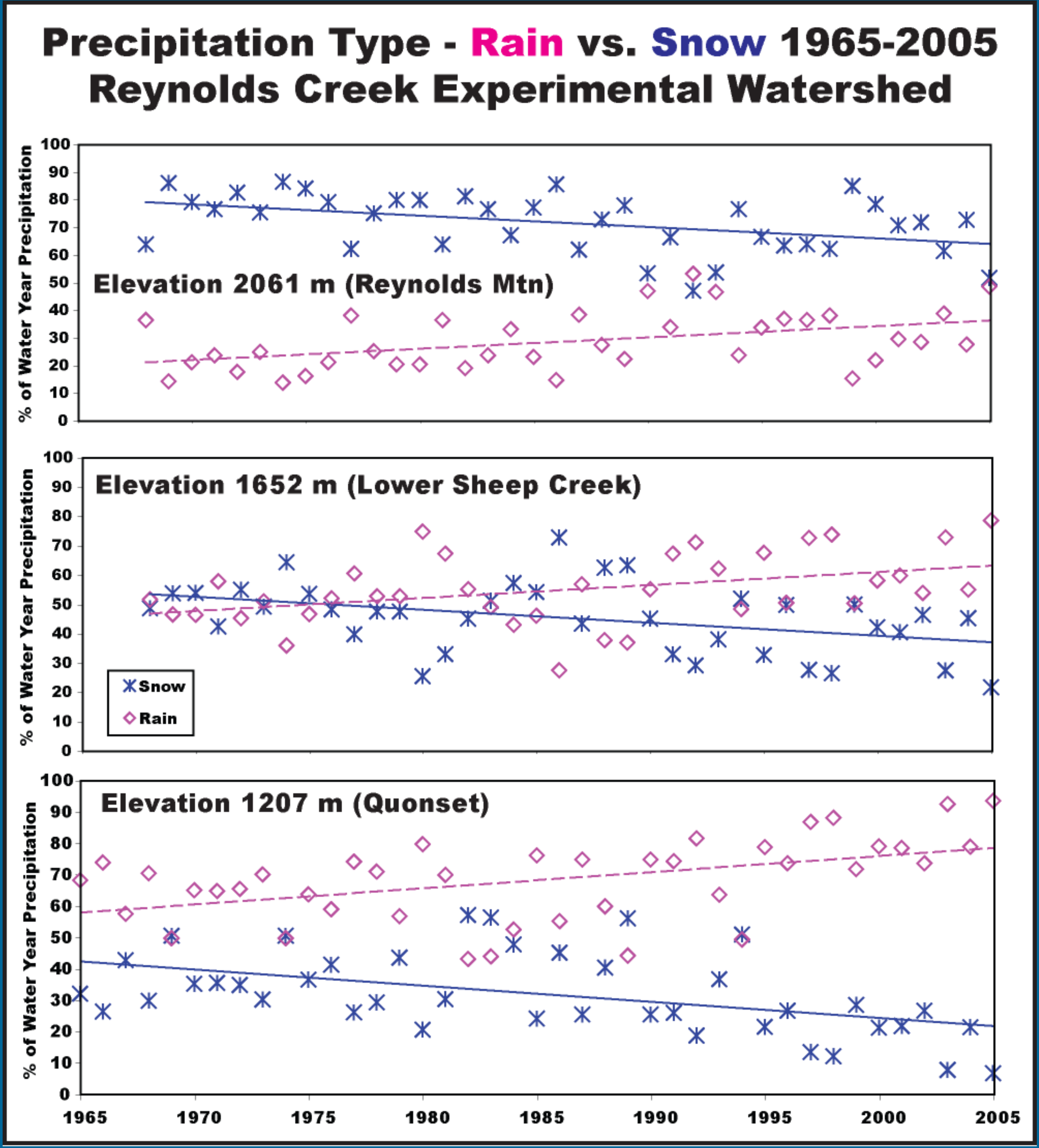
Snow: -16%:
80% to 62%

Snow: -17%:
55% to 38%

Snow: -22%:
41% to 19%



Still Snow Dominated

Now Rain Dominated

Almost Never Snows

95%

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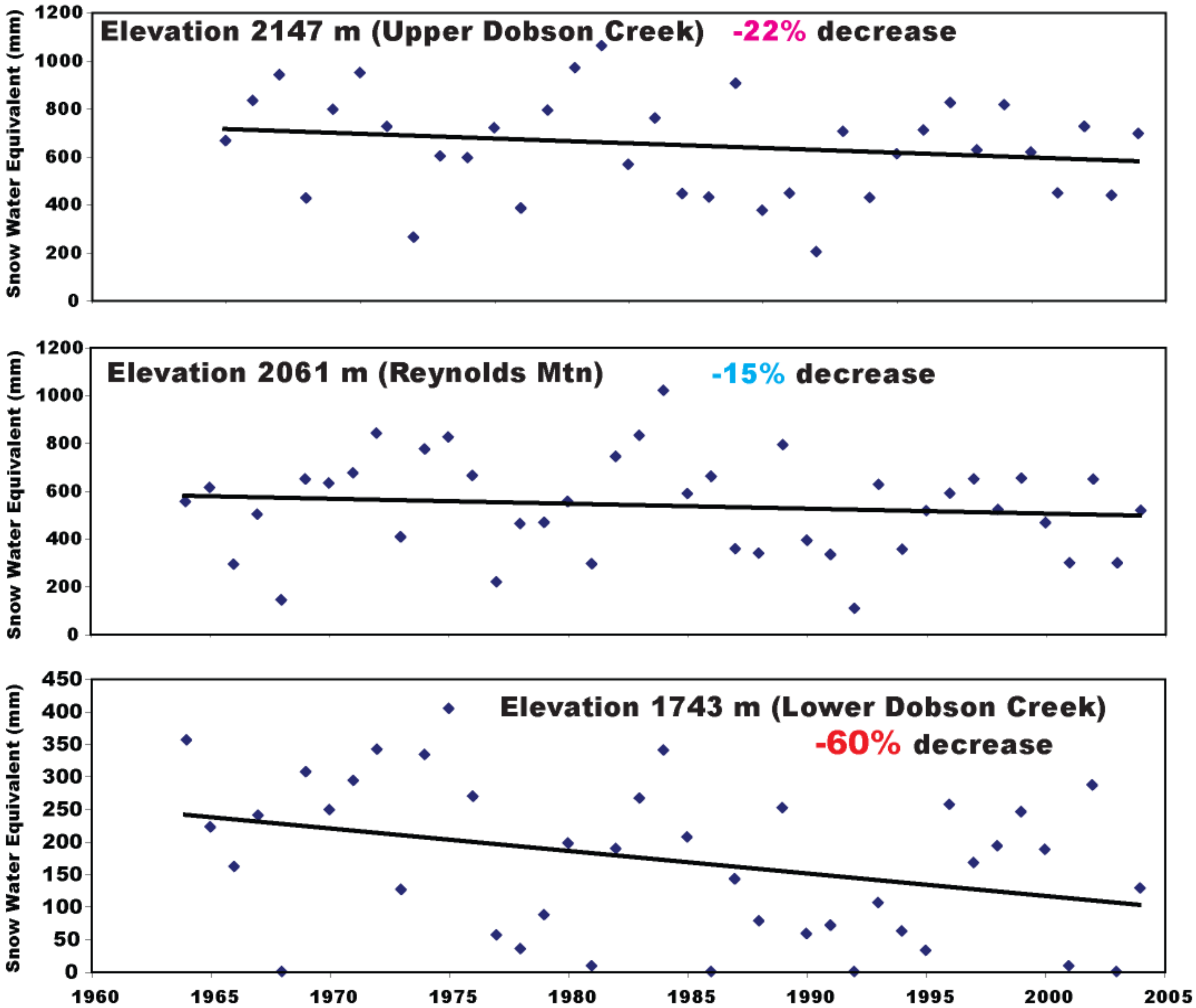
April 1 Snow Water Equivalent - 1960-2005
Reynolds Creek Experimental Watershed



90%

90%

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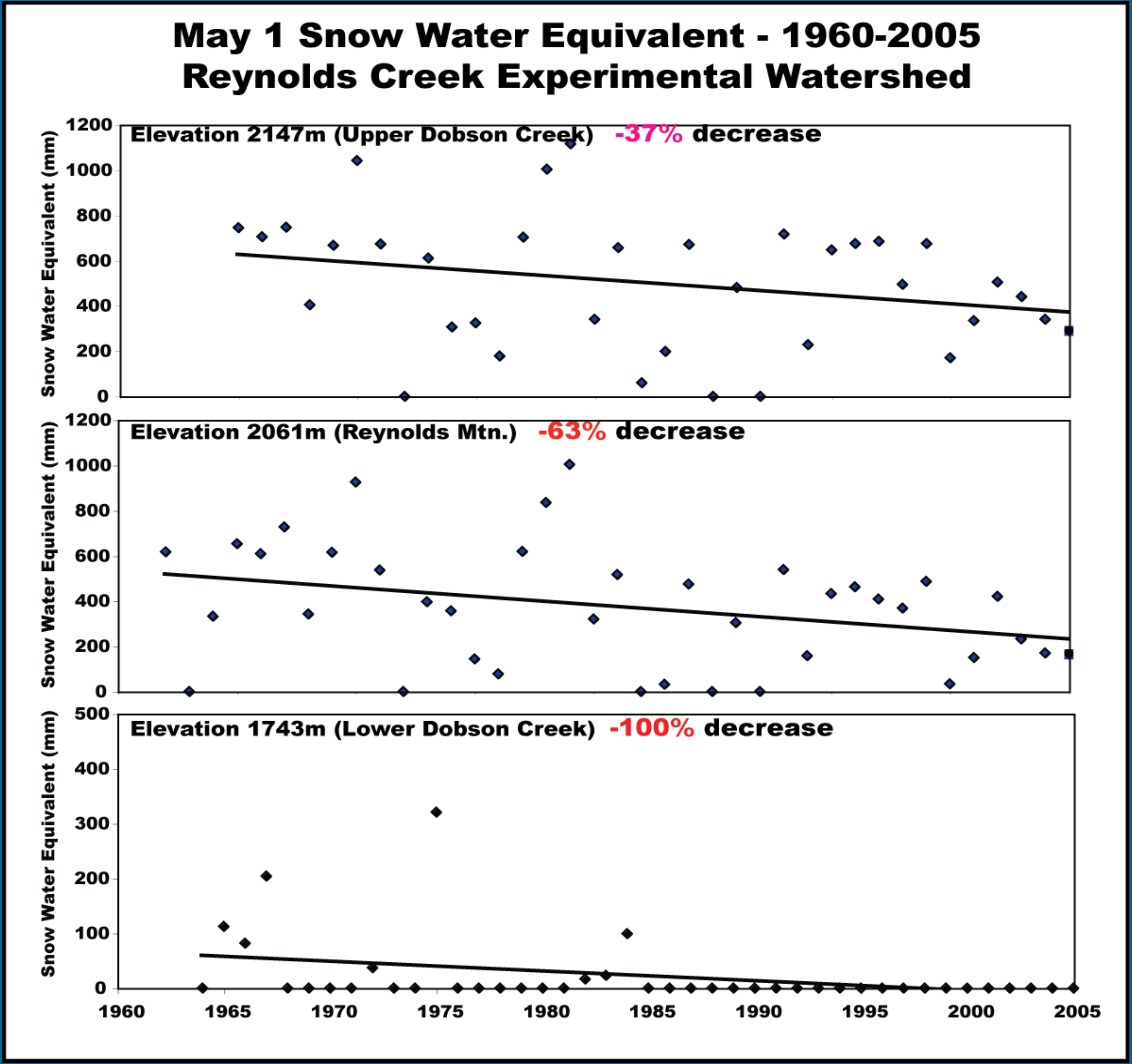

90%

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Conclusions:

Annual precipitation & discharge are unchanged
- However, early spring flows are increased
- Summer flows are significantly reduced

- Climate is warming
  - All temperatures have increased
  - Minimum temperatures increased the most

- More precipitation falls as rain
  - Smaller change at high elevation
  - Large change at low elevation

- Strong elevation effect
  - Effects availability of water in summer
  - More area at lower elevation
  - Increase in winter ROS events

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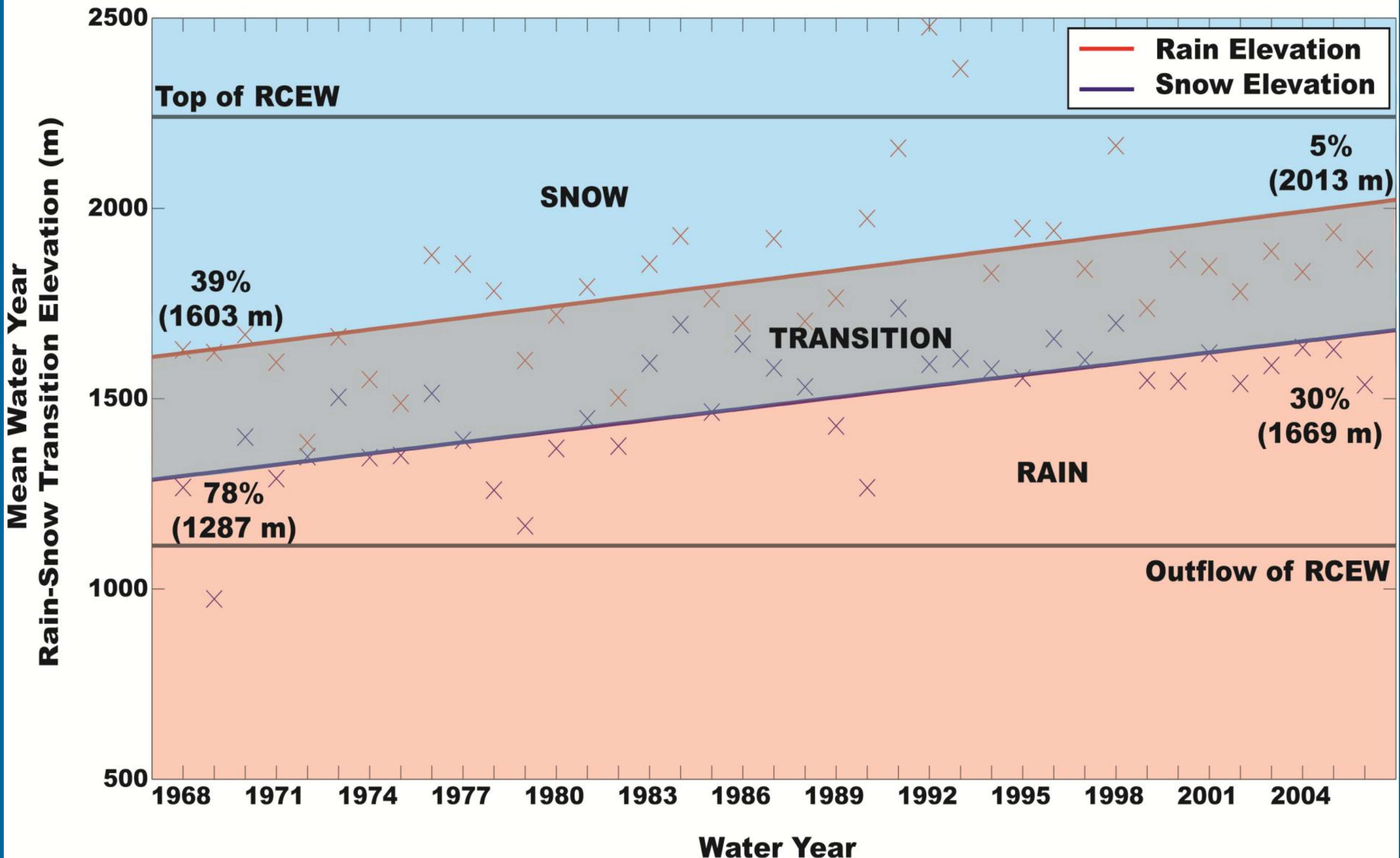
Changes in the Rain/Snow Transition Elevation
1968-2006 Water Years



RCEW 1968-2006
Mass – Weighted Rain/Snow Elevation:

- RSE computed for Individual Storms

Rain Level: T_d = +1C; +108 m decade^{-1}
Snow Level: T_d = 0C; +100 m decade^{-1}

Both significant at 95% level

R/S Transition Zone is between these

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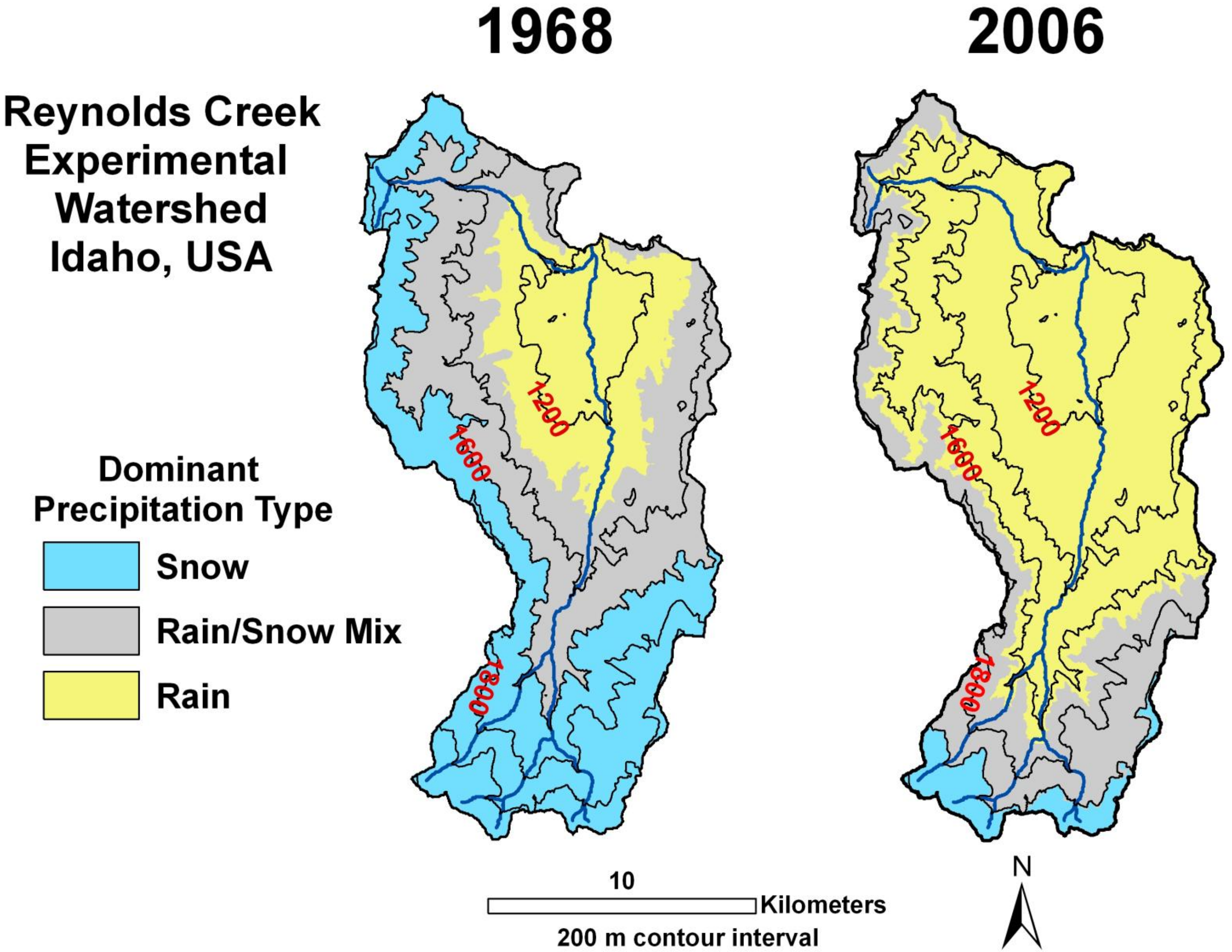

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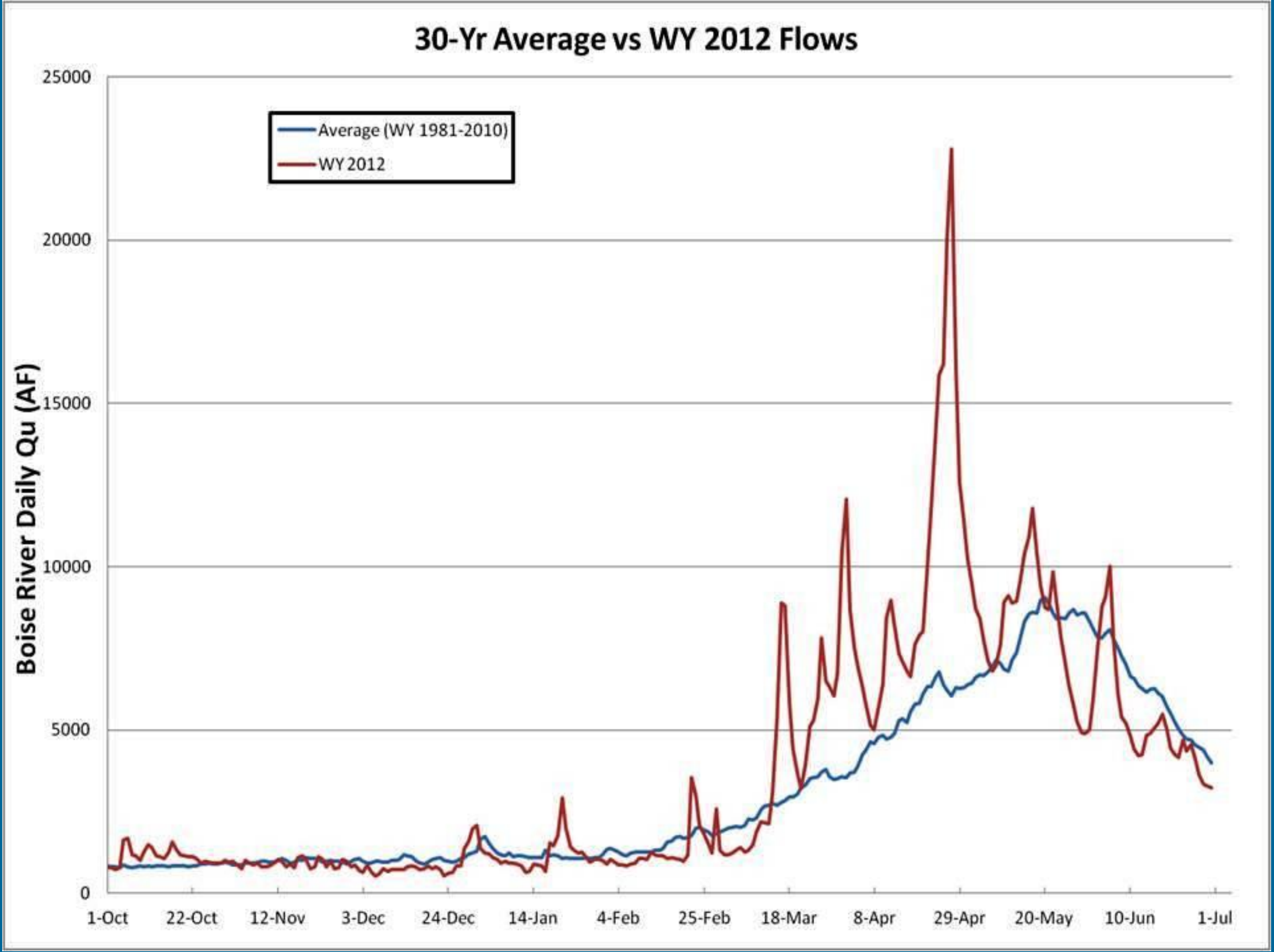

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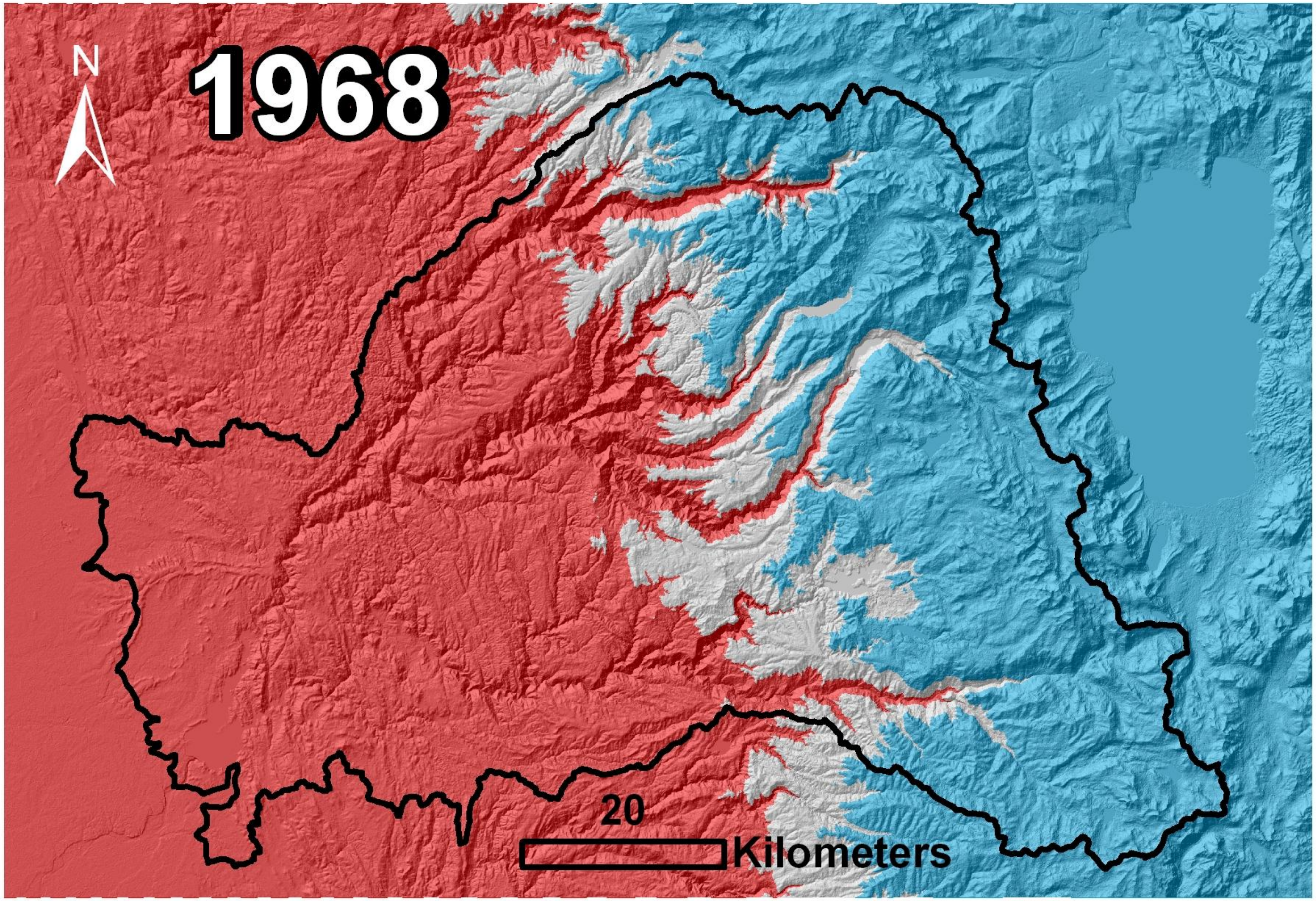
Dominant Precipitation Phase

Rain Mix Snow



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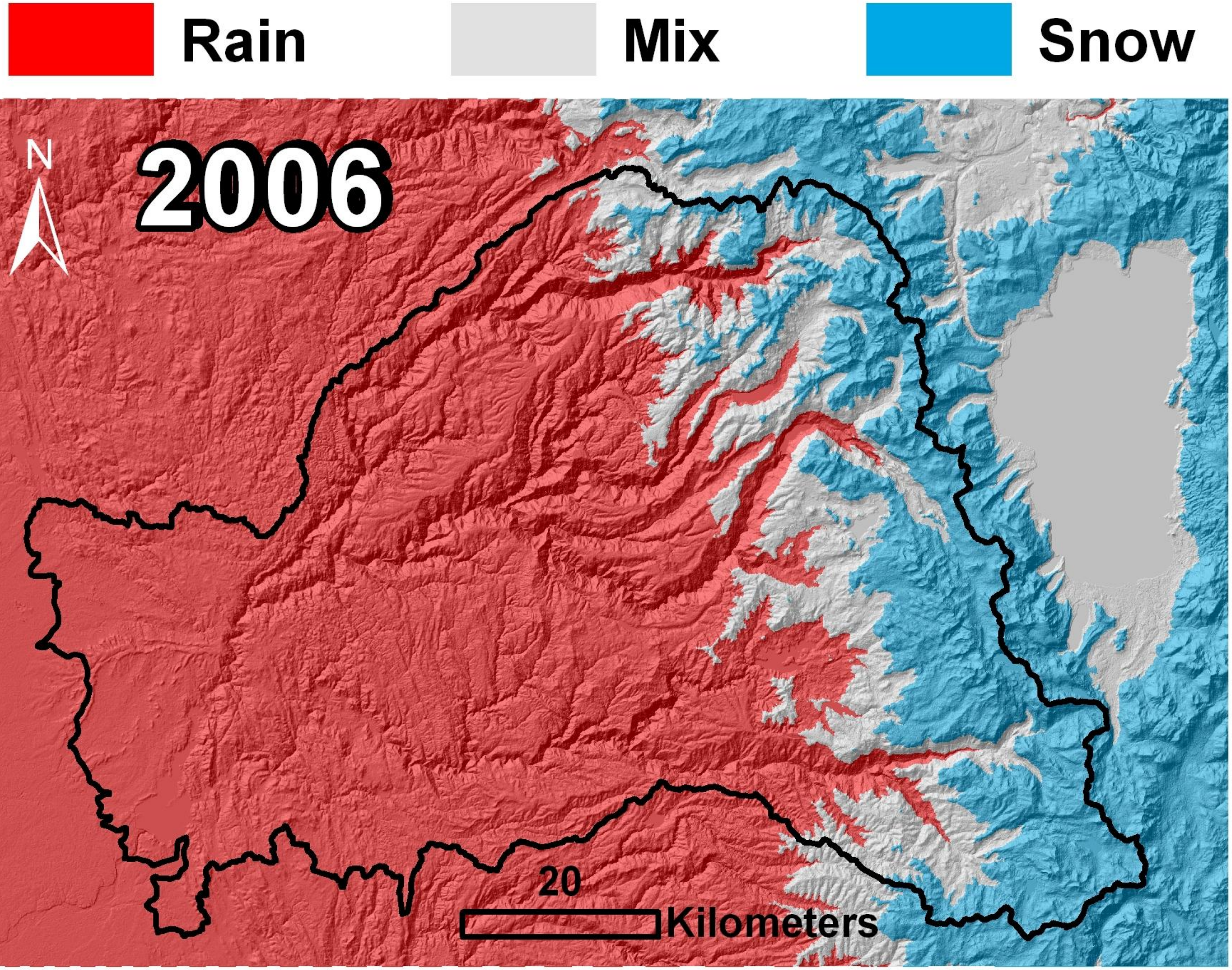
Dominant Precipitation Phase



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