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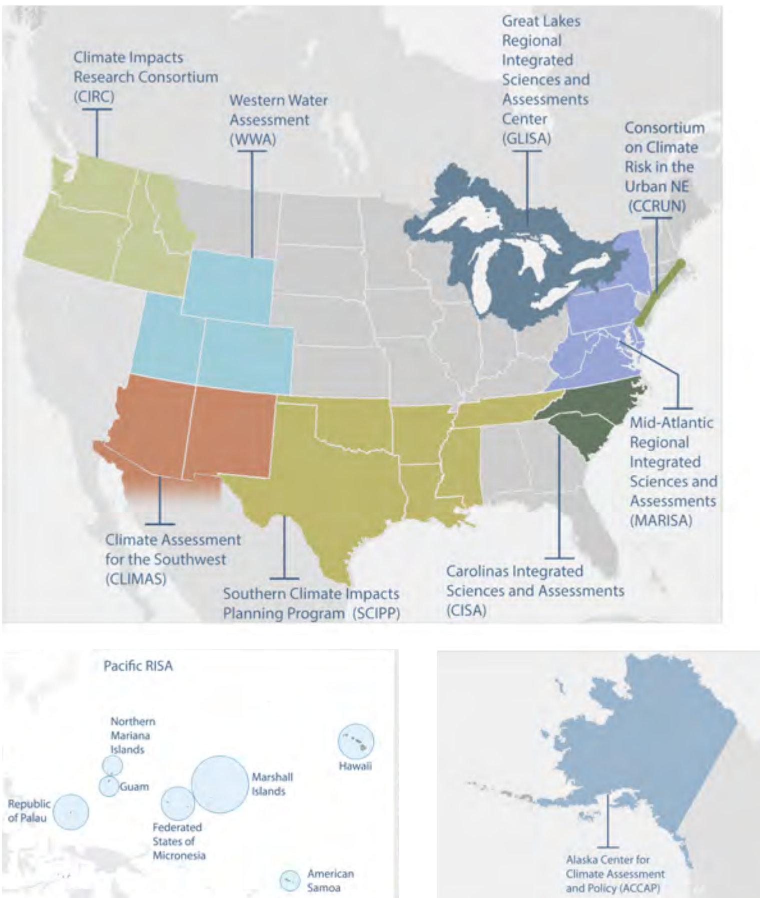
2016 Stakeholder Meeting

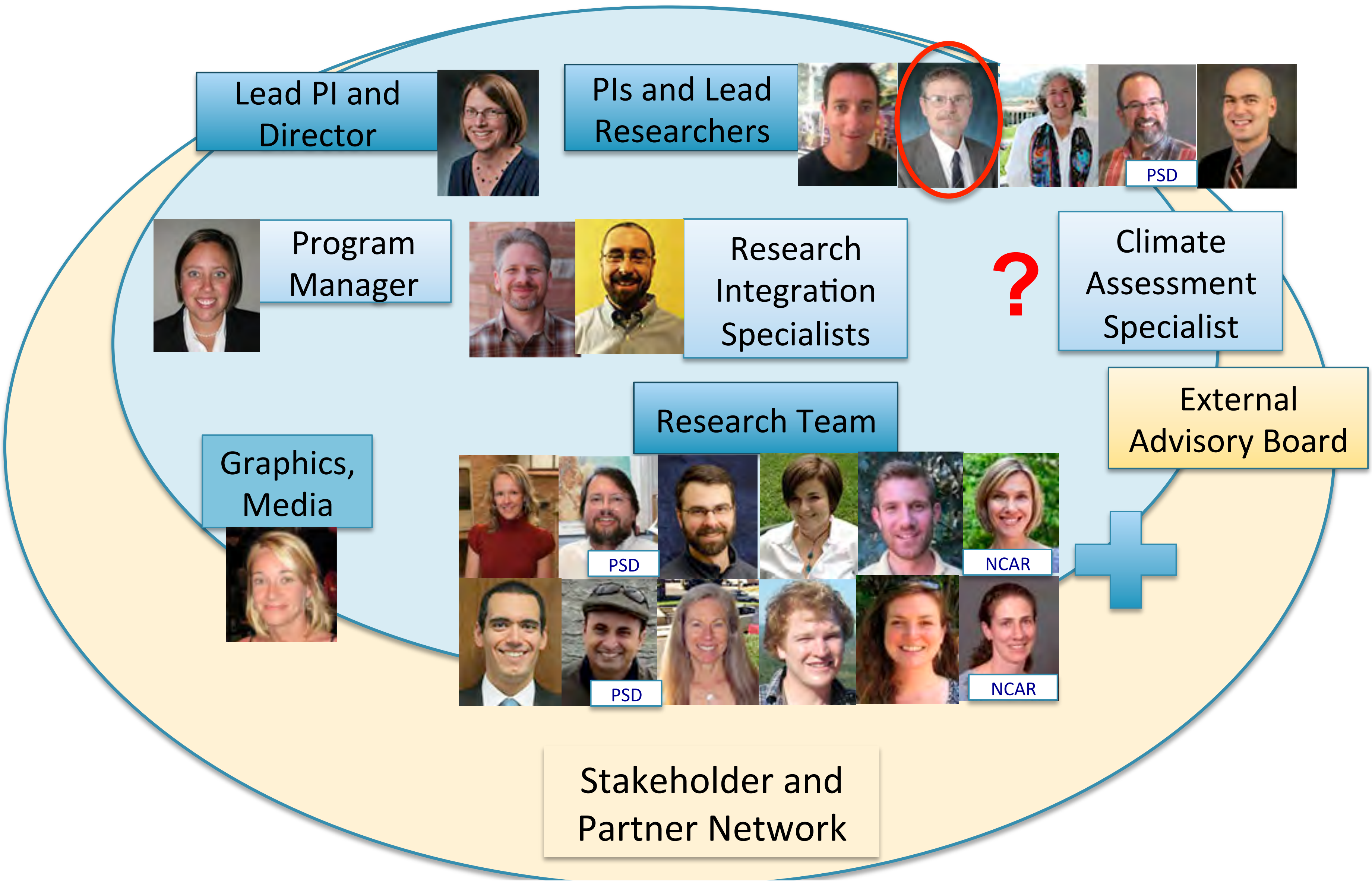
Monday, October 24, 2016

Part of the NOAA RISA Network



- Established in 1999 by CIRES researchers at CU-Boulder and PSD
- Serves stakeholders in Colorado, Wyoming and Utah
- 20+ researchers with expertise in hydrology, climate modeling, social sciences, ecology, policy, and social sciences

WWA Team and Partners



WWA's Working Principles

We conduct our projects following these principles:

1. Begin with the decision context
2. Prioritize use-inspired science (that is, science that is responsive to and inspired by user needs for decision making)
3. Follow the principles of co-production by directly interacting with stakeholders; and
4. Work in interdisciplinary teams

Overarching Five-Year Questions/ Research Themes

1. How does the region's changing exposure to climate affect the region's adaptive capacity?
2. How can we leverage understanding of past extremes and projected future extremes to better inform societal decision making in a changing climate?
3. How do we design organizations, institutions, and information networks to build climate resilience across a variety of contexts?

Meeting Purpose

- Inform you of our current research and products/tools
- Generate discussion about these
- Networking and new relationships
- Hear from our stakeholders and partners
  - What has changed in your world since 2013
  - What has worked recently to connect science and decision-making (tools, organizations, methods, types of engagement, etc.)

WESTERN WATER ASSESSMENT
A NOAA RISA TEAM
CIRES
University of Colorado **Boulder**

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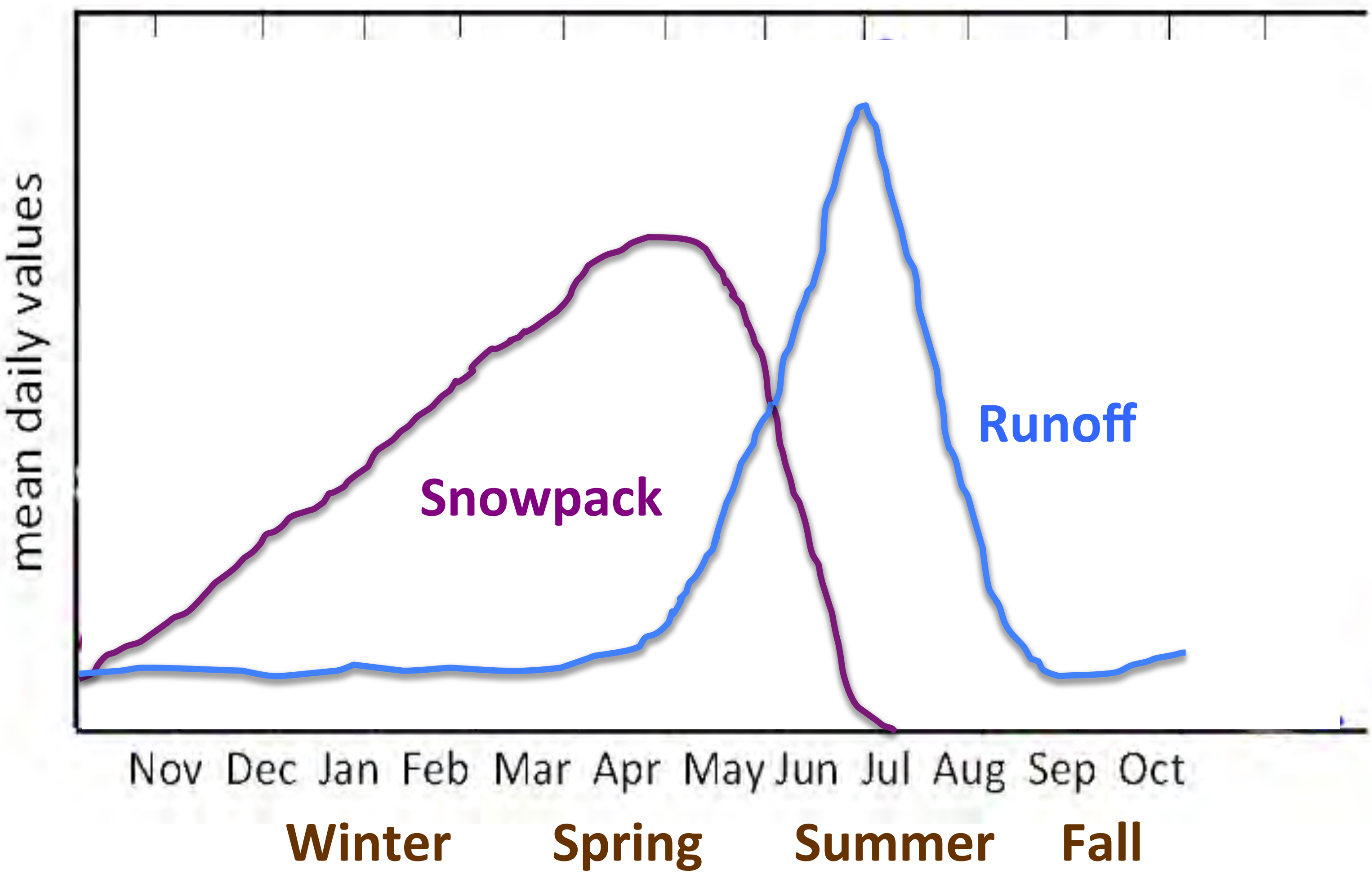
WWA research on snowpack monitoring

Noah Molotch, Jeff Deems, Jeff Lukas, Ben Livneh, Mark Raleigh, Dominik Schneider, Keith Jennings, Leanne Lestak, John Berggren, Elizabeth McNie

2016 WWA Stakeholder Meeting

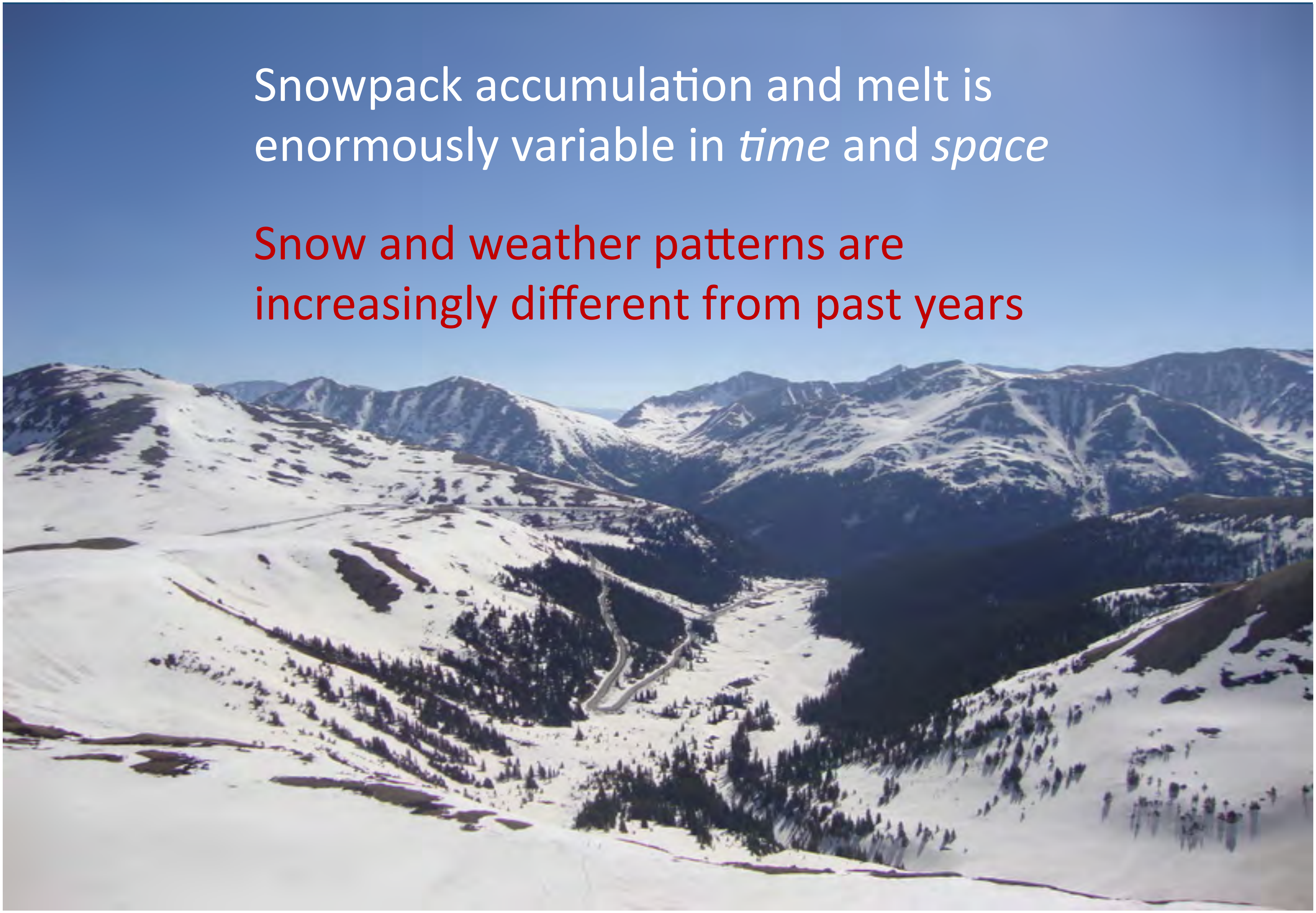
Typical snowpack and runoff curves



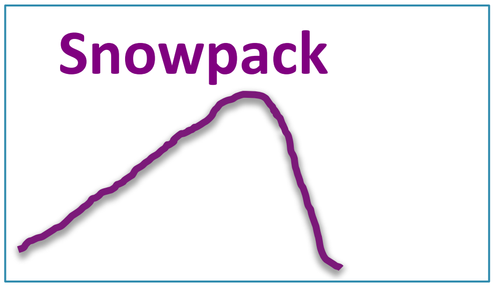
Graphic: adapted from J. Deems, after Peterson et al. (1997)

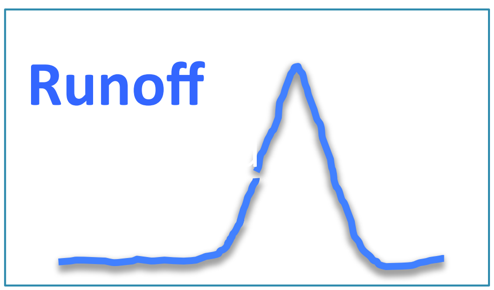
Snowpack accumulation and melt is enormously variable in *time* and *space*

Snow and weather patterns are increasingly different from past years

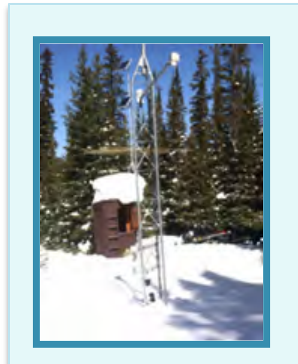


Snowpack monitoring and runoff forecasting





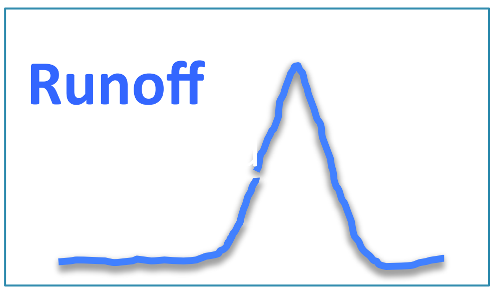
SNOTEL



NOAA & NRCS runoff forecasts

Operational decision-making

Snowpack monitoring and runoff forecasting



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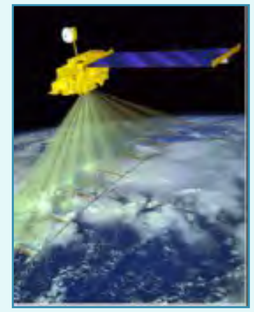
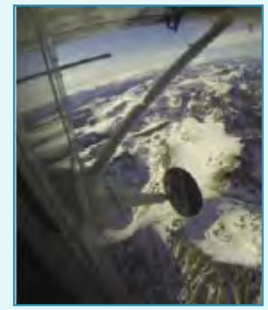
Satellite



Airborne

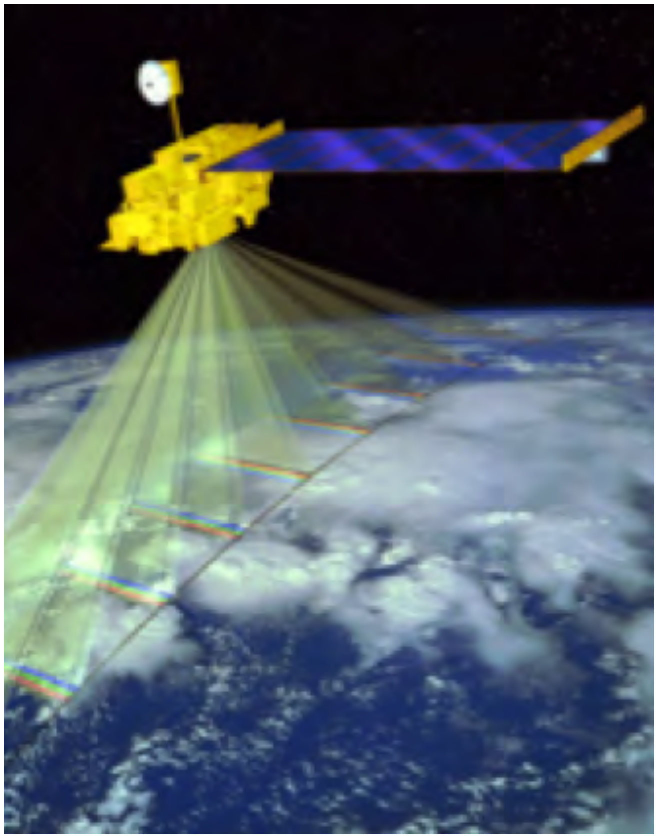


NOAA & NRCS runoff forecasts

Operational decision-making

MODIS-based, real-time SWE product

Noah Molotch, Dominik Schneider, Leanne Lestak



- Range/region-scale moderate-resolution spatial snow product
- Reconstruct historic SWE distributions using MODIS snow cover data and an energy balance model
- Interpolate real-time SNOTEL SWE based on topography, historical SWE reconstructions, and real-time MODIS snow cover
- Products: Reanalysis (2000-2015) and Real-time daily SWE, at 500-m

MODIS-based, real-time SWE product

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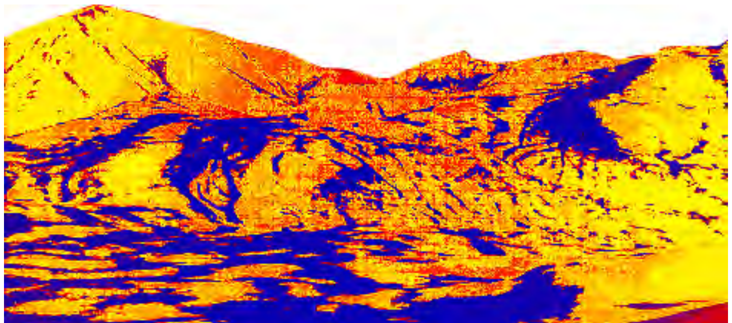

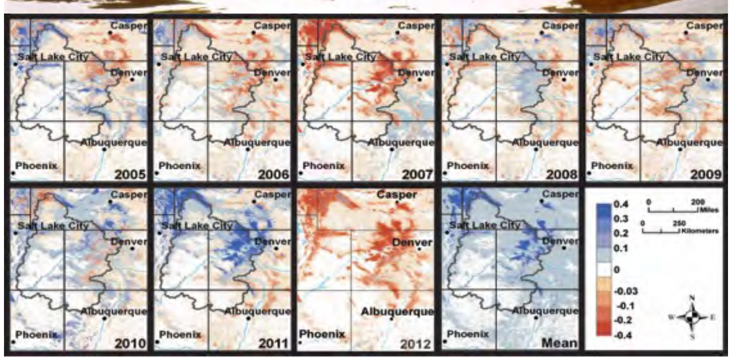

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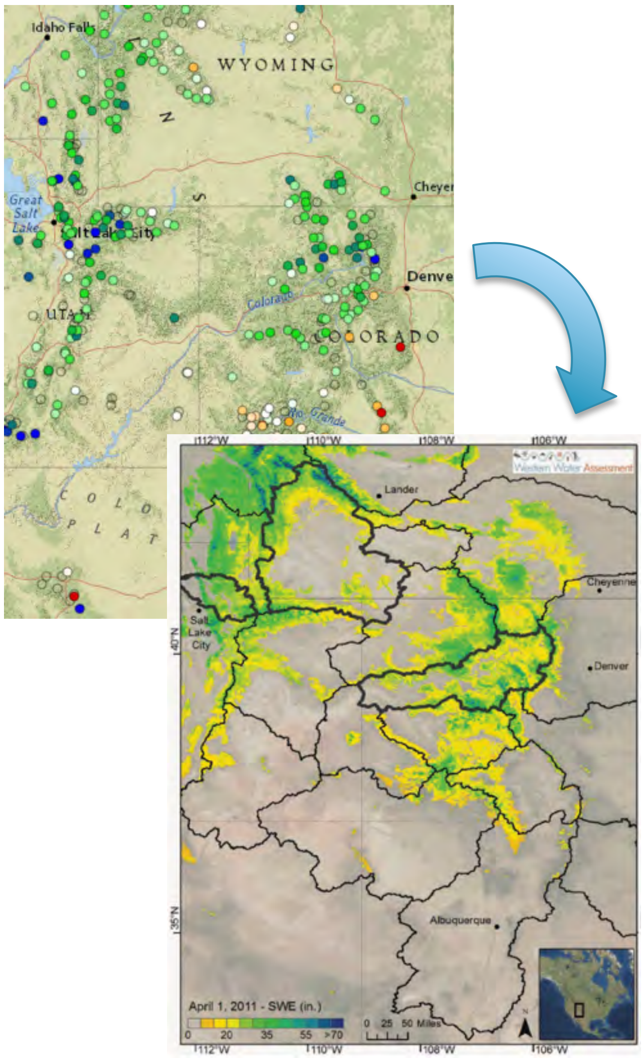

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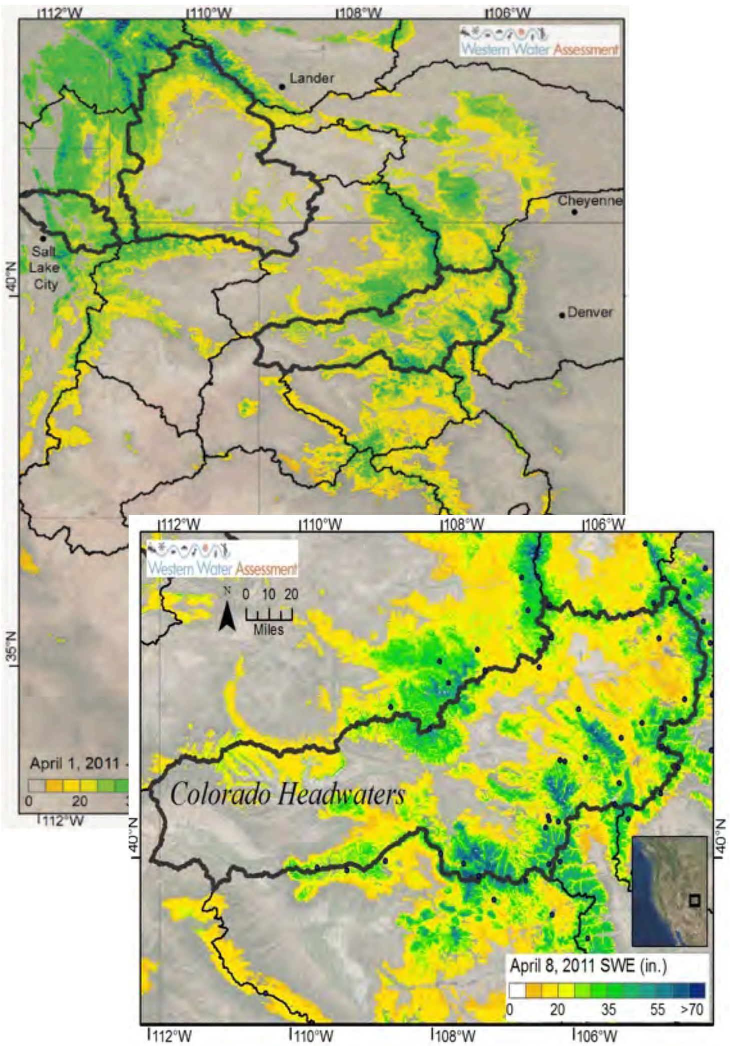

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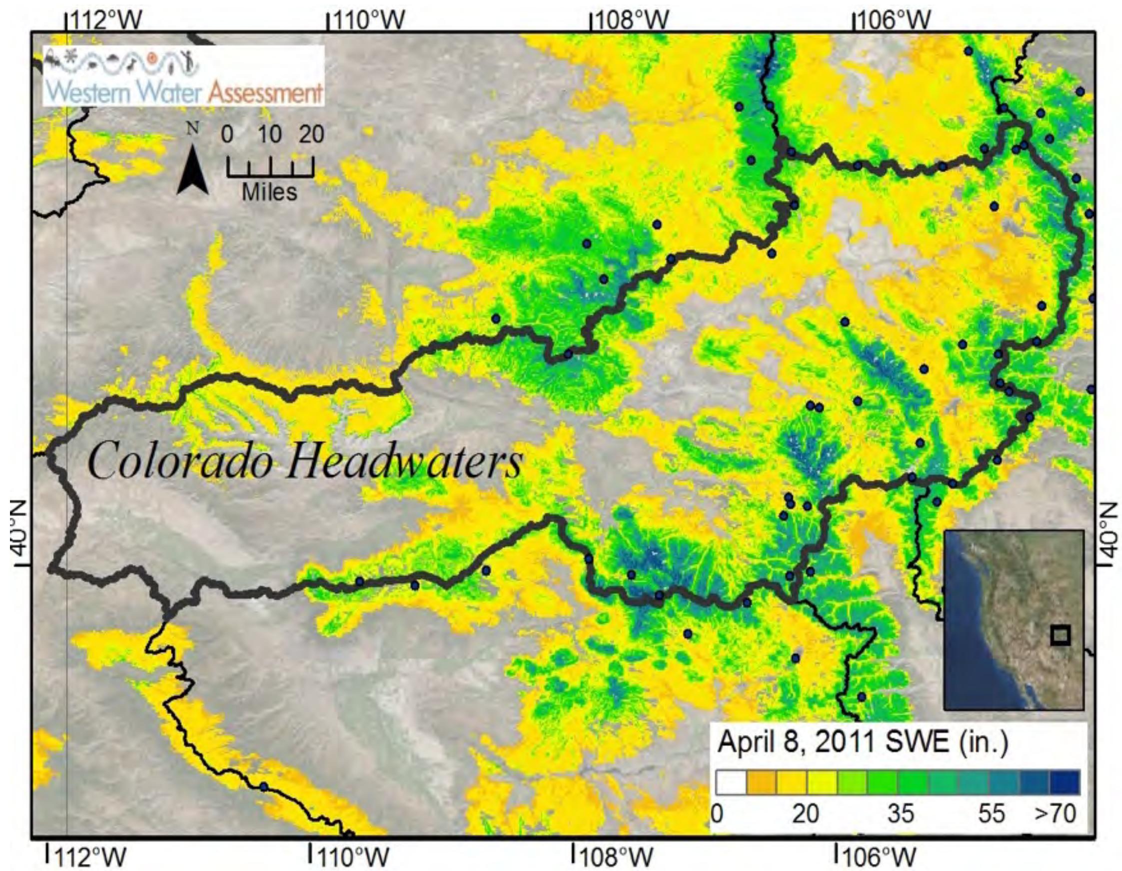
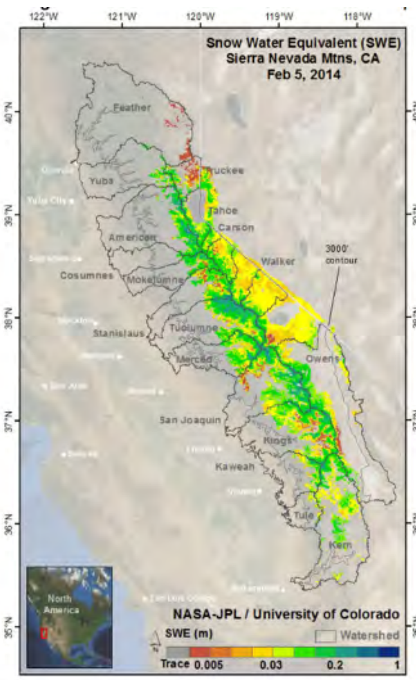
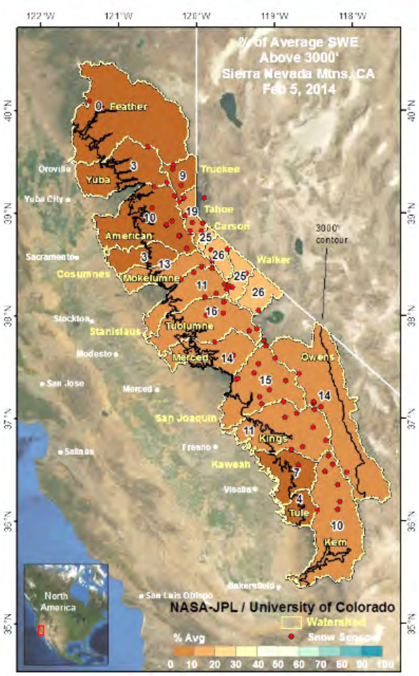
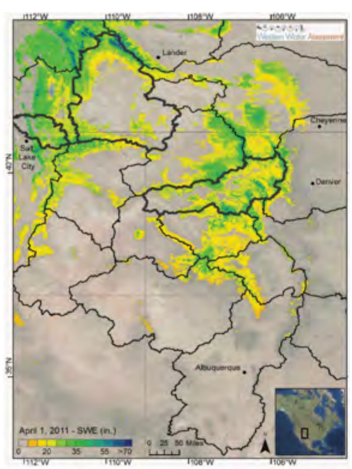


- Lower error in interpolated SWE estimates
- Captures broader range of snow conditions
- Can be generated over large areas at relatively low cost

MODIS-based, real-time SWE product







- California – Produced operationally in near real-time for CADWR and others since 2012
- Wyoming – Produced retrospectively for 2000–2012 to diagnose errors in water supply forecasts
- Colorado - Produced retrospectively to evaluate hydrologic impacts of bark beetles and to evaluate regional climate models

NASA/JPL Airborne Snow Observatory (ASO)

Tom Painter (JPL, former WWA), Jeff Deems, and ASO Team

- Watershed-scale, super-high-resolution spatial snow product
- Aircraft carries two sensors: LIDAR (surface height) and spectrometer (albedo/dust)
- LIDAR height data is combined with snow density model to estimate SWE
- Main product: Near-real-time SWE, at 50-m resolution

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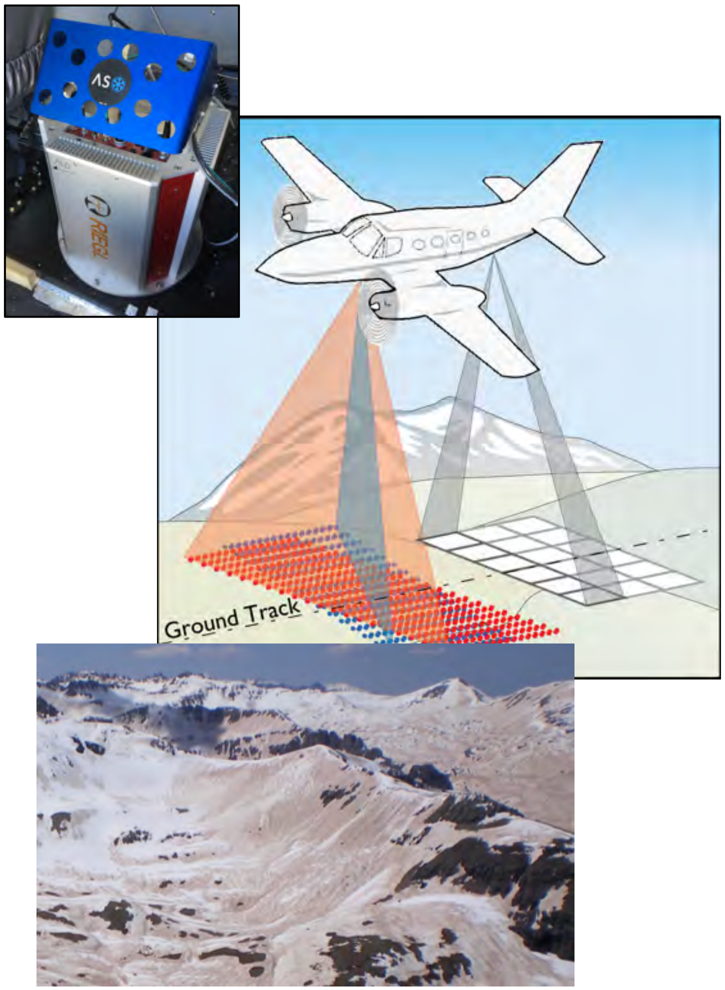

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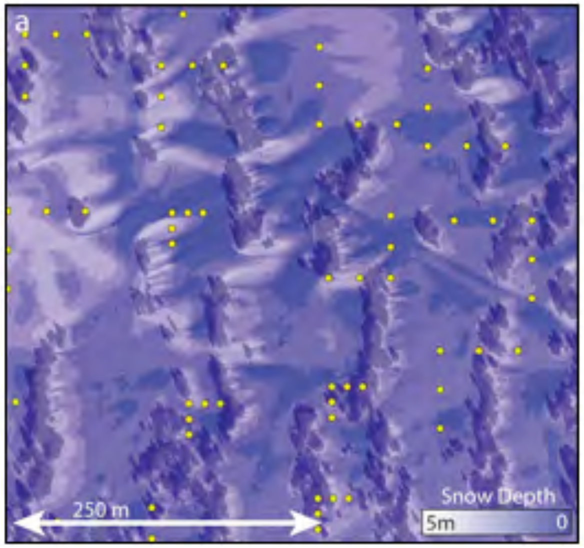

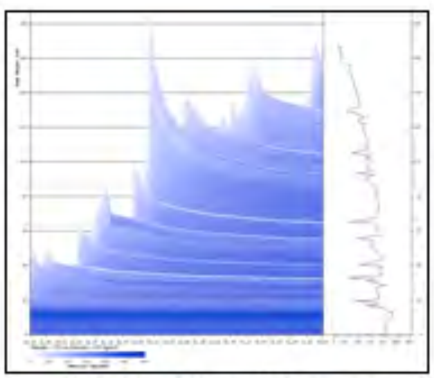

SNOWPACK model, courtesy CAIC

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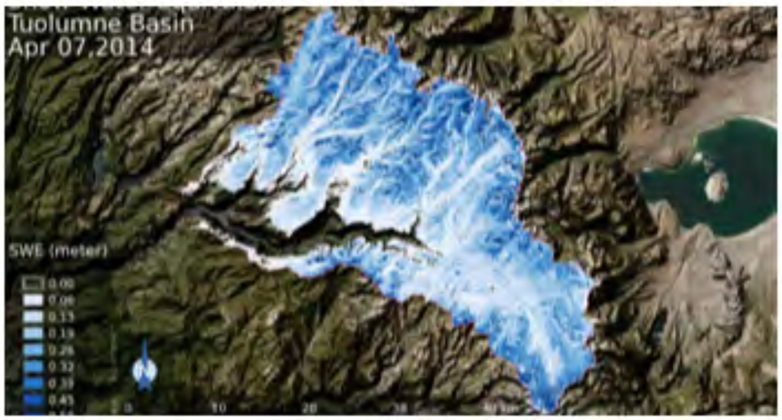

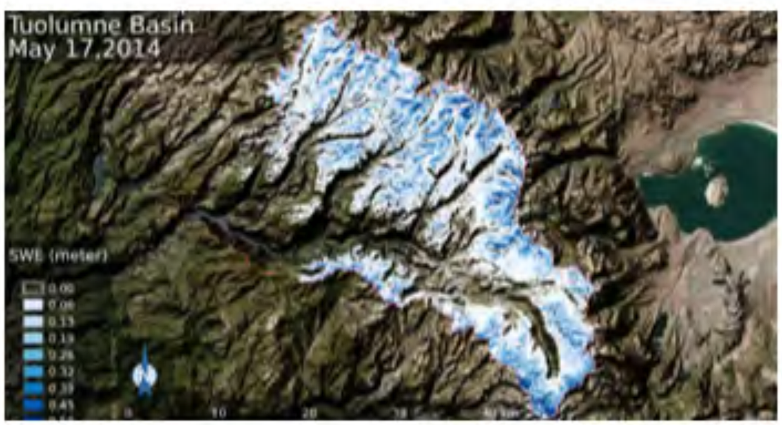

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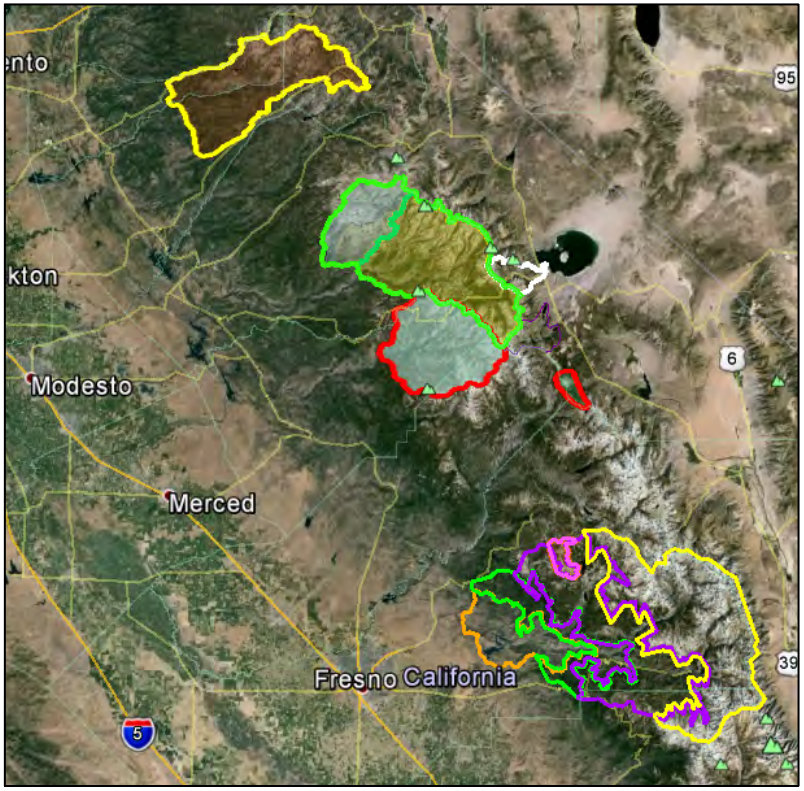
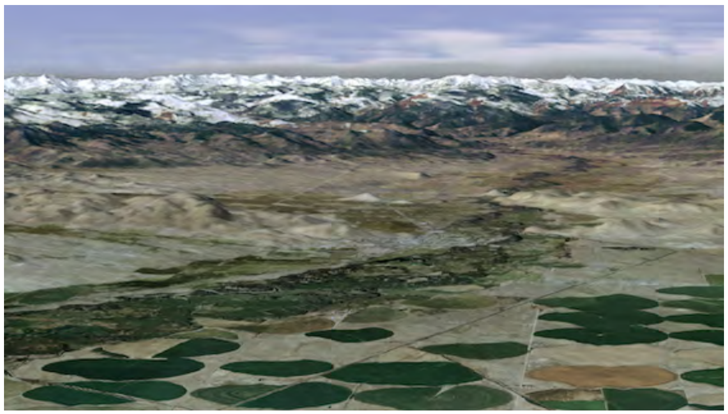


- **Colorado** – Rio Grande, Uncompahgre, Grand Mesa, and East River basins
- **Wyoming** – expansion to Wind River, Wyoming, Sierra Madre, & Snowy Ranges
- **California** – Tuolumne, Merced, Kings, Lakes, Rush Creek, Lee Vining Creek basins, Sagehen Experimental Forest; expanding to Mokelumne and San Joaquin
- **Oregon** – McKenzie & Deschutes Rivers
- **Idaho** – Reynolds Creek
- **Washington** – Olympic mountains (OlympEX GPM satellite validation)

Remotely Sensed Snowpack Data for Streamflow Forecasting and Water System Management

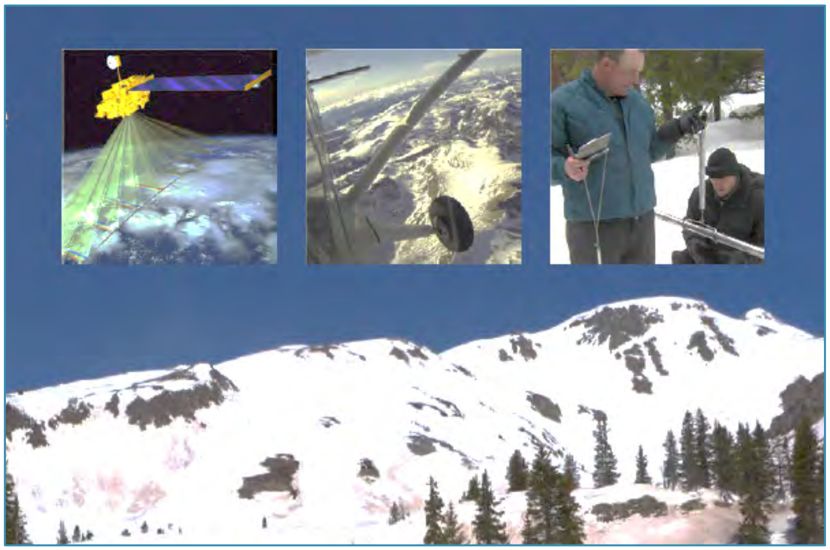
Molotch, Deems, Livneh, Jennings, Raleigh, Lukas, Berggren



- Assessing the additional utility of MODIS and ASO snowpack data in the Uncompahgre and Rio Grande basins
- Could MODIS & ASO data have helped water managers better cope with stressful drought and flood periods since 2000?
- Water manager interviews completed, modeling begun

2015 WWA Snowpack Monitoring Workshops

Lukas, McNie, Bardsley, Molotch, Deems



- Three one-day workshops in Utah, Wyoming, Colorado with 180 participants total
- Presentations from WWA, NIDIS, CBRFC, NRCS Snow Survey, water managers
- Discussions of how to improve snowpack monitoring

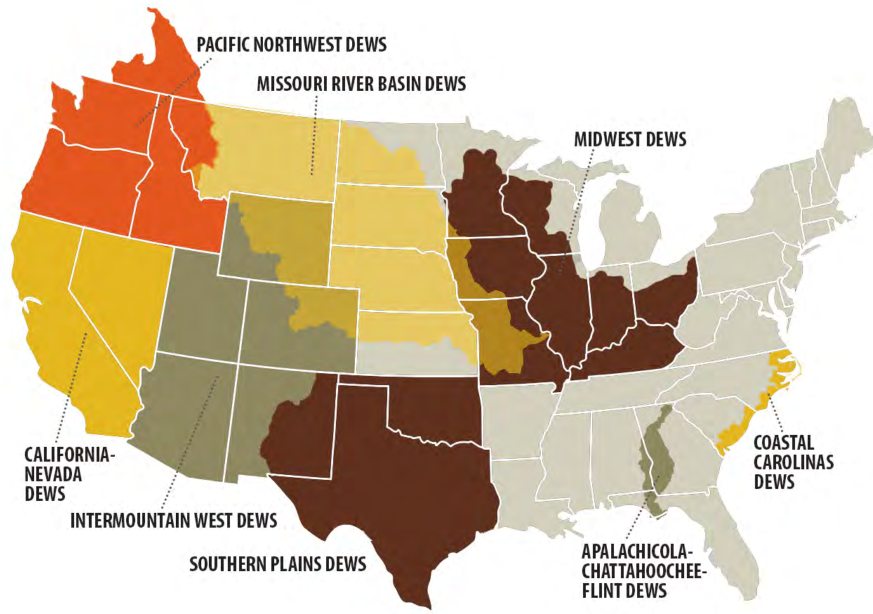
NIDIS Intermountain West Drought Early Warning System (IMW DEWS)

Alicia Marrs, NOAA/NIDIS

October 24, 2016

What is the National Integrated Drought Information System (NIDIS)?

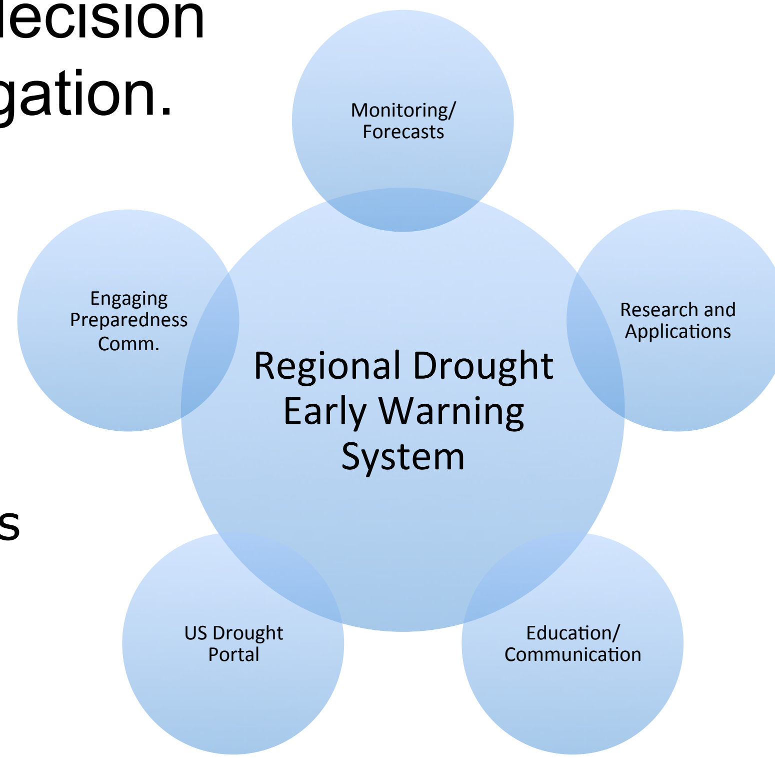
- A NOAA program with an interagency mandate.
- Provide a better understanding of how and why droughts affect society, the economy and the environment.
- Improve accessibility, dissemination and use of early warning information for drought risk management.
- Build off of a network of Regional Drought Early Warning Systems (DEWS) to create a National Drought Early Warning System.



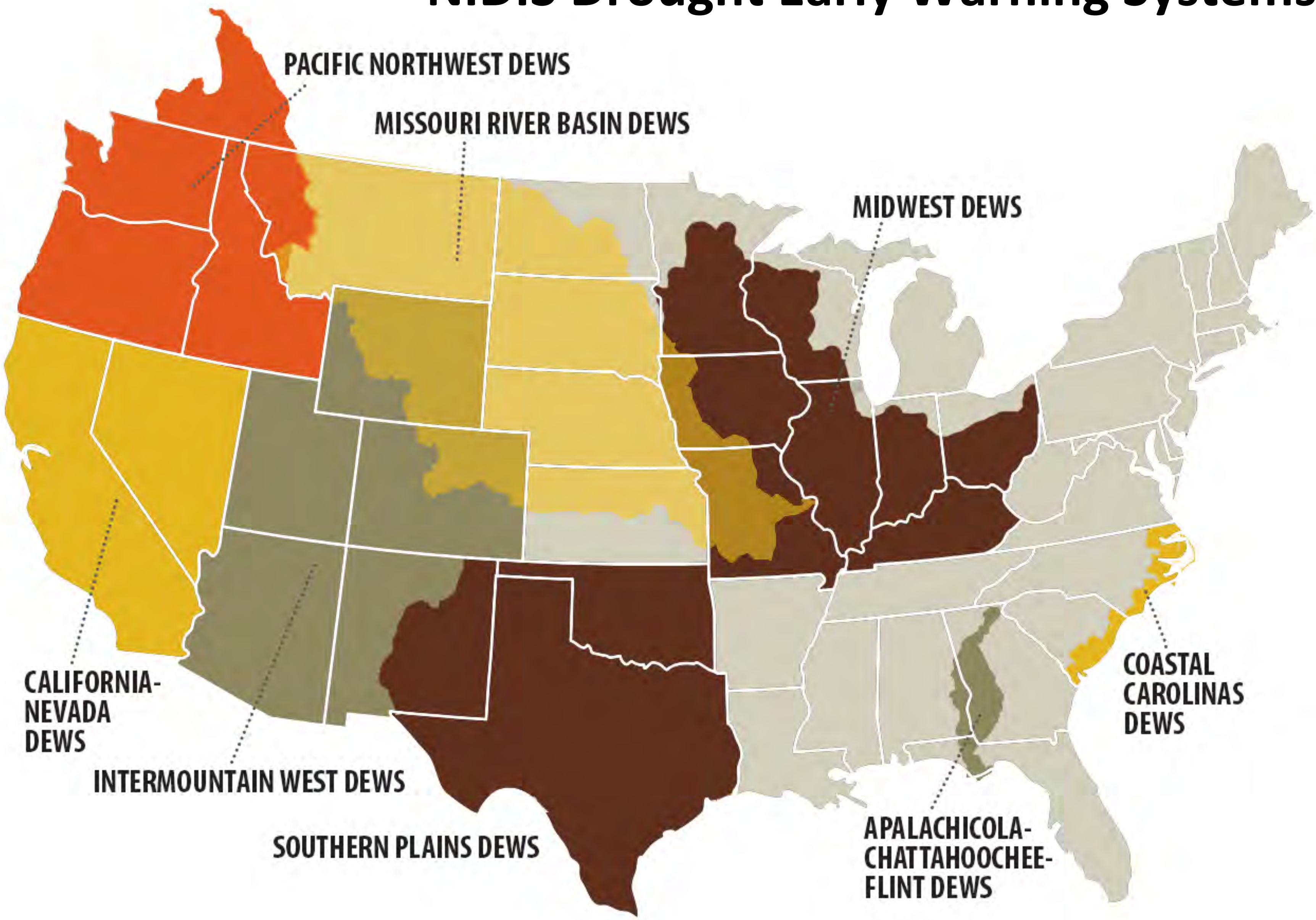
Regional Drought Early Warning Systems (DEWS)

Working with communities and existing networks to build capacity for better decision making for drought planning and mitigation.

- Drought & risk assessments
- Climate outlook forums
- Education and outreach webinars
- Engaging the preparedness community
- Builds capacity to utilize existing products
  - Provide test beds for new products
- Develop new/utilize existing networks



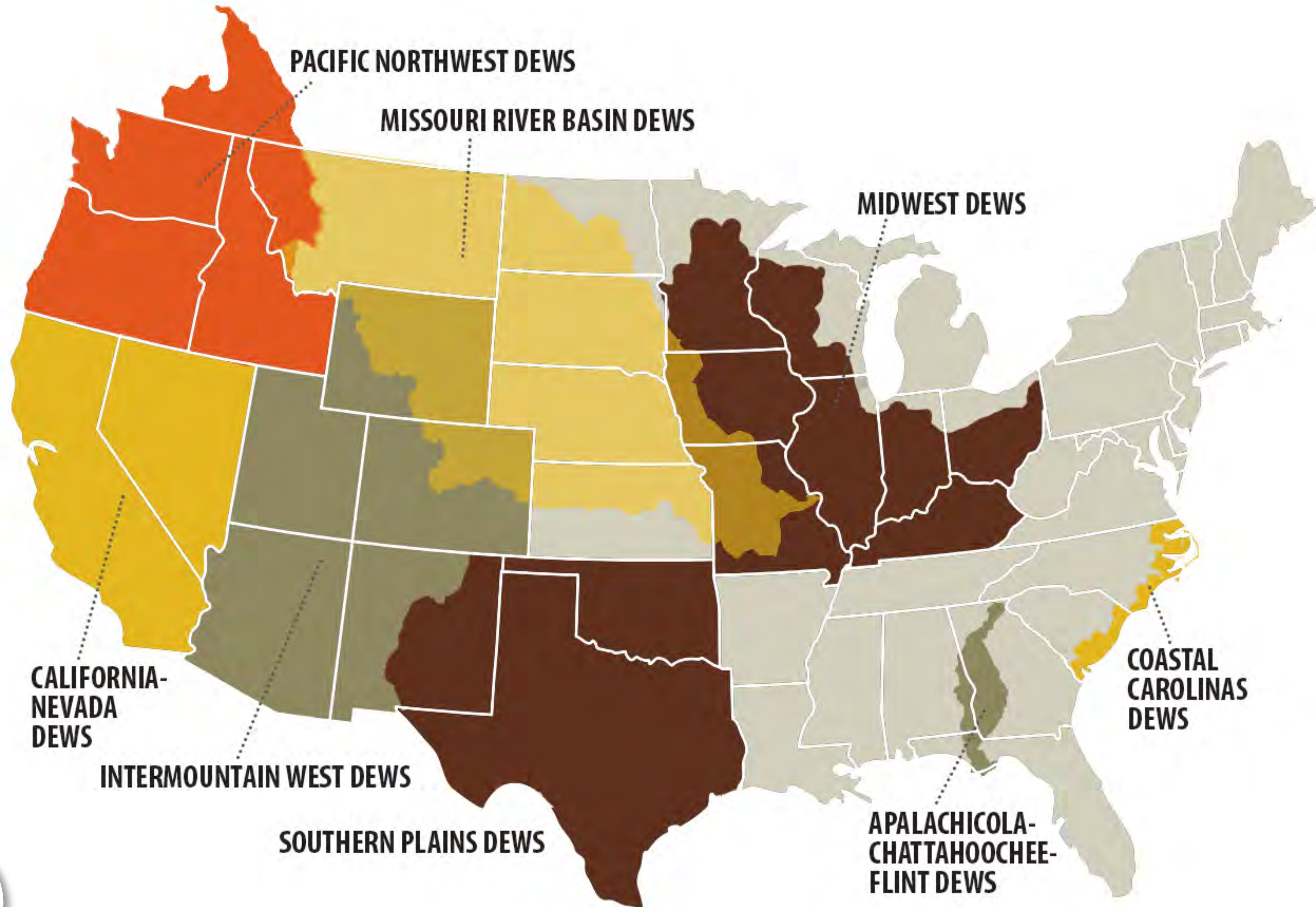
NIDIS Drought Early Warning Systems



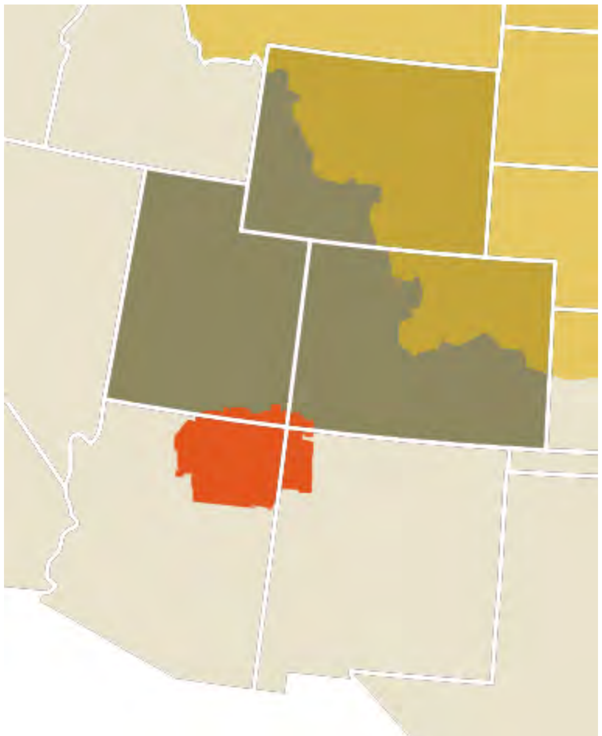
UCRB/IMW DEWS Activities

- **Monitoring & Prediction**
  - Upper Colorado River Basin Drought Assessments
  - Colorado Water Availability Task Force
  - Western Water Assessment Intermountain West Dashboard
- **Innovative Research, Applications & Assessments**
  - Evaporative Demand Drought Index (EDDI)
  - Water Resources Monitor & Outlook (WRMO)
  - Testing the utility of highly-resolved spatial snow data
- **Engaging Preparedness & Adaptation Communities**
  - WWA Snowpack Monitoring Workshops in CO, UT & WY (2015)
  - Colorado Drought Tournament (2012)

How did we get to the Intermountain West DEWS?



What were the boundaries Upper Colorado River Basin DEWS?



OR?

Intermountain West DEWS

IMW DEWS Strategic Plan

- Roadmap for moving forward with the IMW DEWS
- Identify existing and new drought-related activities throughout the region
- Living document w/ 2-yr time frame
- Focus is on activities in the region
  - Not limited to NIDIS funded/led projects

IMW DEWS Strategic Plan

- NIDIS and Western Water Assessment are leading development of strategic plan in collaboration with the Colorado Climate Center, CLIMAS, CWCB and other regional partners

- NIDIS/NOAA funding opportunities
  - RISAs, NOAA Regional Climate Centers and Cooperative Institutes
  - SARP – Sectorial Application Research Program
  - MAPP – Modeling, Analysis, Predictions and Projections
  - Additional NIDIS investments within NOAA

- Partner agency/organization initiatives (may or may not include NIDIS funding)
  - USDA Climate Hubs (Northern Plains & Southwest)
  - DOI Climate Science Centers
  - Bureau of Reclamation
  - USGS
  - NRCS

SAVE THE DATE

Intermountain West Drought Early Warning System
Drought & Climate Outlook

October 25, 2016 // The Alliance Center, 1536 Wynkoop Street, Denver CO

The National Integrated Drought Information System (NIDIS) and its partners are holding a Drought & Climate Outlook and Stakeholder Meeting as part of the Intermountain West Drought Early Warning System (IMW DEWS) on October 25, 2016 at the Alliance Center in Denver, CO.

In addition to providing an update on current drought status and a preview of current and developing climatic events (i.e. El Niño and La Niña) for the region, this one-day event will bring together a diverse group of federal, tribal, state, academic and local partners and stakeholders from the water, climate and land management communities for an in-depth discussion on drought in the Intermountain West and opportunities to improve capacity to meet the needs of decision makers in the region.

Register: http://bit.ly/2dr3b2E

For more information contact Alicia Marrs, NIDIS (**alicia.marrs@noaa.gov**)

Contact Information

Alicia Marrs
Regional Drought Information Coordinator
NOAA/NIDIS
303-497-4624
alicia.marrs@noaa.gov

Advancing the use of Drought Early Warning Systems in the Upper Colorado River Basin

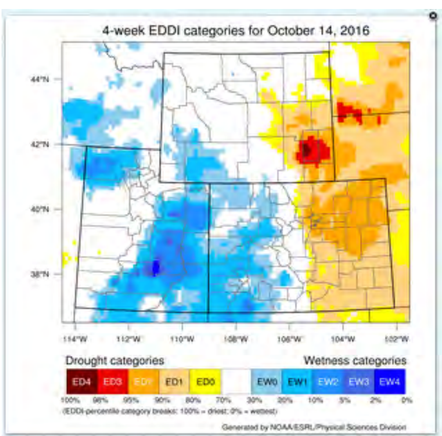
Lisa Dilling, Ben Livneh, Bill Travis, Jeff Lukas, Rebecca Page (WWA)

Nolan Doesken (Colorado Climate Center, CSU)

Eric Kuhn (Colorado River District)

2016 WWA Stakeholder Meeting

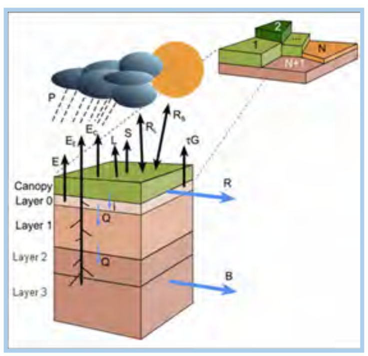
Project objectives



Advance the NIDIS DEWS in our region and strengthen drought risk management practices on Colorado's Western Slope by:

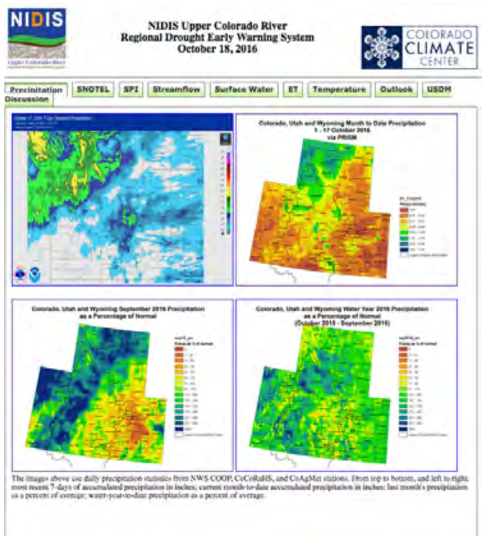
- Providing a clearer understanding of the decision and risk management process for water entities facing drought
- Identifying barriers to introducing new indicators into the drought management process
- Evaluating how the usefulness of drought indicators may be affected by climate change

Project activities



- Work with several Western Slope water entities (Colorado River District, Eagle River W&SD, Upper Gunnison River WCD, Upper Yampa WCD, and others)
- Interview key staff; observe meetings; review drought response and planning documents; and hold small-group discussions
- Run hydrologic models to assess whether snowpack and other drought indicators will continue to provide useful information in a changing climate
- *Workshop in 2018 (and 2017?)*

Sister project: Selecting Decision Support for Climate Adaptation: Why Drought Decision Makers Choose to Use Tools (or Not)



- Amanda Cravens (USGS) interviewing both drought tool *creators* and tool *users*
- Examine how resource managers choose to use particular decision support tools in decision making processes
- And how tool creators fund, design, develop, and disseminate tools
- Identify opportunities to better match how the two groups go about their work
- And ultimately: Help improve the Intermountain West DEWS
- *Workshop in mid-2017*

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EDDI Drought Indicator

Development and Outreach

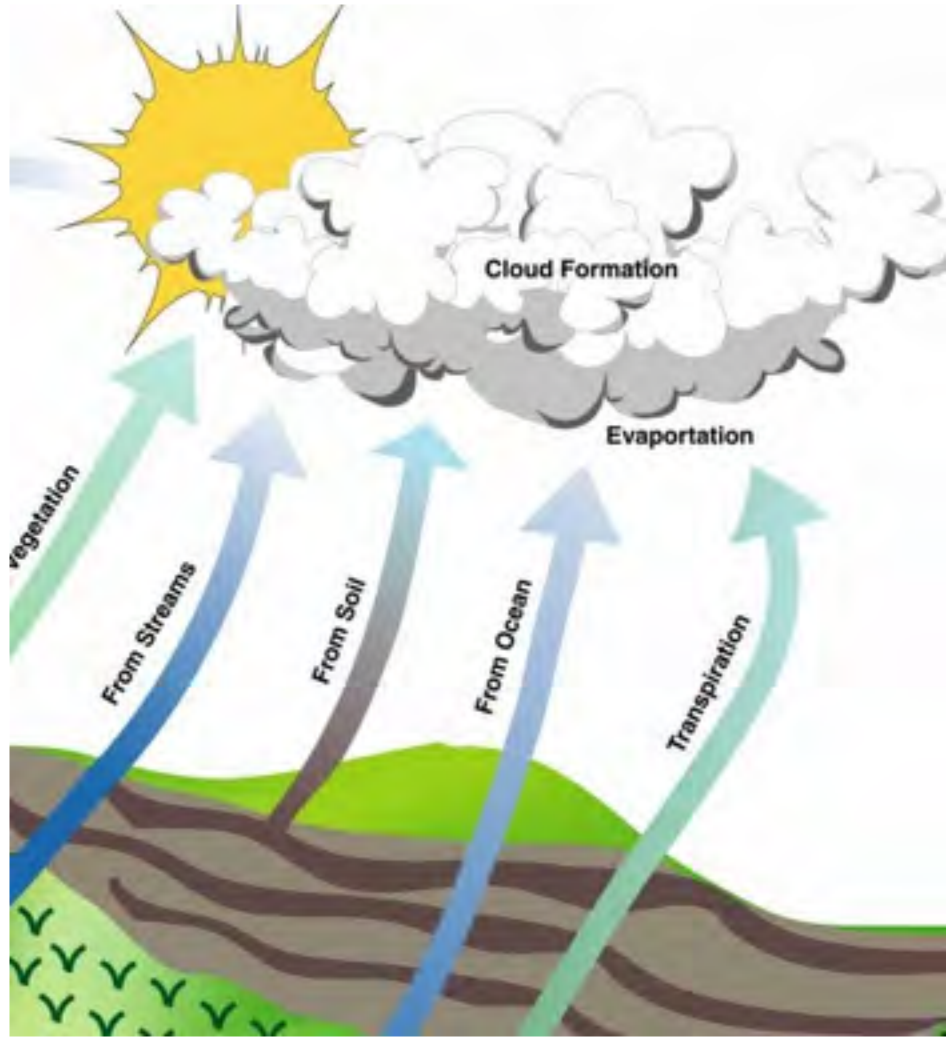
Imtiaz Rangwala, Mike Hobbins, Candida Dewes,
Jeff Lukas & Dan McEvoy

Evaporative demand = the atmosphere's thirst for surface moisture

As calculated from
- temperature
- humidity
- solar radiation
- wind speed

- but *not* precipitation

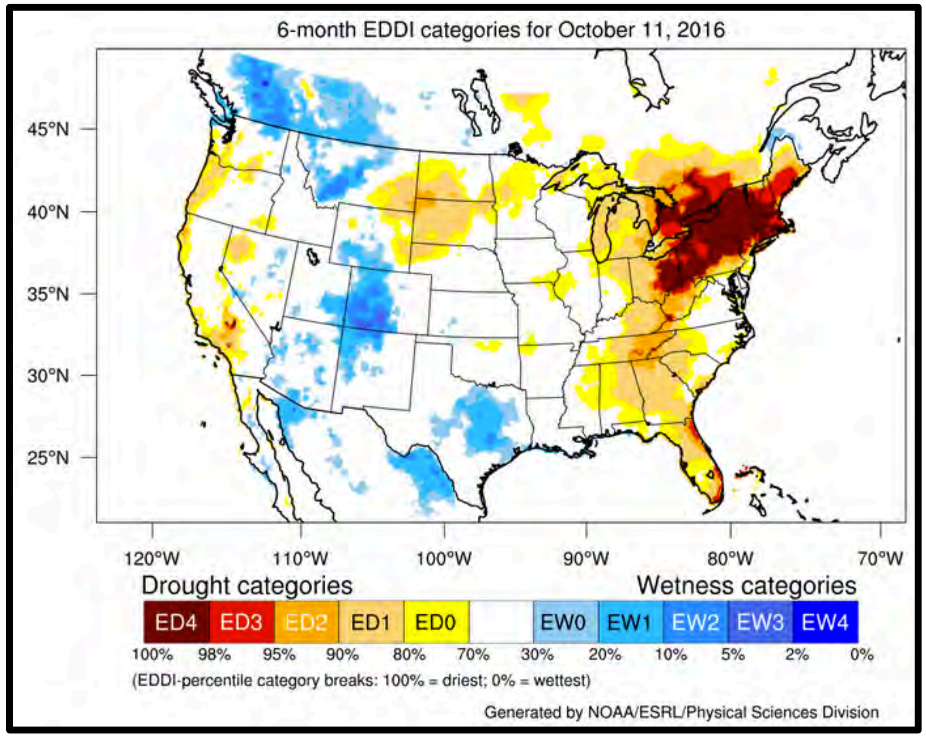
(i.e., reference ET from the Penman-Monteith equation)



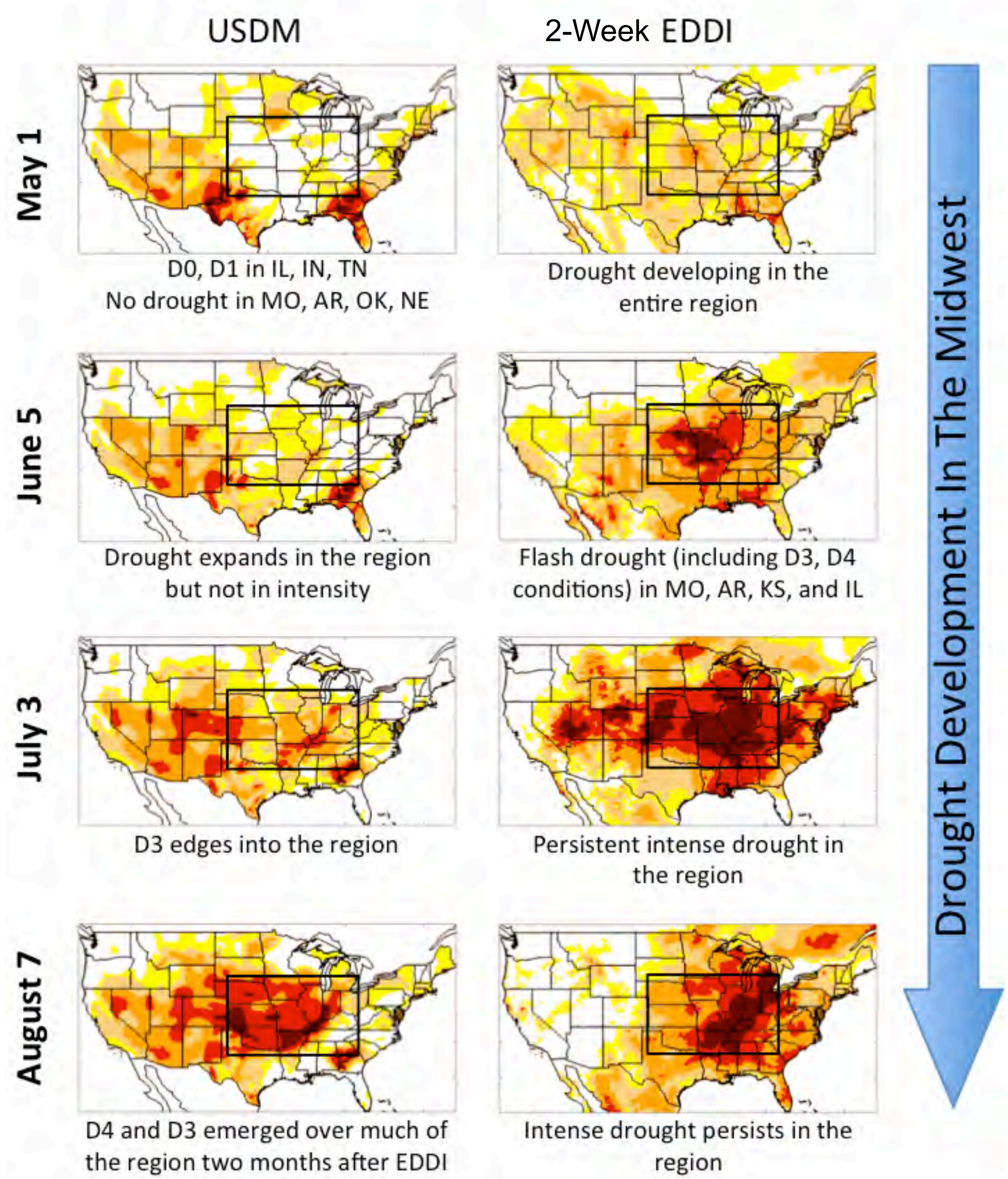
EDDI: Evaporative Demand Drought Index

How anomalous is the evaporative demand at a particular place relative to the 1979–2016 period?

- ❖ Standardized Index
- ❖ Near-real-time: 5-day lag
- ❖ Spatial resolution: 12 km
- ❖ Time windows considered
  - 2 weeks to 6 months
- ❖ Effective for drought early warning
- ❖ Captures rapidly evolving changes in evaporative stress, i.e., flash droughts

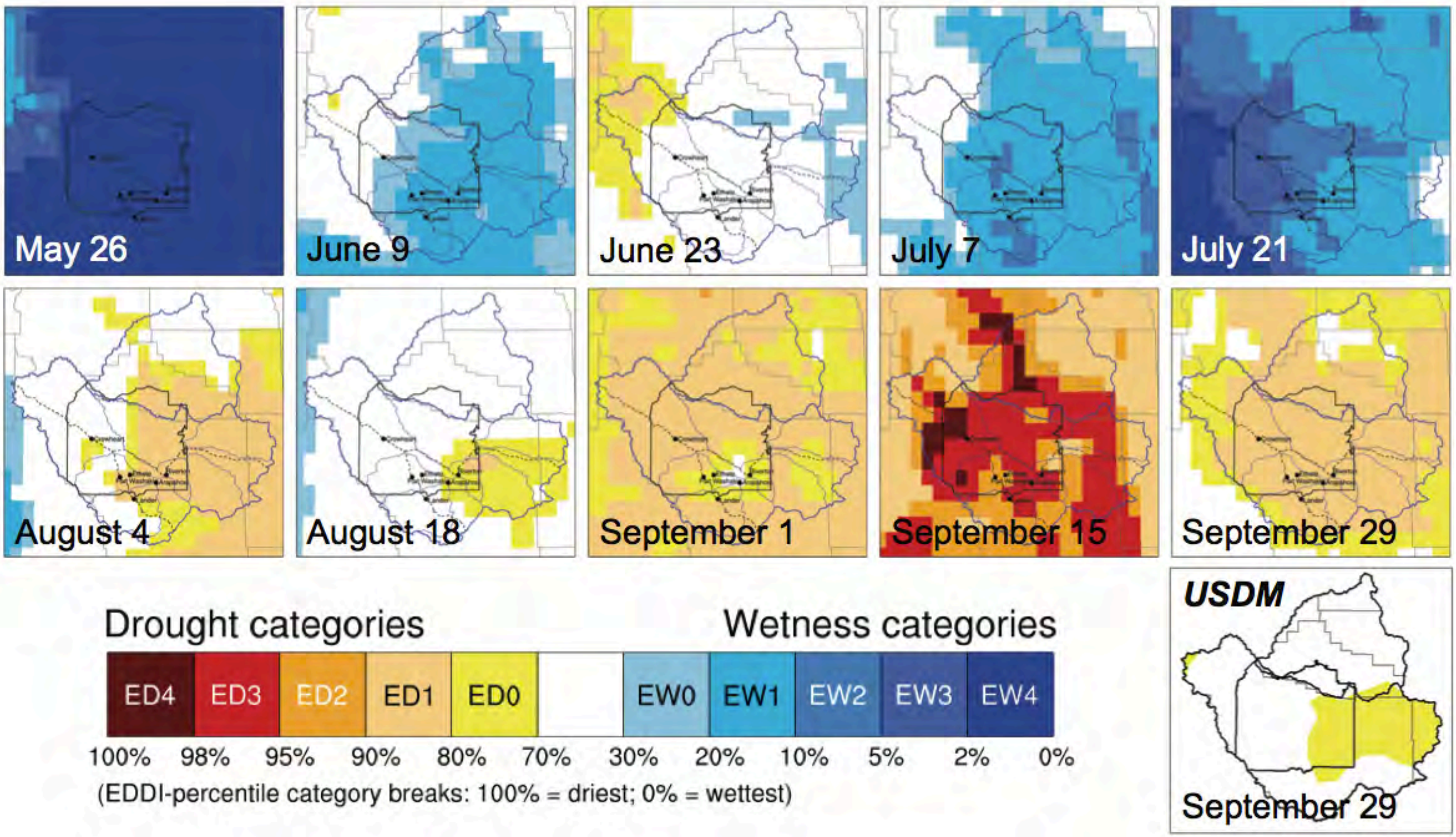


Year 2012



Credit: Mike Hobbins

2-week EDDI: 2015 Growing Season in Wind River, WY

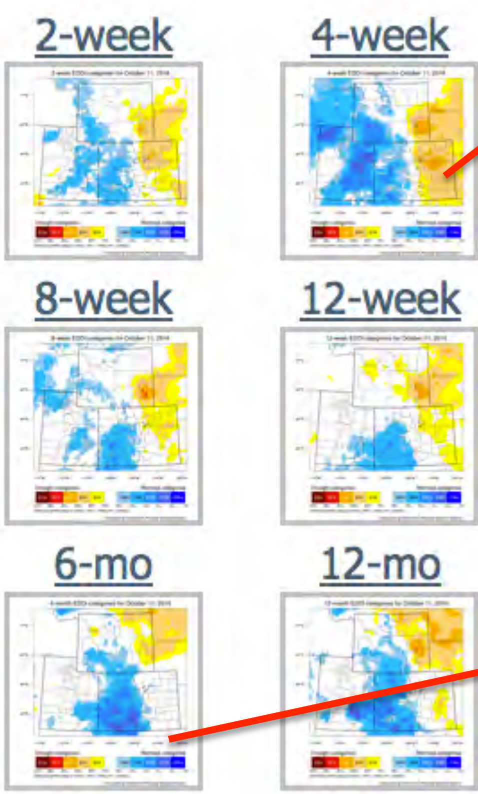


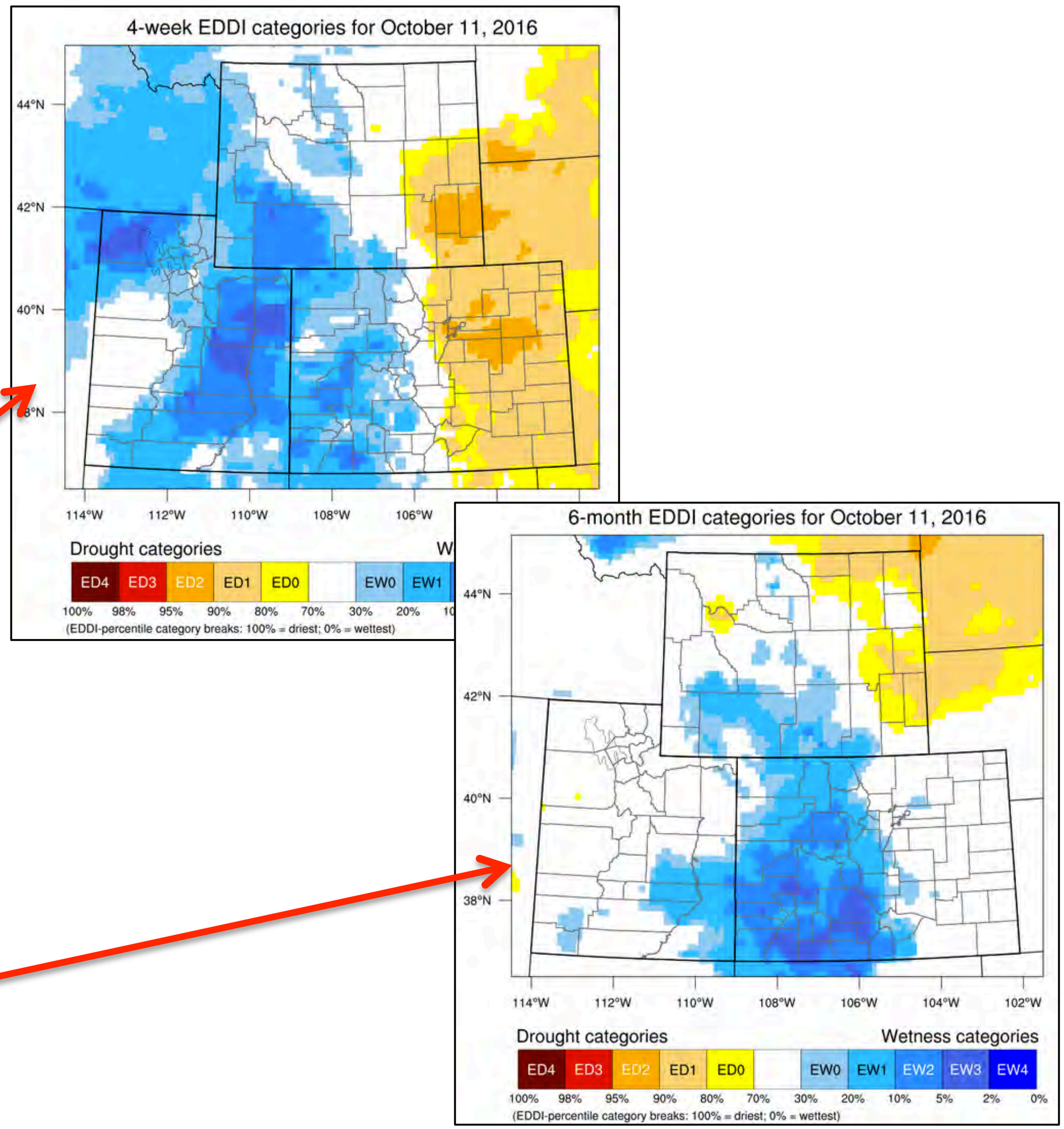
EDDI on WWA Dashboards

Evaporative Demand Drought Index (EDDI)

(NOAA ESRL PSD, WWA, and DRI)

(updated daily)





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EDDI 2-Pager

http://wwa.colorado.edu/publications/reports/EDDI_2-pager.pdf

Green River, Wyoming. Photo: K. Miller, USGS.

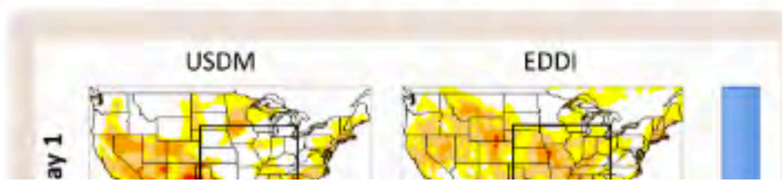
What is EDDI?

EDDI, which stands for *Evaporative Demand Drought Index*, is a drought index that can serve as an indicator of both rapidly evolving "flash" droughts (developing over a few weeks) and sustained droughts (developing over months but lasting up to years).

Why use EDDI?

EDDI has been shown to offer early warning of drought stress relative to current operational drought indicators, such as the US Drought Monitor (USDM) (***see Figure 1***). A particular

transpiration until the available soil moisture becomes limiting, potentially leading to flash droughts; and (ii) as surface water becomes increasingly scarce in sustained droughts, evapotranspiration declines, which leads to higher air temperature and lower humidity, and thereby increases E_0.



EDDI: Some Next Steps

- Provide **historical (1979-present) EDDI data** at 4-km grid to researchers investigating drought-related impacts to different socio-ecological systems
- Propose to develop a user-friendly platform to access these 4-km data CONUS-wide
- Development of an EDDI User's Manual

Climate adaptation decision models: Agriculture

http://wwa.colorado.edu/resources/tools/decision_models/index.html

Goal: Apply risk and decision analysis to situations in which producers must chose responses to uncertain, risky conditions

10/24/16

Drought decision making on the western cow-calf ranch

[A collaboration of WWA, USDA Northern Great Plains Climate Hub and the DoI North central Climate Science Center]

The basic decision problem is whether to *change management practices in the face of drought*, by:

- Destocking drought-affected range and putting cattle on purchased feed or rented pasture elsewhere
- Weaning calves and selling early (at lower weights)
- Selling part or all of the herd (calves and mother cows) and re-building after the drought
- Switch to stockers

Each decision has different financial and management implications.

Drought decision making on the ranch

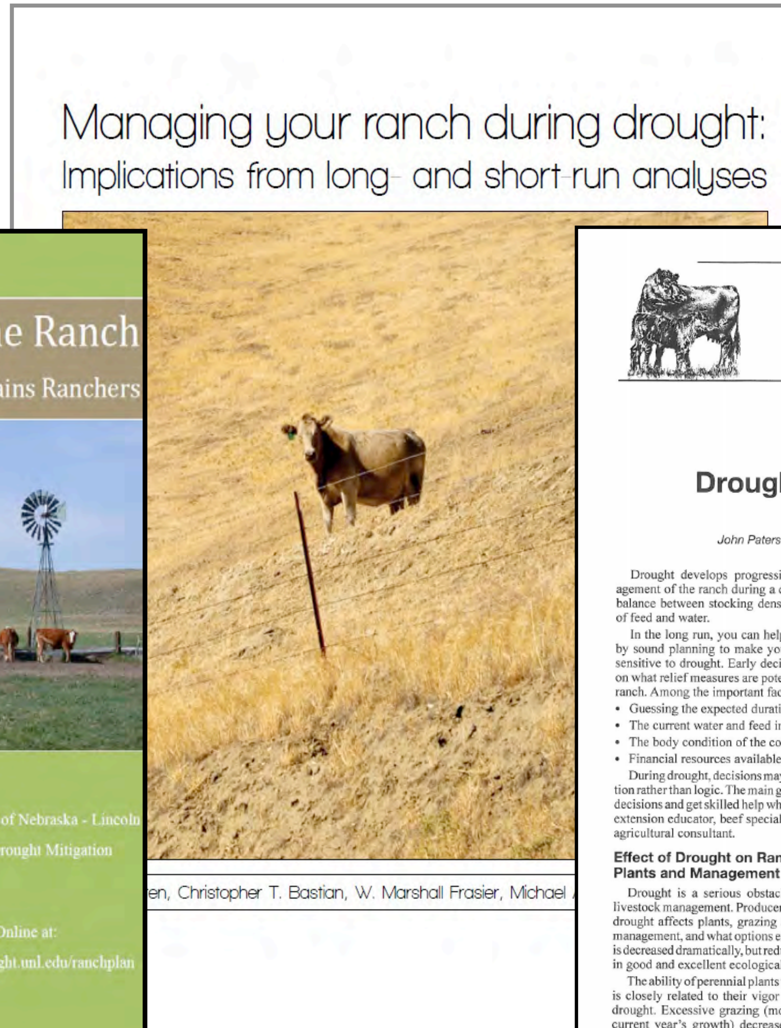
Some other factors include:

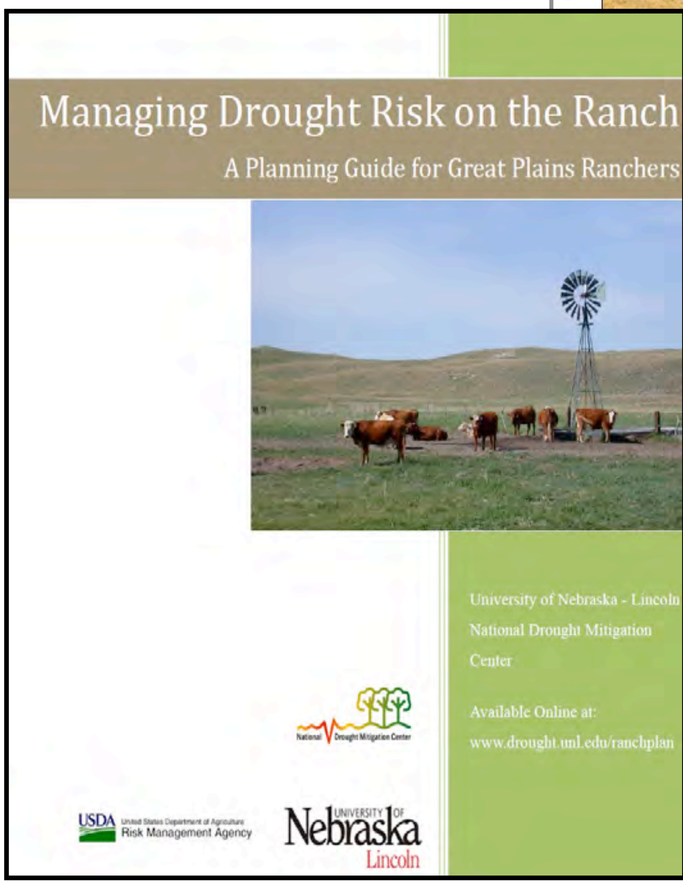
- Expectations about future drought conditions, what's the forecast? What about next year?
- Current market conditions, net worth, financial plan, and potential market response to drought
- What other ranchers will do
- Potential insurance payments (e.g., USDA RMA)

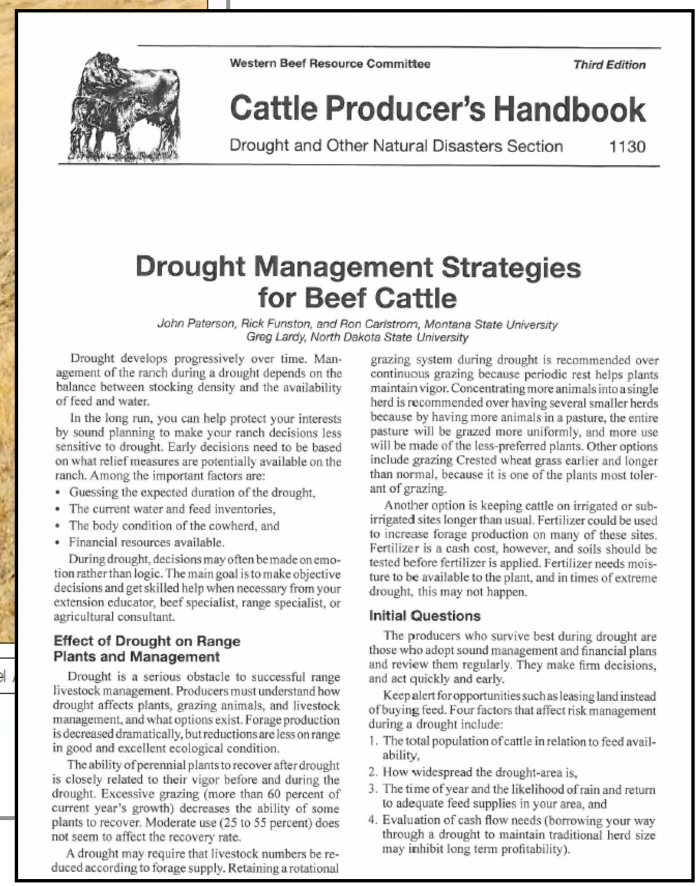
A classic case of **decision-making under uncertainty**:

- Will the drought continue, worsen, or improve?
- How will markets respond to adjustments made by livestock producers?

Plenty of good advice is available from ranch and range management experts






Western Beef Resource Committee — *Third Edition*

Cattle Producer's Handbook

Drought and Other Natural Disasters Section 1130

Drought Management Strategies for Beef Cattle

John Paterson, Rick Funston, and Ron Carlstrom, Montana State University
Greg Lardy, North Dakota State University

Drought develops progressively over time. Management of the ranch during a drought depends on the balance between stocking density and the availability of feed and water.

In the long run, you can help protect your interests by sound planning to make your ranch decisions less sensitive to drought. Early decisions need to be based on what relief measures are potentially available on the ranch. Among the important factors are:

- Guessing the expected duration of the drought,
- The current water and feed inventories,
- The body condition of the cowherd, and
- Financial resources available.

During drought, decisions may often be made on emotion rather than logic. The main goal is to make objective decisions and get skilled help when necessary from your extension educator, beef specialist, range specialist, or agricultural consultant.

Effect of Drought on Range Plants and Management

Drought is a serious obstacle to successful range livestock management. Producers must understand how drought affects plants, grazing animals, and livestock management, and what options exist. Forage production is decreased dramatically, but reductions are less on range in good and excellent ecological condition.

The ability of perennial plants to recover after drought is closely related to their vigor before and during the drought. Excessive grazing (more than 60 percent of current year's growth) decreases the ability of some plants to recover. Moderate use (25 to 55 percent) does not seem to affect the recovery rate.

A drought may require that livestock numbers be reduced according to forage supply. Retaining a rotational grazing system during drought is recommended over continuous grazing because periodic rest helps plants maintain vigor. Concentrating more animals into a single herd is recommended over having several smaller herds because by having more animals in a pasture, the entire pasture will be grazed more uniformly, and more use will be made of the less-preferred plants. Other options include grazing Crested wheat grass earlier and longer than normal, because it is one of the plants most tolerant of grazing.

Another option is keeping cattle on irrigated or sub-irrigated sites longer than usual. Fertilizer could be used to increase forage production on many of these sites. Fertilizer is a cash cost, however, and soils should be tested before fertilizer is applied. Fertilizer needs moisture to be available to the plant, and in times of extreme drought, this may not happen.

Initial Questions

The producers who survive best during drought are those who adopt sound management and financial plans and review them regularly. They make firm decisions, and act quickly and early.

Keep alert for opportunities such as leasing land instead of buying feed. Four factors that affect risk management during a drought include:

1. The total population of cattle in relation to feed availability,
2. How widespread the drought-area is,
3. The time of year and the likelihood of rain and return to adequate feed supplies in your area, and
4. Evaluation of cash flow needs (borrowing your way through a drought to maintain traditional herd size may inhibit long term profitability).

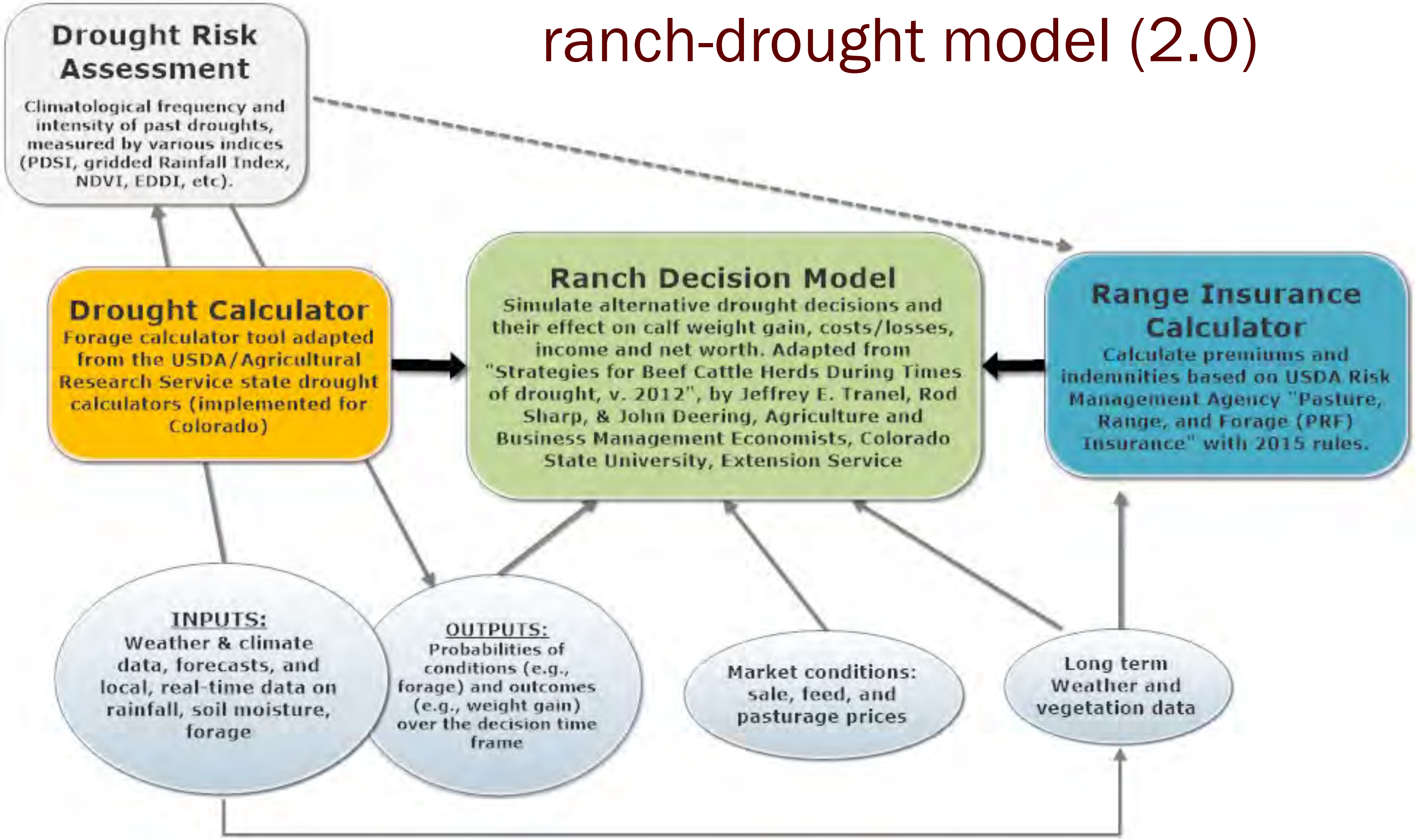
The most common advice is to make decisions earlier, more adaptive herd management and land use, reduce pressure on the range—which is good for the enterprise *and* range ecology

But what can help ranchers make this choice earlier in a drought? And what if the drought improves or abates?

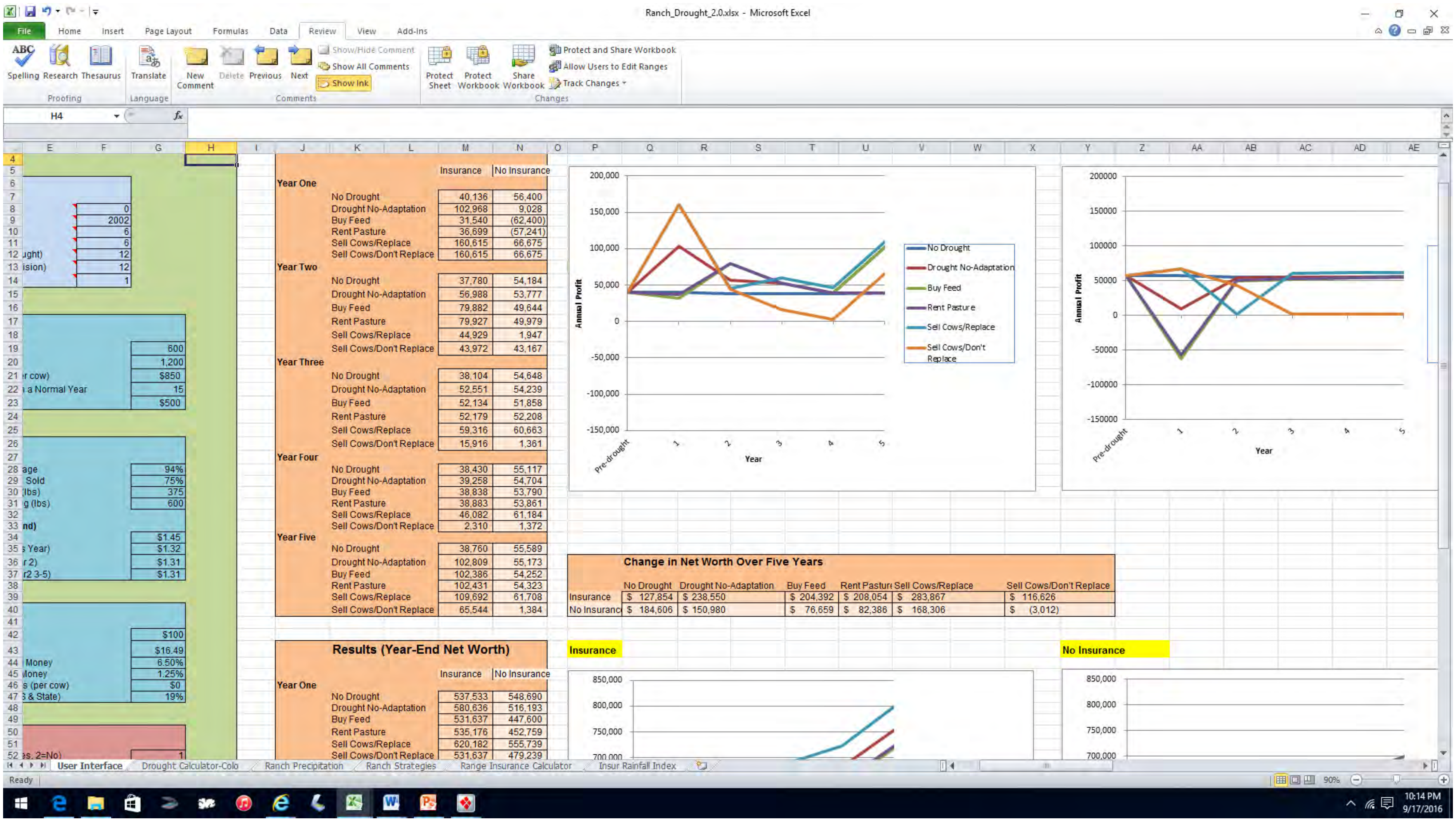
- Better information (on both climate and market responses)
- Efficient decisions and risk management (decision support)
- Risk mitigation tools (e.g., insurance)

We test these with an **integrated ranch-drought decision-model**

The structure of the current ranch-drought model (2.0)

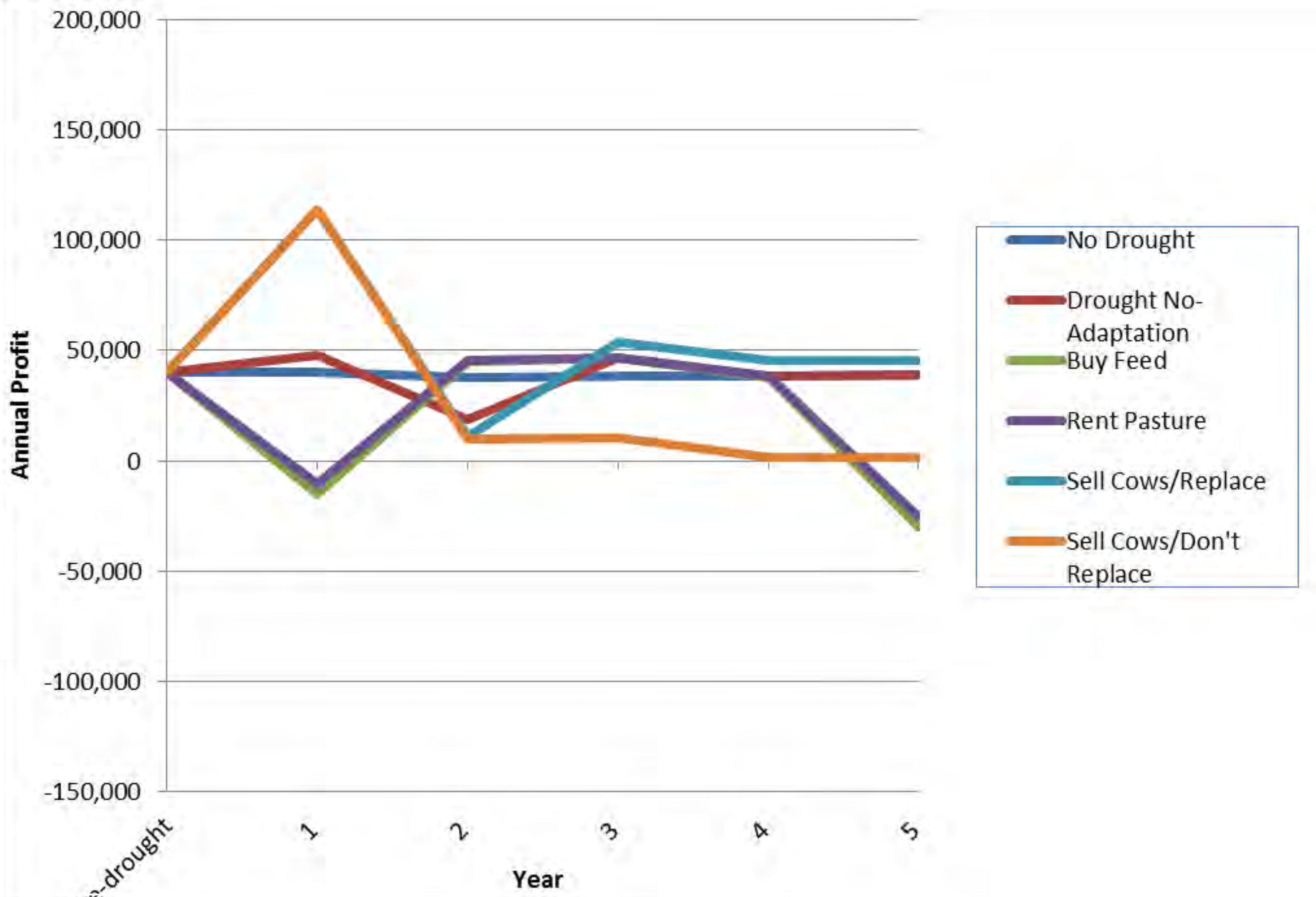


Ranch-Drought Decision Model 2.0 implemented in Excel



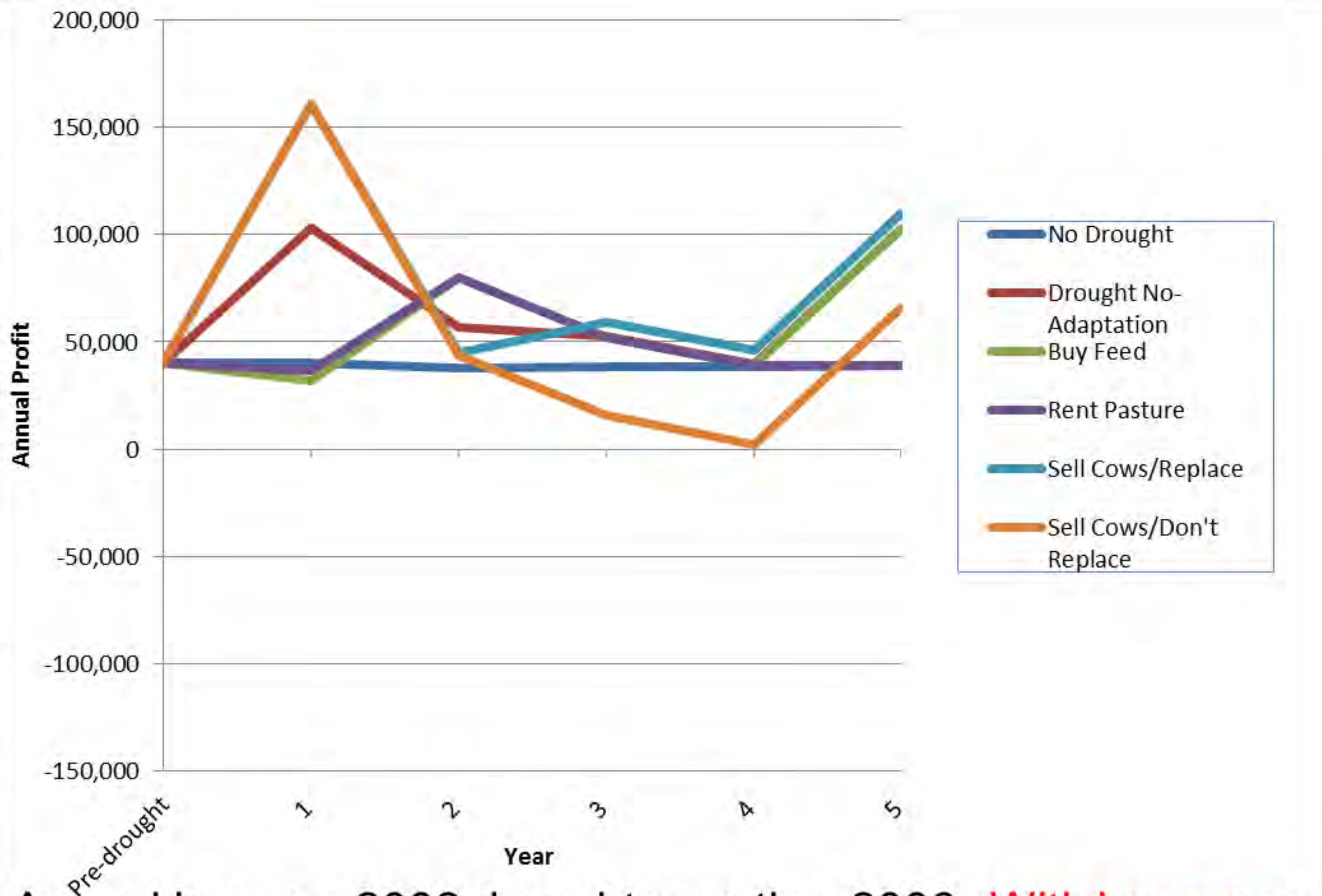
- ***R*** version with more extensive simulation being developed

Five-year runs for a 600-head cow-calf operation accessing 8,000 [insured] acres in eastern Colorado ***without*** *PRF insurance*



Annual profit 2002 drought year thru 2006---Without insurance

Five-year runs for a 600-head cow-calf operation accessing 8,000 [insured] acres in eastern Colorado ***with** PRF insurance*



Annual income, 2002 drought year thru 2006--With insurance

Ongoing and future directions

- Examine the value of additional information (VAI) in decision-making (SDO & other forecasts, alternative drought indices)
- Assess the ranch outcomes when the RMA PRF insurance payouts are pegged to different drought indices (USDM, EDDI, NDVI, etc.)
- Invite ranchers to participate in simulation experiments at CSU/NC CSC's RAM simulation studio, and in Earth Lab's visualization lab

http://wwa.colorado.edu

Potential evapotranspiration and water demand in Salt Lake Valley

Seth Arens 10/24/16

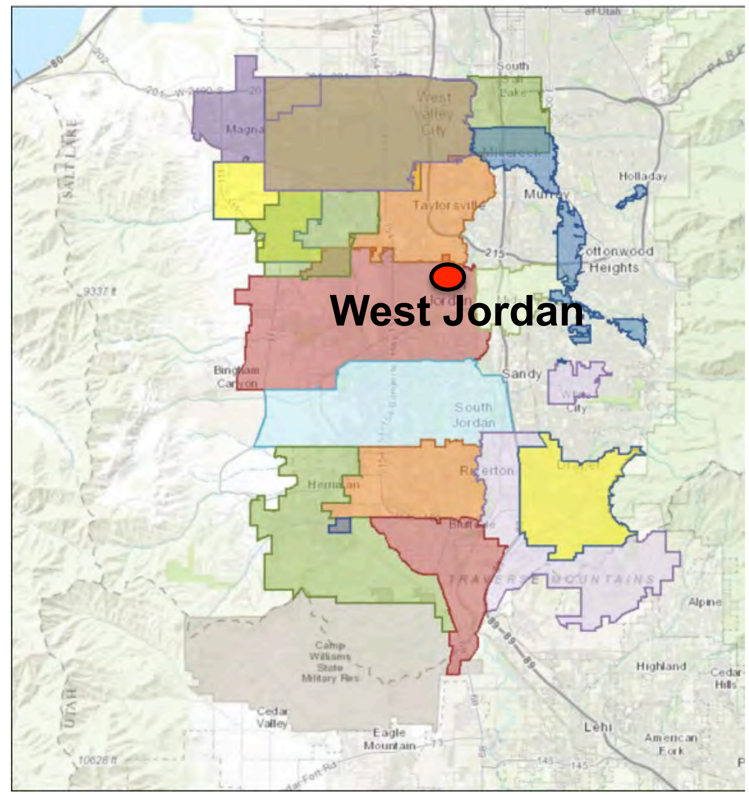
Jordan Valley Water Conservancy District (JVWCD)

- Wholesale water provider in Salt Lake County
- Sources: Provo River system, wells

How will climate change affect water demand?

Potential Evapotraspiration (PET)

- Penman-Monteith method
- Historical PET
  - Limited record length
- Projected PET
  - Downscaled climate data
  - MACA projections for West Jordan
  - 17 models
  - Historic (1950-2005)
  - RCP4.5 & 8.5 (2006-2099)



JVWCD service area

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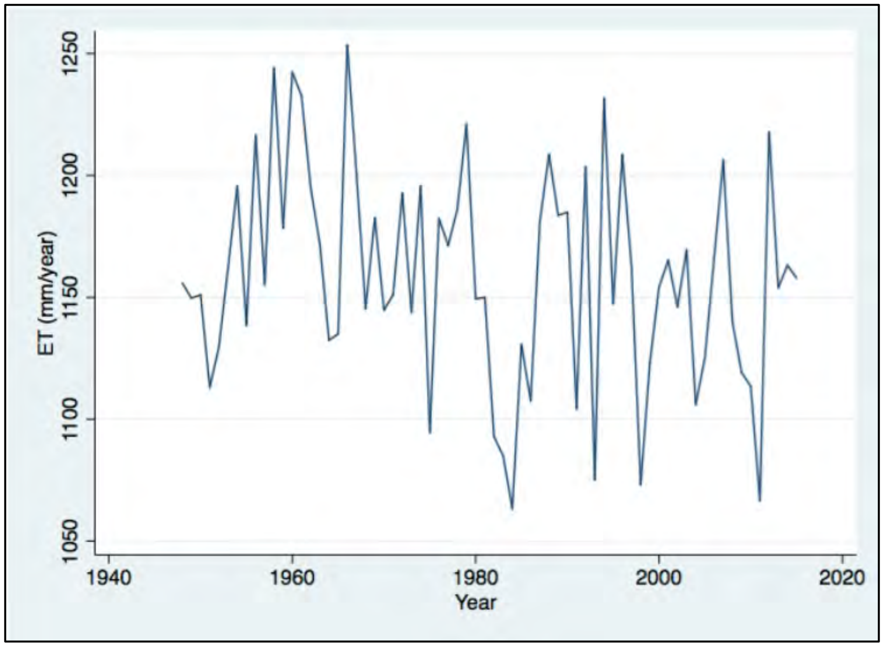
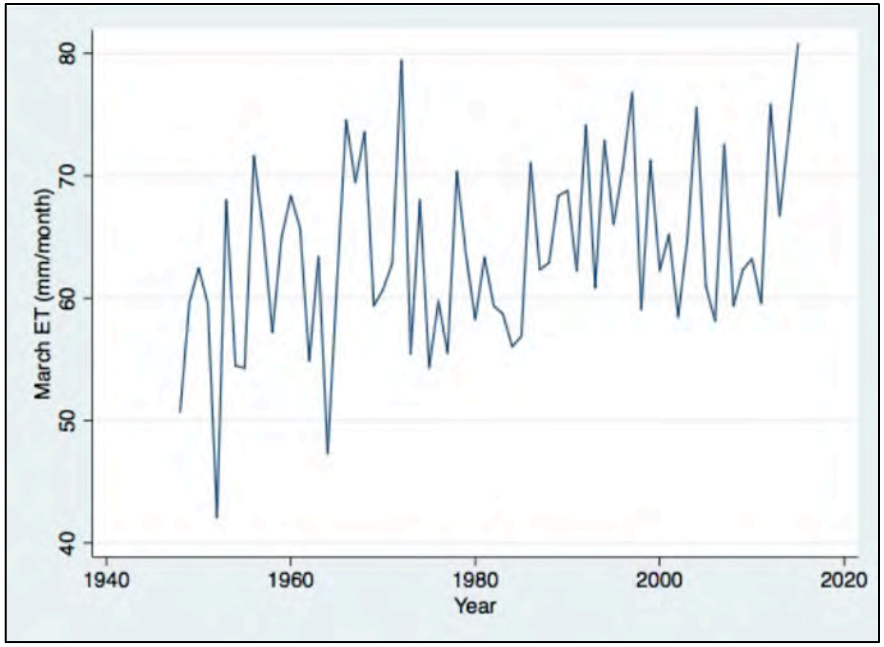
Historic evapotranspiration (ET) in Salt Lake City



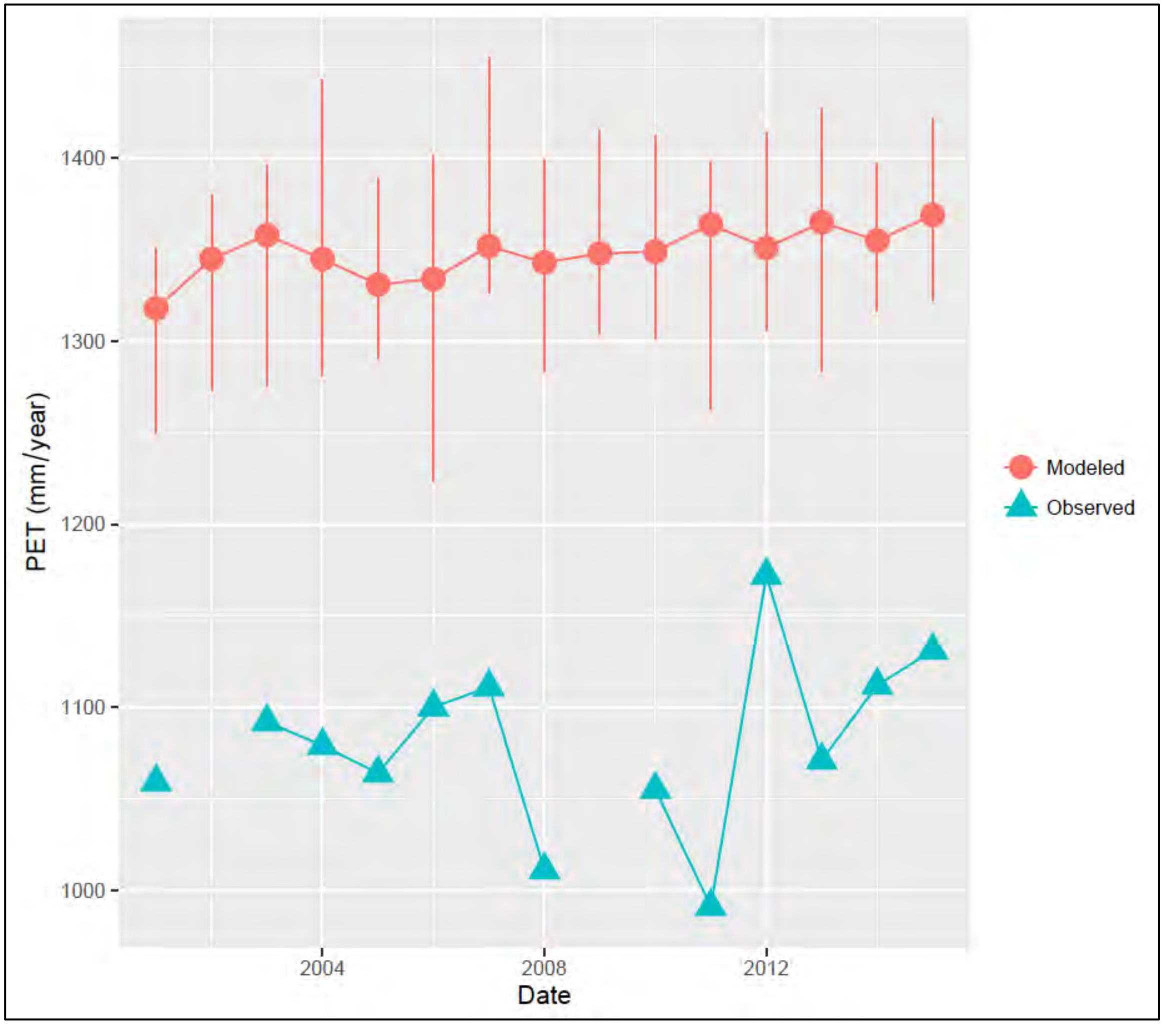
Annual ET SLC airport (1948-2015)



March ET SLC airport (1948-2015)

ET calculated using Hargreaves equation; based on max/min temperature

Observed and modeled PET

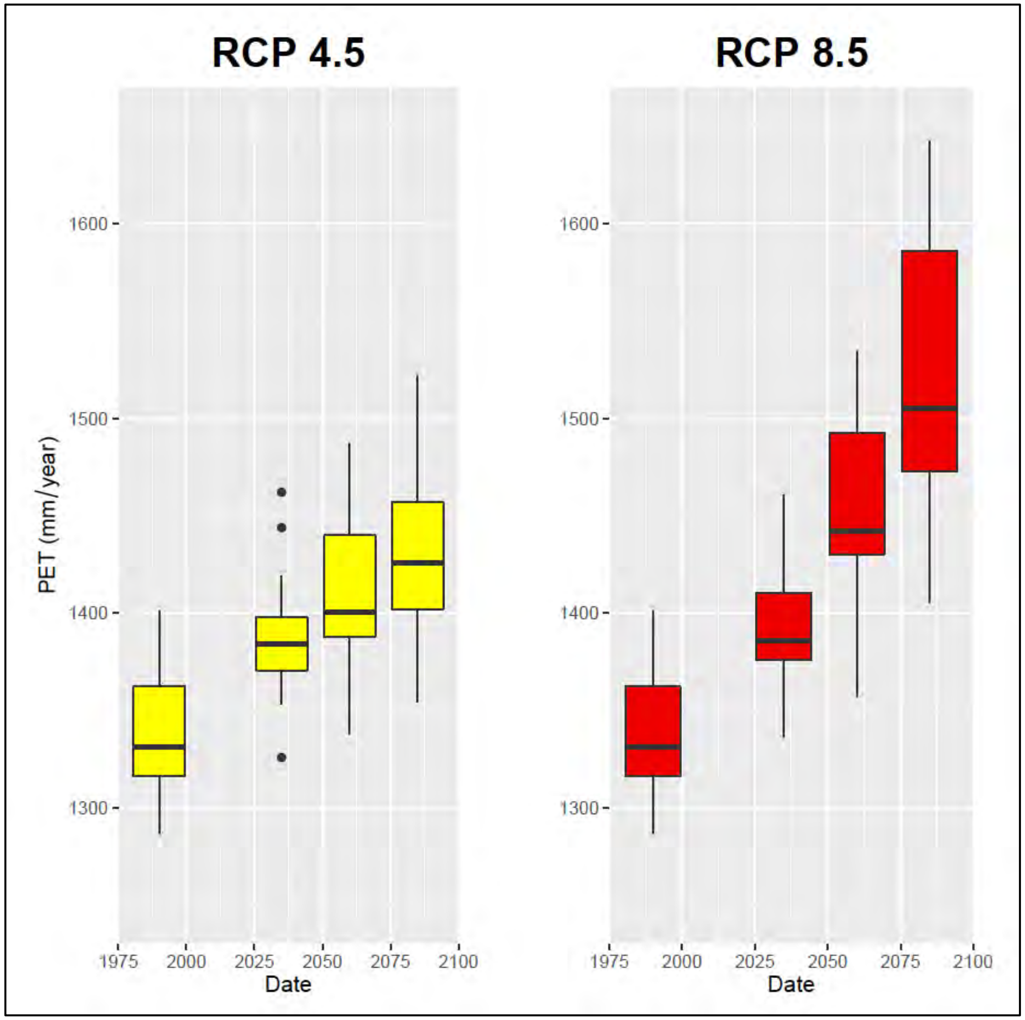


-MACA downscaled GCM dataset
-Median of 17 models

-Strong positive bias of modeled data

-Limited PET observations
-2001-2016 from University of Utah

PET Projections for West Jordan, UT



Projections are 30 year for 1990, 2035, 2060, 2085

2060

- 5.9% increase - RCP4.5
- 8.3% increase - RCP8.5

2085

- 7.1% increase - RCP4.5
- 13.1% increase - RCP8.5

WHAT DOES THIS MEAN TO WATER MANAGERS?

Taking the next steps: water demand

- PET projections must be put in context
- Build model between water demand and observed PET
- Strong correlation between PET and water demand
- Assumptions, statistics and scale

BREAK

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http://wwa.colorado.edu

Regional extreme events database and maps

Jeff Lukas, Bill Travis, Klaus Wolter, Imtiaz Rangwala, Adam McCurdy, Joe Tuccillo

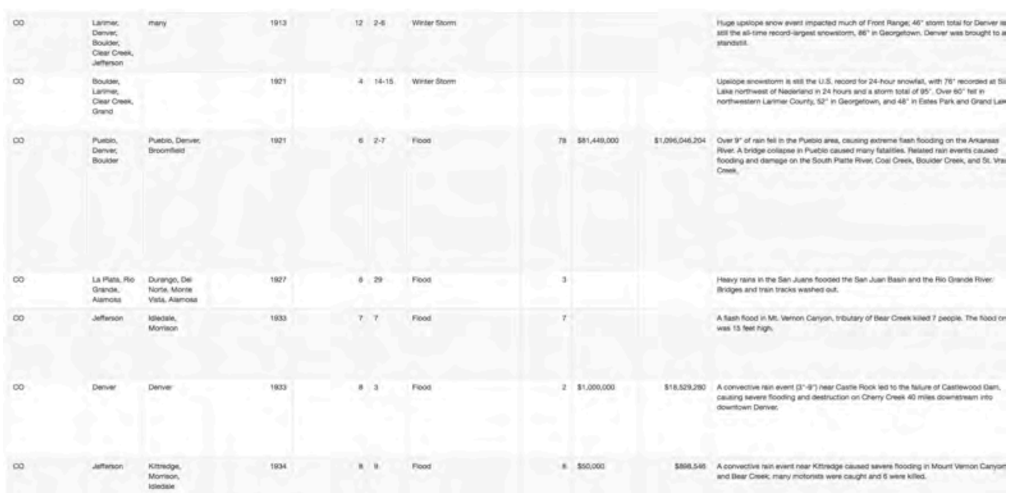
2016 WWA Stakeholder Meeting

2013 Front Range Flood: A wake-up call regarding the risk of extreme events in our region…

…and the need for more information on these events

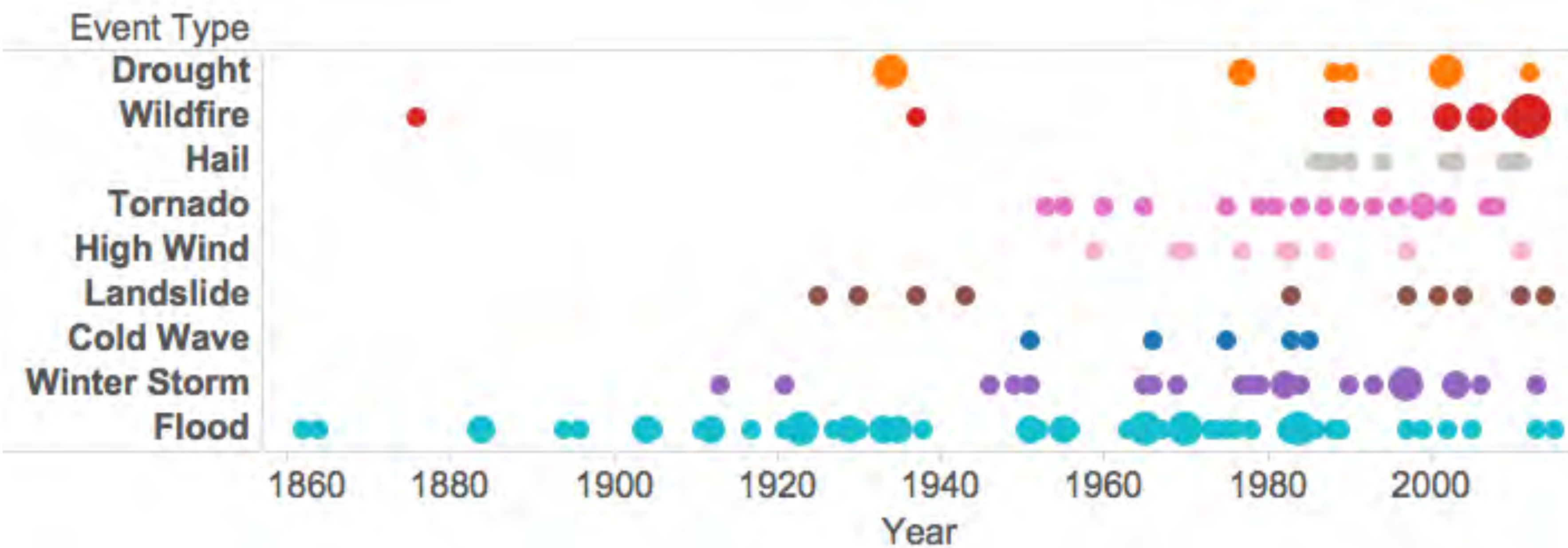
Regional Extreme Events Database

- Web-based searchable database of 160+ significant historical extreme weather/climate events in Colorado, Utah, Wyoming
- Floods, snowstorms, cold waves, droughts, wildfires, landslides, windstorms, tornadoes from 1864–2015
- Key attributes of each event plus links to resources
- http://wwa.colorado.edu/climate/extremes/database/



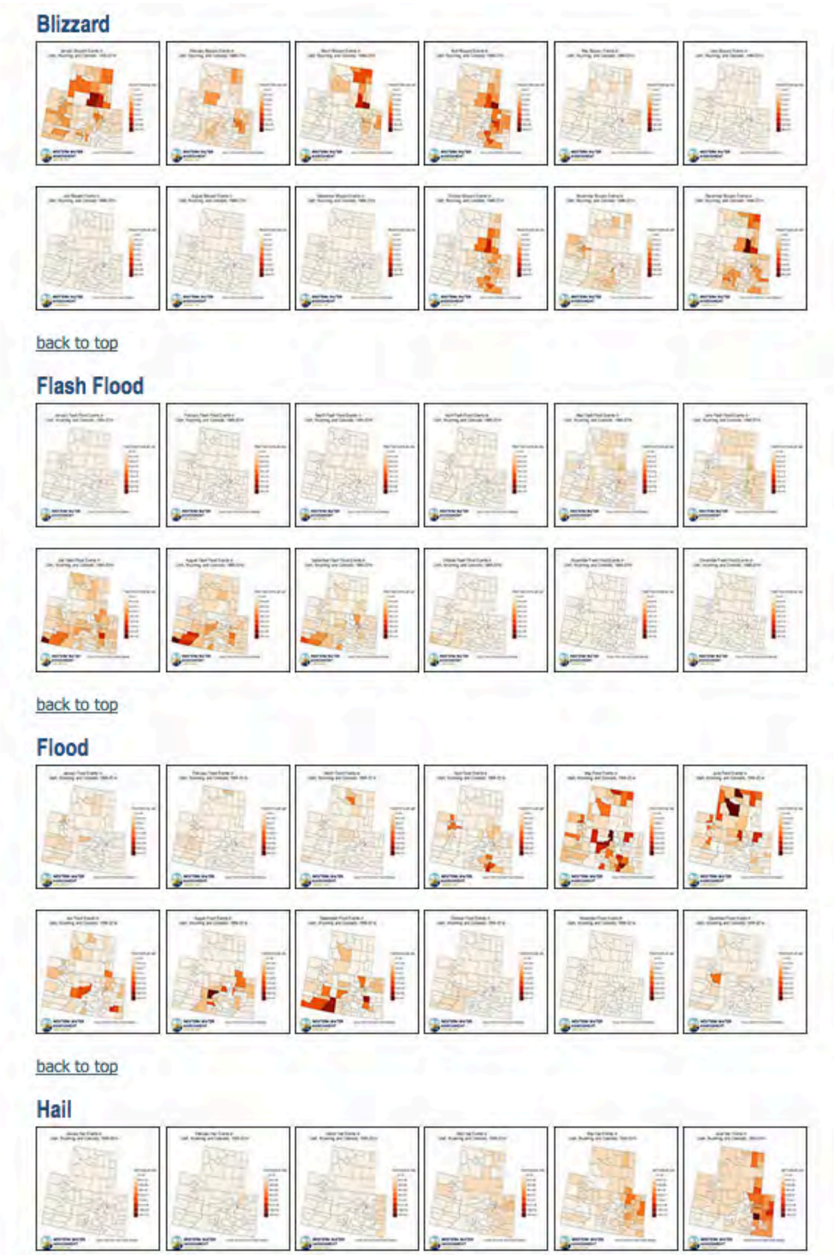
CO	Larimer, Denver, Boulder, Clear Creek, Jefferson	many	1913	12	2-6	Winter Storm				Huge upslope snow event impacted much of Front Range; 46" storm total for Denver is still the all-time record-largest snowstorm, 86" in Georgetown. Denver was brought to a standstill.
CO	Boulder, Larimer, Clear Creek, Grand		1921	4	14-15	Winter Storm				Upslope snowstorm is still the U.S. record for 24-hour snowfall, with 76" recorded at Si Lake northwest of Nederland in 24 hours and a storm total of 95". Over 60" fell in northwestern Larimer County, 52" in Georgetown, and 48" in Estes Park and Grand La
CO	Pueblo, Denver, Boulder	Pueblo, Denver, Broomfield	1921	6	2-7	Flood	78	$81,449,000	$1,096,046,204	Over 9" of rain fell in the Pueblo area, causing extreme flash flooding on the Arkansas River. A bridge collapse in Pueblo caused many fatalities. Related rain events caused flooding and damage on the South Platte River, Coal Creek, Boulder Creek, and St. Vra Creek.
CO	La Plata, Rio Grande, Alamosa	Durango, Del Norte, Monte Vista, Alamosa	1927	6	29	Flood	3			Heavy rains in the San Juans flooded the San Juan Basin and the Rio Grande River. Bridges and train tracks washed out.
CO	Jefferson	Idledale, Morrison	1933	7	7	Flood	7			A flash flood in Mt. Vernon Canyon, tributary of Bear Creek killed 7 people. The flood cr was 15 feet high.
CO	Denver	Denver	1933	8	3	Flood	2	$1,000,000	$18,529,280	A convective rain event (3"-9") near Castle Rock led to the failure of Castlewood Dam, causing severe flooding and destruction on Cherry Creek 40 miles downstream into downtown Denver.
CO	Jefferson	Kittredge, Morrison, Idledale	1934	8	9	Flood	6	$50,000	$898,546	A convective rain event near Kittredge caused severe flooding in Mount Vernon Canyon and Bear Creek; many motorists were caught and 6 were killed.

Regional Extreme Events Database



- Floods have been the most prevalent event in almost every decade since the 1860s
- Increase in most events after 1950 due to better reporting, more people and property at risk, not underlying trends in physical hazard
- Increase in wildfire events after 1985 is consistent with broader regional trends in large wildfires

Regional Significant Weather Event Maps



- Monthly occurrence maps based on NOAA Storm Events Database (>20,000 events for our region)
- Blizzard, Flash Flood, Flood, Hail, Heavy Snow, High Wind, Thunderstorm, Tornado, Wildfire, Winter Storm
- Period of record for most events: 1996-2014
- http://wwa.colorado.edu/climate/extremes/maps/

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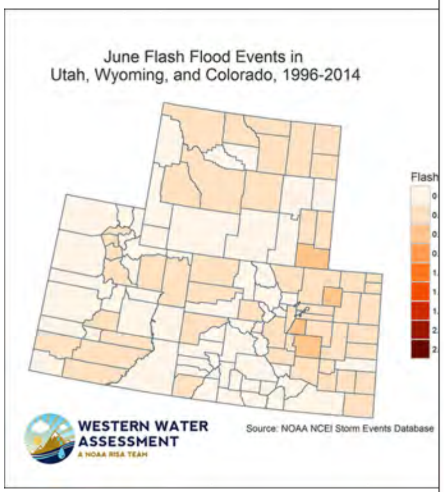
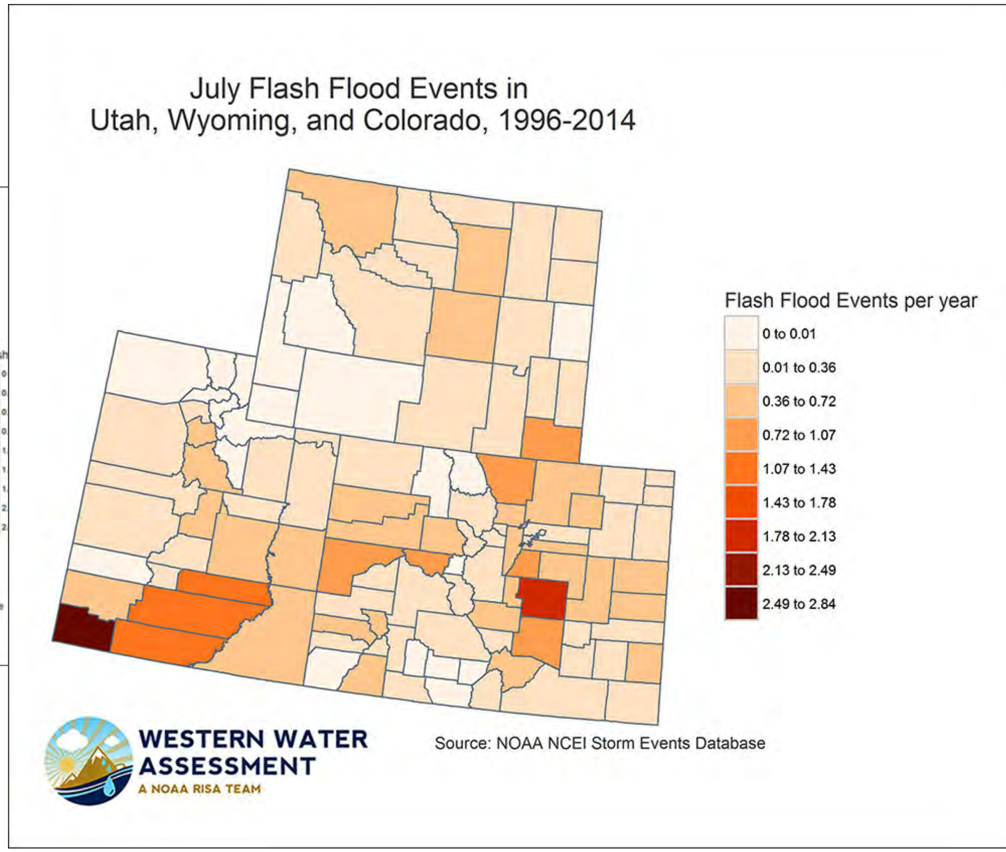
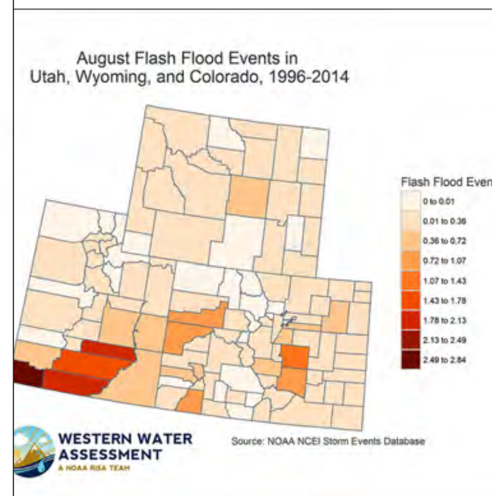
Regional Significant Weather Event Maps







- Hot spots for summer flash floods: El Paso County, CO, and Washington County, UT

Forthcoming *Extreme* products

- Summary of current and future risk from extreme precipitation events for our region

Balancing Severe Decision Conflicts under Climate Extremes in Water Resource Management

WWA Stakeholder Meeting: October 24, 2016

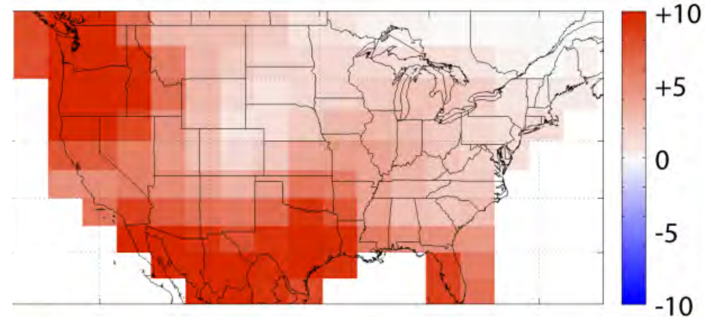
Funded by the NOAA Sectoral Applications Research Program (SARP)

PI: Lisa Dilling

Team: Joseph Kasprzyk, Imtiaz Rangwala, Eric Gordon, Kristen Averyt (CU), Laurna Kaatz (Denver Water), Leon Basdekas (formerly, Colorado Springs Utilities)

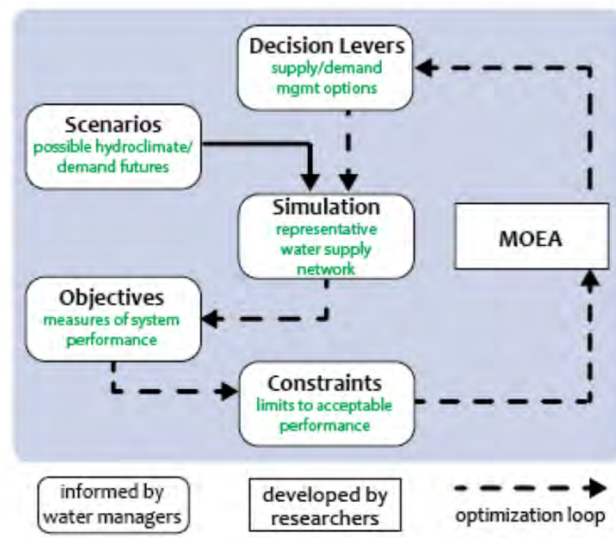
Graduate Assistant: Rebecca Smith

Motivation



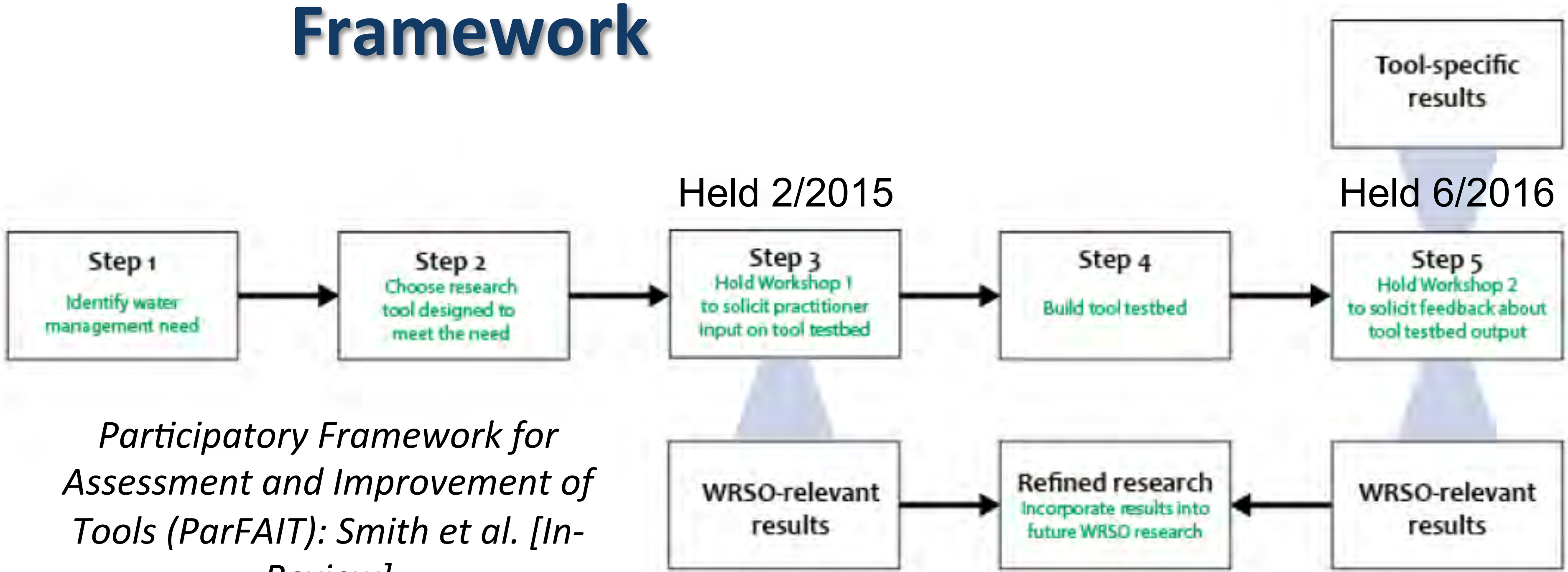
GCM ensemble estimate of change in maximum consecutive dry days per year, between 2080-2099 and 1950-2000, from Kollat et al. [2012]

- Increasing calls for decision support for climate change
- Managers are interested in new decision support tools such as multiobjective evolutionary algorithms (MOEAs), but they have not been extensively tested.
- Partnered with: Boulder, Aurora, Colorado Springs Utilities, Denver Water, Fort Collins, Northern Water
- Funding through NOAA Sectoral Applications Research Program



MOEA search loop, from Smith et al [In-Review]

Framework



Participatory Framework for Assessment and Improvement of Tools (ParFAIT): Smith et al. [In-Review]

*WRSO: Water Resources Systems Optimization

Goals:

(i) design an MOEA testbed

(ii) assess how MOEA results might contribute to long-term planning

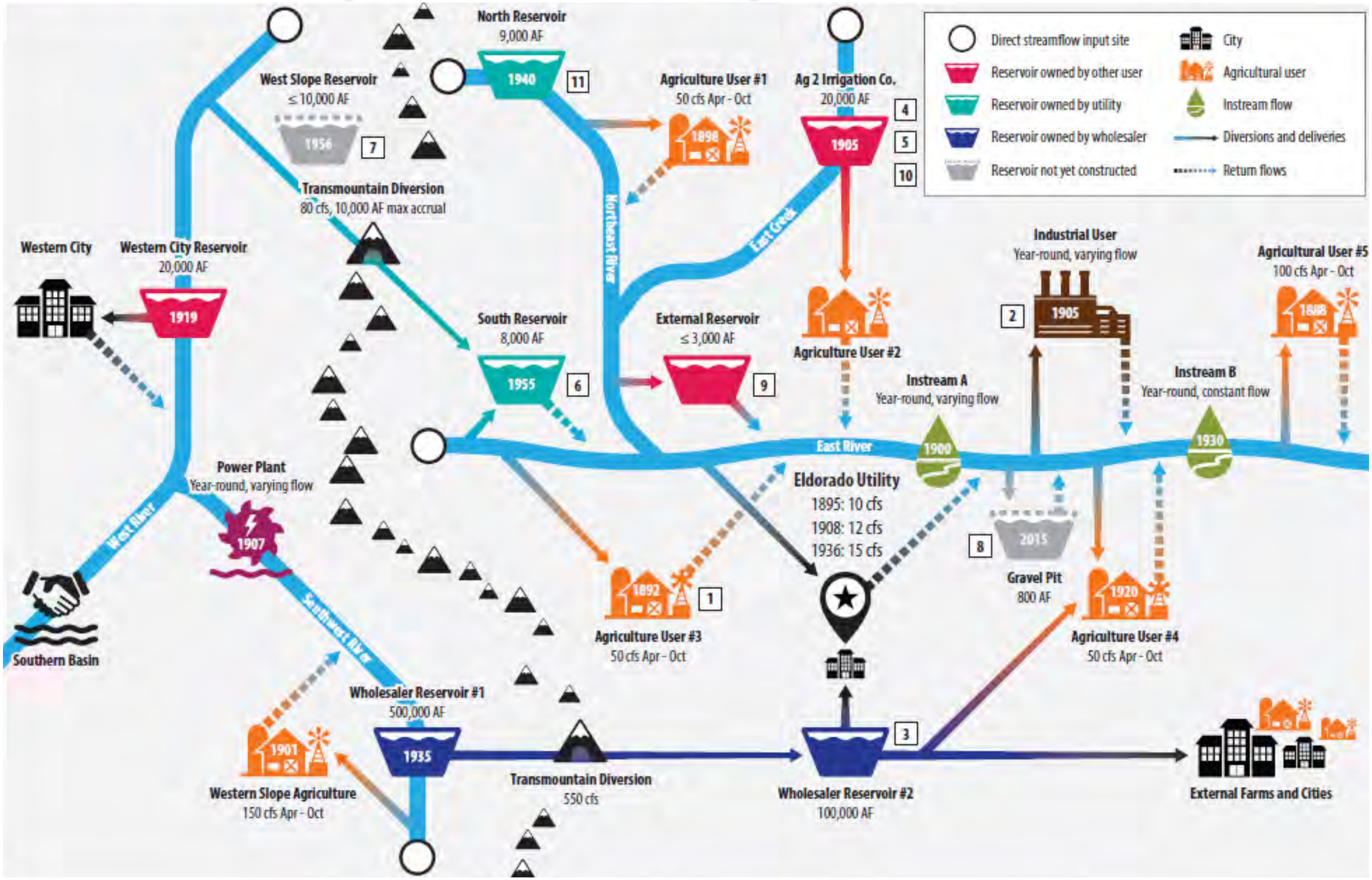
(iii) foster research to improve relevance of MOEA research

MOEA Problem Formulation

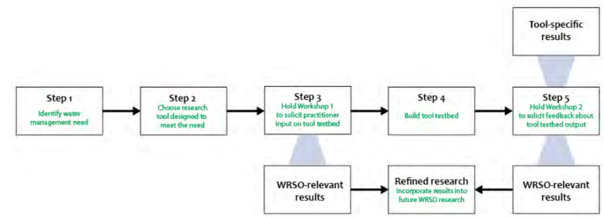
Decision Levers					Objectives	
Supply				Demand	Reliability	Other
add supply	add infrastructure	manage supply	manage system	change restriction triggers change building codes increase xeric landscaping expand conservation education	minimize time or frequency of certain restrictions? maintain certain level of storage? maintain storage to weather certain level of drought?	minimize cost??? minimize spill maximize fill minimize pumping/GHG maximize resilience* minimize vulnerability*
senior rights wholesaler shares lease water interruptible supply agreement	build or expand reservoir build gravel pits build aquifer storage add redundancy	increase carryover storage expand or implement reuse	fix leaks line canals improve watershed alter pumping			

Constraints			
	meet 100% indoor demand	environmental obligations	no stranded assets

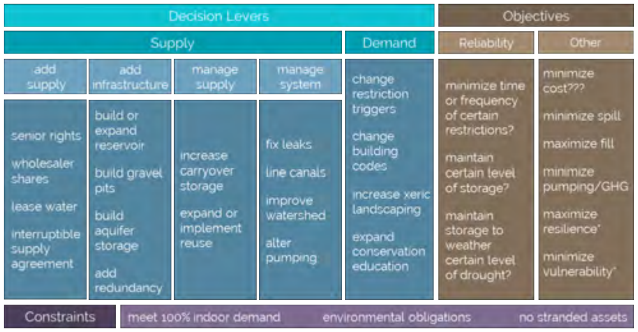
Representative System Model

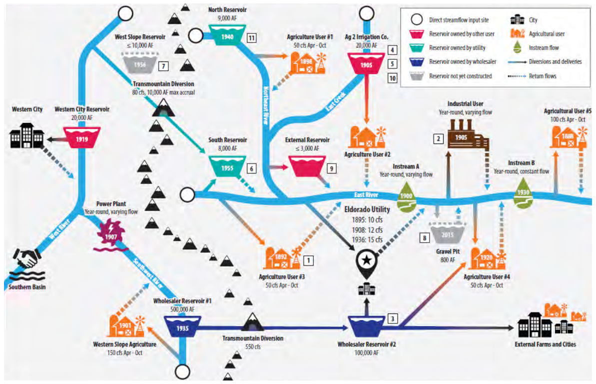


Conclusions



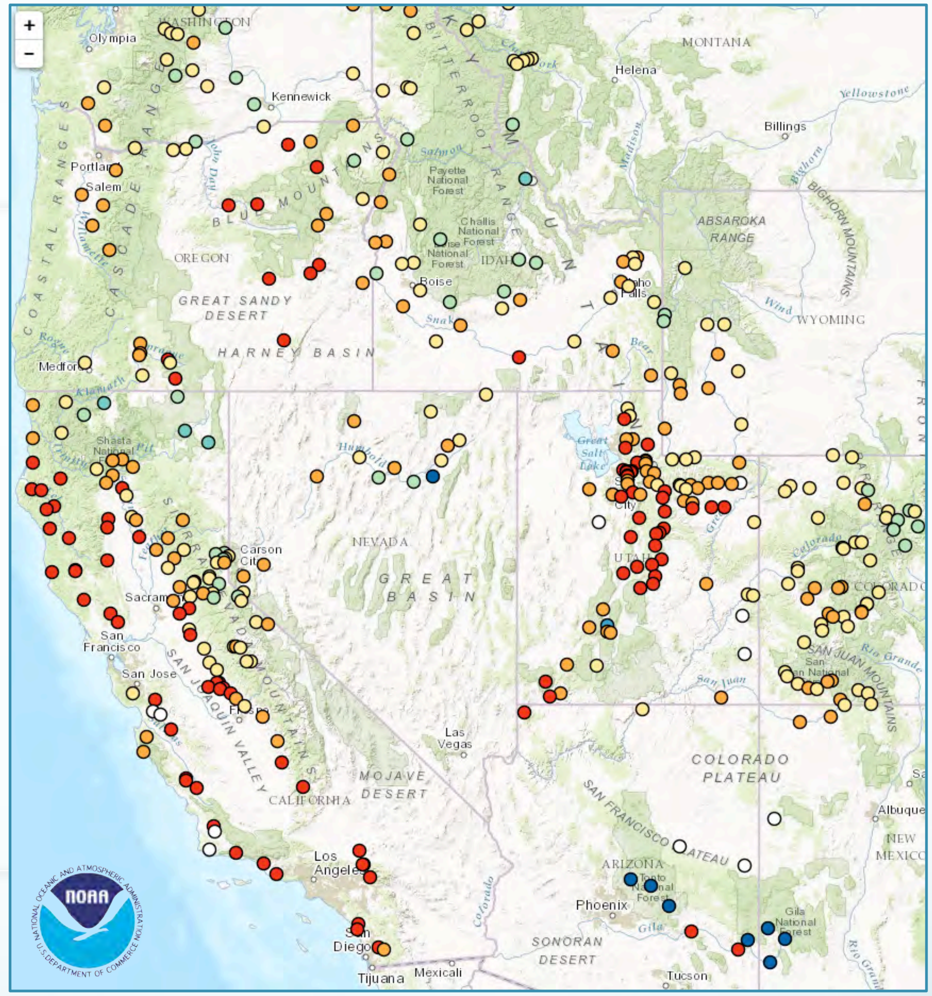
- **Applying** ideas of co-production into decision support research, assessing and improving our tools
- **Guidance** for formulating problems for multi-objective decision support (e.g., focus on reliability as performance metric)
- Providing new infrastructure for continued collaboration: **representative** model of Colorado can be used for education, training
- **Publications:** reports, journal articles, conference presentations (AGU 2016)





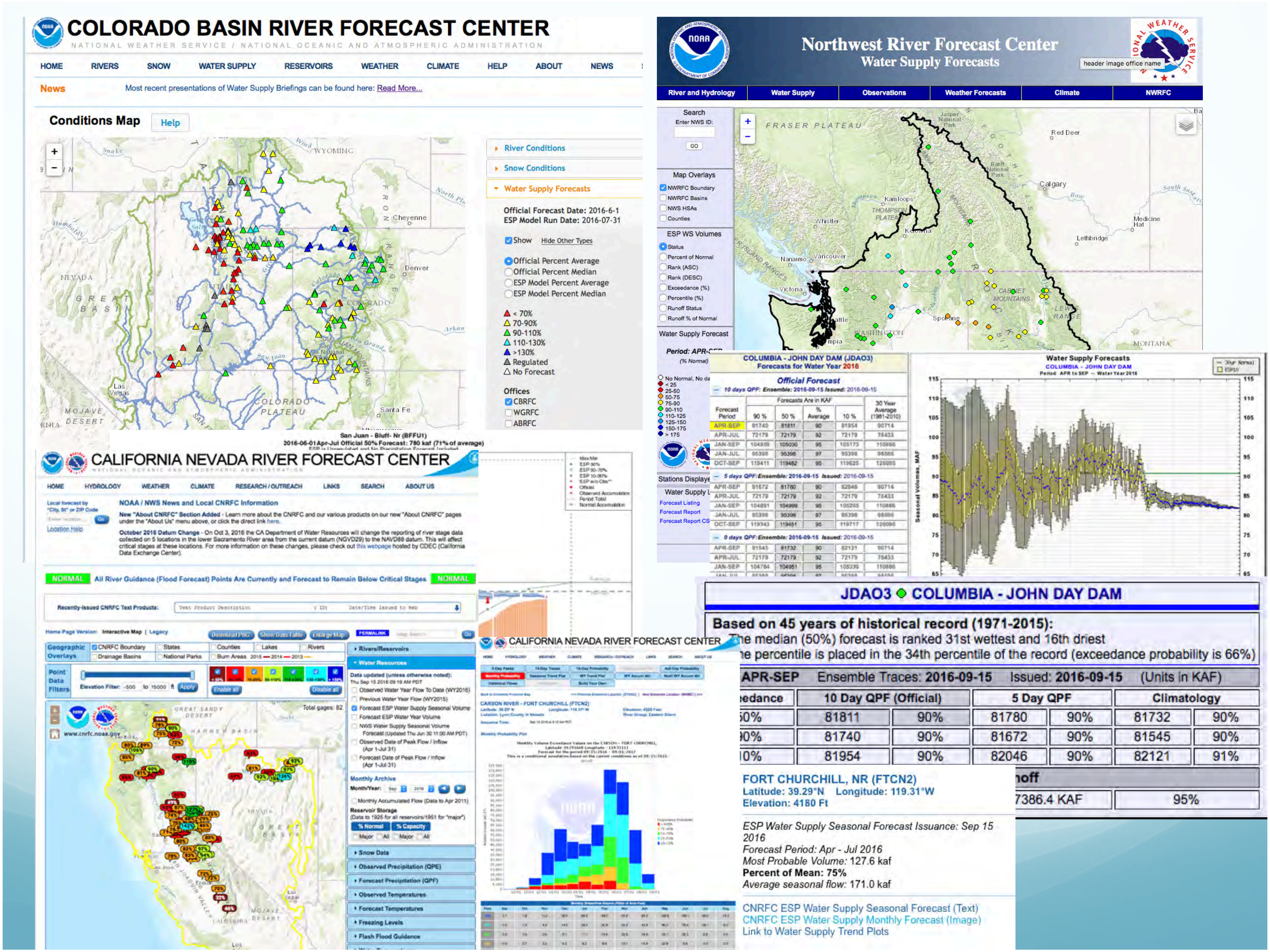
Water Resources Monitoring and Outlook

Andrea J. Ray, NOAA/ESRL Physical Sciences Division, Michelle Stokes, NOAA Colorado Basin River Forecast Center

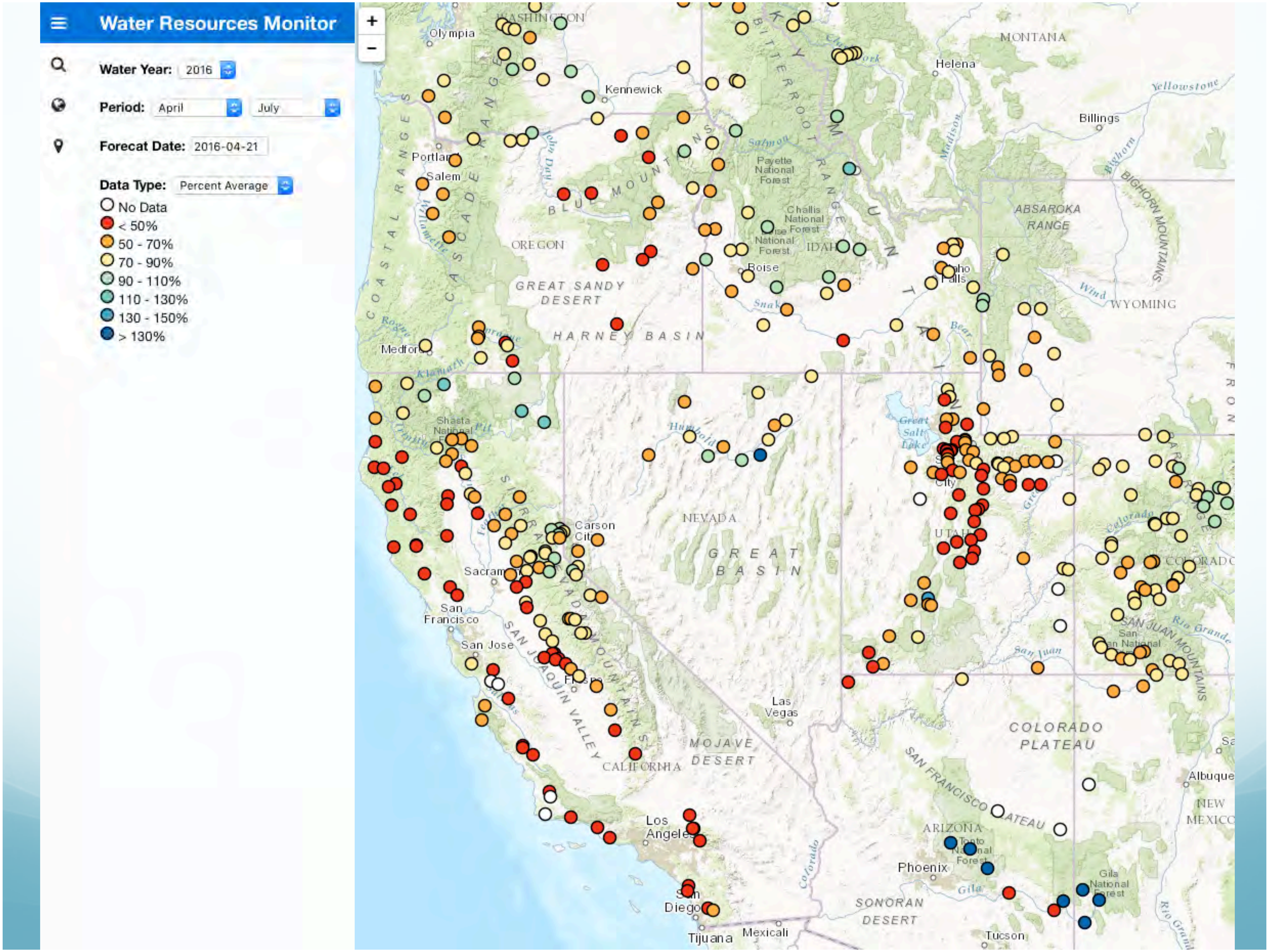


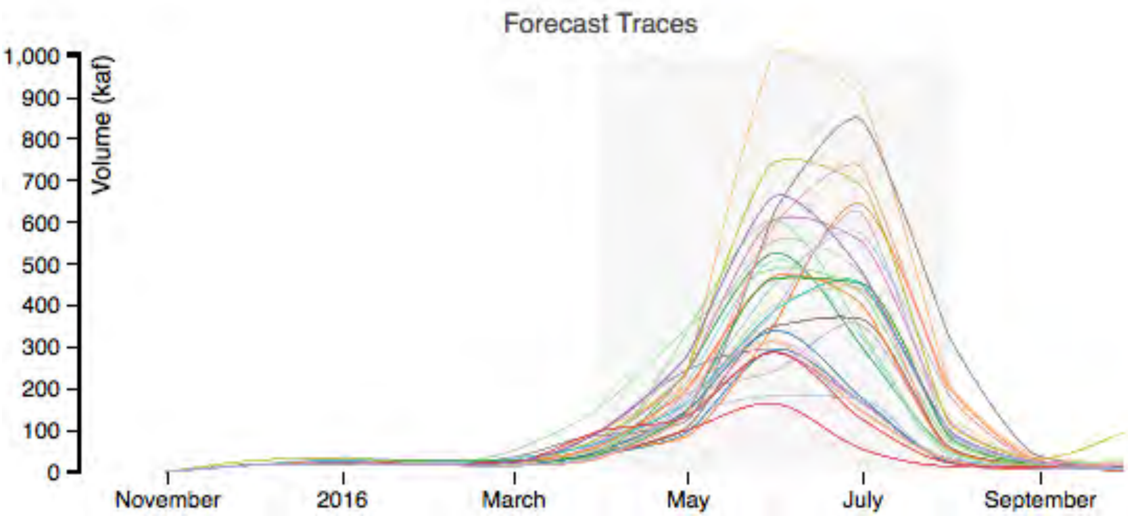
- Case for the WRMO
- WRMO prototype demo
- Future enhancements to the WRMO
- Feedback

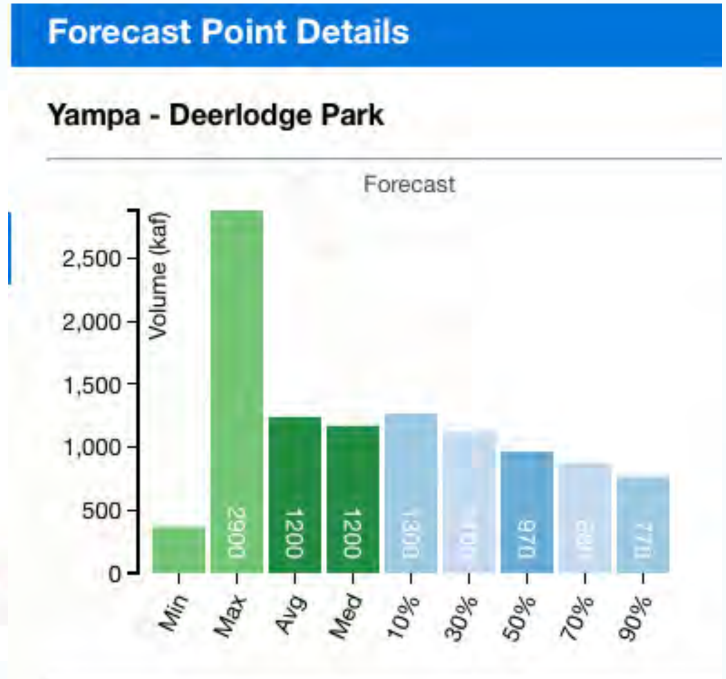
For more info: CBRFC.noaa.gov/WRMO, prototype also will be available in late 2016

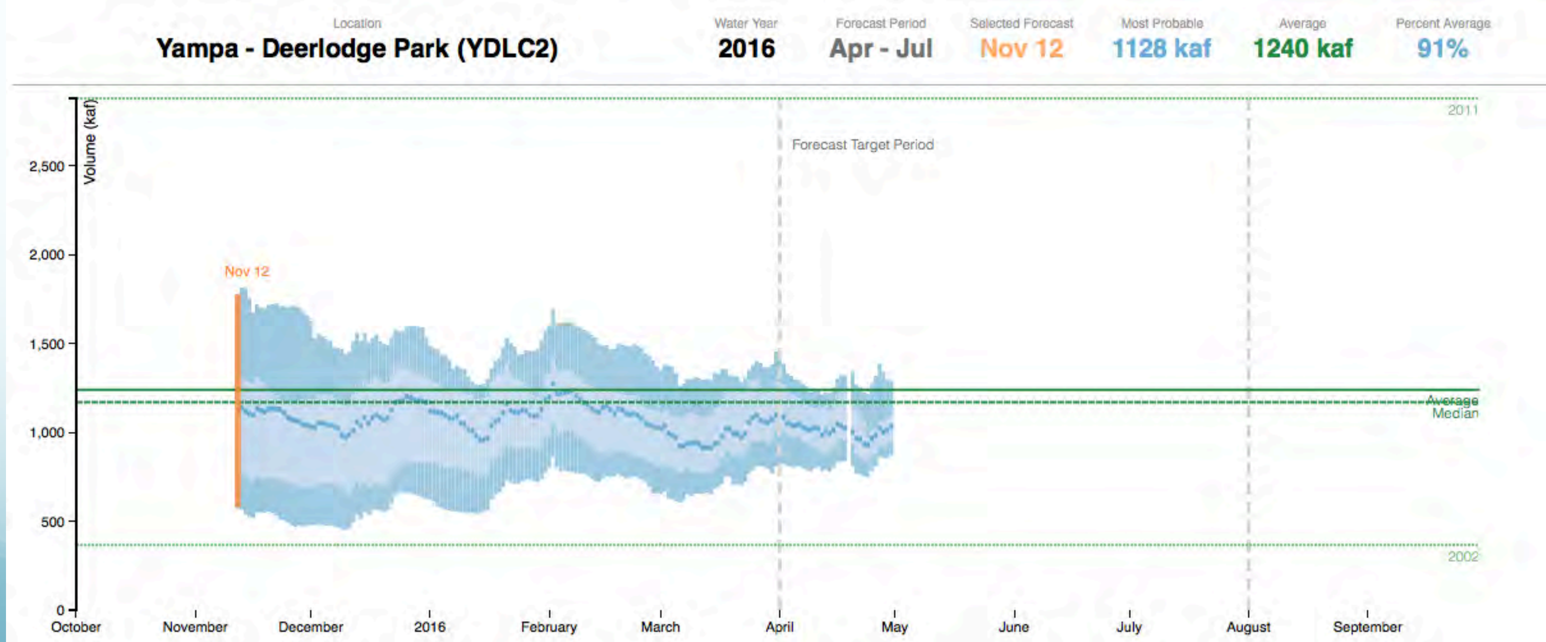


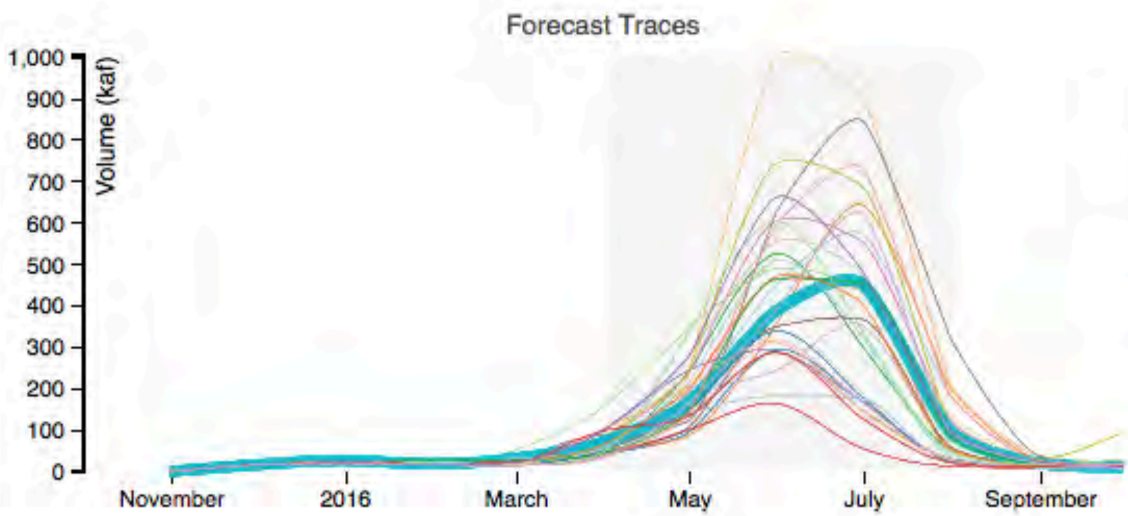
COLORADO BASIN RIVER FORECAST CENTER
NATIONAL WEATHER SERVICE / NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
HOME RIVERS SNOW WATER SUPPLY RESERVOIRS WEATHER CLIMATE HELP ABOUT NEWS
News
Most recent presentations of Water Supply Briefings can be found here: Read More...
Conditions Map
Help
River Conditions
Snow Conditions
Water Supply Forecasts
Official Forecast Date: 2016-6-1
ESP Model Run Date: 2016-07-31
Show
Hide Other Types
Official Percent Average
Official Percent Median
ESP Model Percent Average
ESP Model Percent Median
< 70%
70-90%
90-110%
110-130%
>130%
Regulated
No Forecast
Offices
CBRFC
WGRFC
ABRFC
San Juan - Bluff- Nr (BFFU1)
2016-06-01 Apr-Jul Official 50% Forecast: 780 kaf (71% of average)
Northwest River Forecast Center
Water Supply Forecasts
River and Hydrology
Water Supply
Observations
Weather Forecasts
Climate
NWRFC
Search
Enter NWS ID:
GO
Map Overlays
NWRFC Boundary
NWRFC Basins
NWS HSAs
Counties
ESP WS Volumes
Status
Percent of Normal
Rank (ASC)
Rank (DESC)
Exceedance (%)
Percentile (%)
Runoff Status
Runoff % of Normal
Water Supply Forecast
COLUMBIA - JOHN DAY DAM (JDAO3)
Forecasts for Water Year 2016
Official Forecast
Water Supply Forecasts
COLUMBIA - JOHN DAY DAM
Seasonal Volumes, MAF
CALIFORNIA NEVADA RIVER FORECAST CENTER
HOME HYDROLOGY WEATHER CLIMATE RESEARCH / OUTREACH LINKS SEARCH ABOUT US
NOAA / NWS News and Local CNRFC Information
NORMAL
All River Guidance (Flood Forecast) Points Are Currently and Forecast to Remain Below Critical Stages
NORMAL
Recently-Issued CNRFC Text Products:
Rivers/Reservoirs
Water Resources
Snow Data
Observed Precipitation (QPE)
Forecast Precipitation (QPF)
Observed Temperatures
Forecast Temperatures
Freezing Levels
Flash Flood Guidance
CALIFORNIA NEVADA RIVER FORECAST CENTER
CARSON RIVER - FORT CHURCHILL (FTCN2)
JDAO3 COLUMBIA - JOHN DAY DAM
Based on 45 years of historical record (1971-2015):
The median (50%) forecast is ranked 31st wettest and 16th driest
The percentile is placed in the 34th percentile of the record (exceedance probability is 66%)
APR-SEP Ensemble Traces: 2016-09-15 Issued: 2016-09-15 (Units in KAF)
10 Day QPF (Official)
5 Day QPF
Climatology
81811 90% 81780 90% 81732 90%
81740 90% 81672 90% 81545 90%
81954 90% 82046 90% 82121 91%
7386.4 KAF 95%
FORT CHURCHILL, NR (FTCN2)
Latitude: 39.29°N Longitude: 119.31°W
Elevation: 4180 Ft
ESP Water Supply Seasonal Forecast Issuance: Sep 15 2016
Forecast Period: Apr - Jul 2016
Most Probable Volume: 127.6 kaf
Percent of Mean: 75%
Average seasonal flow: 171.0 kaf
CNRFC ESP Water Supply Seasonal Forecast (Text)
CNRFC ESP Water Supply Monthly Forecast (Image)
Link to Water Supply Trend Plots

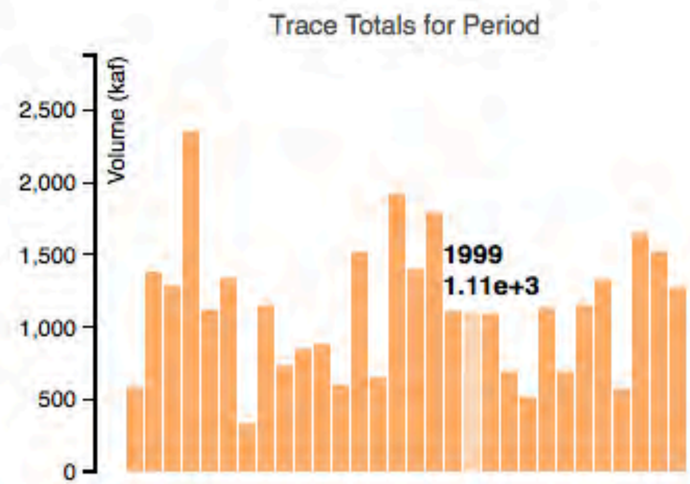

Water Resources Monitor
Water Year: 2016
Period: April July
Forecast Date: 2016-04-21
Data Type: Percent Average
No Data
< 50%
50 - 70%
70 - 90%
90 - 110%
110 - 130%
130 - 150%
> 130%
WASHINGTON
OREGON
IDAHO
MONTANA
WYOMING
NEVADA
UTAH
CALIFORNIA
ARIZONA
GREAT SANDY DESERT
HARNEY BASIN
GREAT BASIN
MOJAVE DESERT
SONORAN DESERT
COLORADO PLATEAU
Olympia
Portland
Salem
Medford
Kennewick
Boise
Helena
Billings
Carson City
Sacramento
San Francisco
San Jose
Las Vegas
Los Angeles
San Diego
Tijuana
Mexicali
Phoenix
Tucson


Forecast Traces
Volume (kaf)
1,000
900
800
700
600
500
400
300
200
100
0
November
2016
March
May
July
September


Forecast Point Details
Yampa - Deerlodge Park
Forecast
Volume (kaf)
2,500
2,000
1,500
1,000
500
0
2900
1200
1200
970
Min
Max
Avg
Med
10%
30%
50%
70%
90%


Location
Yampa - Deerlodge Park (YDLC2)
Water Year
2016
Forecast Period
Apr - Jul
Selected Forecast
Nov 12
Most Probable
1128 kaf
Average
1240 kaf
Percent Average
91%
Volume (kaf)
2,500
2,000
1,500
1,000
500
0
Forecast Target Period
Nov 12
2011
Average
Median
2002
October
November
December
2016
February
March
April
May
June
July
August
September


Forecast Traces
Volume (kaf)
1,000
900
800
700
600
500
400
300
200
100
0
November
2016
March
May
July
September


Trace Totals for Period
Volume (kaf)
2,500
2,000
1,500
1,000
500
0
1999
1.11e+3

Benefits & upcoming features of WRMO

Benefits:

- One location for all forecasts westwide, eventually nationally
- Based on user needs & feedback, including User defined periods, more flexibility
- Updated daily

Upcoming Features:

Supporting data:

- Snow information (observed)
- Soil moisture information
- Temperature and precipitation
- Reservoir conditions

- Documentation & user guide
- Verification information
- Climate outlooks: NOAA CPC week 3-4, monthly, seasonal outlooks
- Seasonal water outlook envisioned based on CPC outlooks and other analysis

For more info: CBRFC.noaa.gov/WRMO, prototype will be available in late 2016

http://wwa.colorado.edu

Mapping Climate Services

Elizabeth McNie
Western Water Assessment
October 24, 2016

Background

- Co-PI: Alison Meadow, U. Arizona, Institute of the Environment
- Sponsor: Kevin Werner/Timi Vann; NOAA West Management Team
- Goal: Characterize climate-services research in NOAA west region
  - Create usable data base
  - Identify patterns and gaps in services
  - Help to close gaps
  - Inform allocation of resources

- What are climate services?
  - AMS (2015) definition:

    Scientifically based information and products that enhance users' knowledge and understanding about the impacts of climate on their decisions and actions.
- Included: public sector, NGO, academic, within NOAA west or providing services to region
- Not included: private, consulting, organizations that do not provide services on an ongoing basis (no one-shot wonders)

- Phase I: Design search strategies, criteria for inclusion
- Phase II: Build database
- Phase III: Vet database with organizations identified in database
  - Right sectors?
  - Right services?
- Phase IV: Analyze findings
  - Identify patterns, gaps, opportunities

Information Collected

- Service provider information
- Provider level
- Funding source
- Sectors served
- Scales served
- Services provided
- Stakeholders served

Information Collected

- Service provider information
- Provider level
- Funding source
- Sectors served
- Scales served
- Services provided
- Stakeholders served

Name
Mission
Location
Director
Contact Info
Web Page
States Served

Information Collected

- Service provider information
- Provider level
- Funding source
- Sectors served
- Scales served
- Services provided
- Stakeholders served

Federal
State
County
Municipality
NGO
University
Federal-University
State-University

Information Collected

- Service provider information
- Provider level
- **Funding source** → Agency / Program Office
- Sectors served
- Scales served
- Services provided
- Stakeholders served

Information Collected

- Service provider information
- Provider level
- Funding source
- **Sectors served**
- Scales served
- Services provided
- Stakeholders served

Agriculture
Climate & Weather
Drought
Economics
Ecosystems
Energy
Extreme Events,
Forests
Geochemical Cycles
Human Health
Indigenous Peoples
Land Use, Land Cover
Oceans, Coasts
Rural Communities
Social
Transportation
Urban
Water
Wildfire
Other

Information Collected

- Service provider information
- Provider level
- Funding source
- Sectors served
- **Scales served**
- Services provided
- Stakeholders served

International
National
Regional
Tribal
State
Municipal

Information Collected

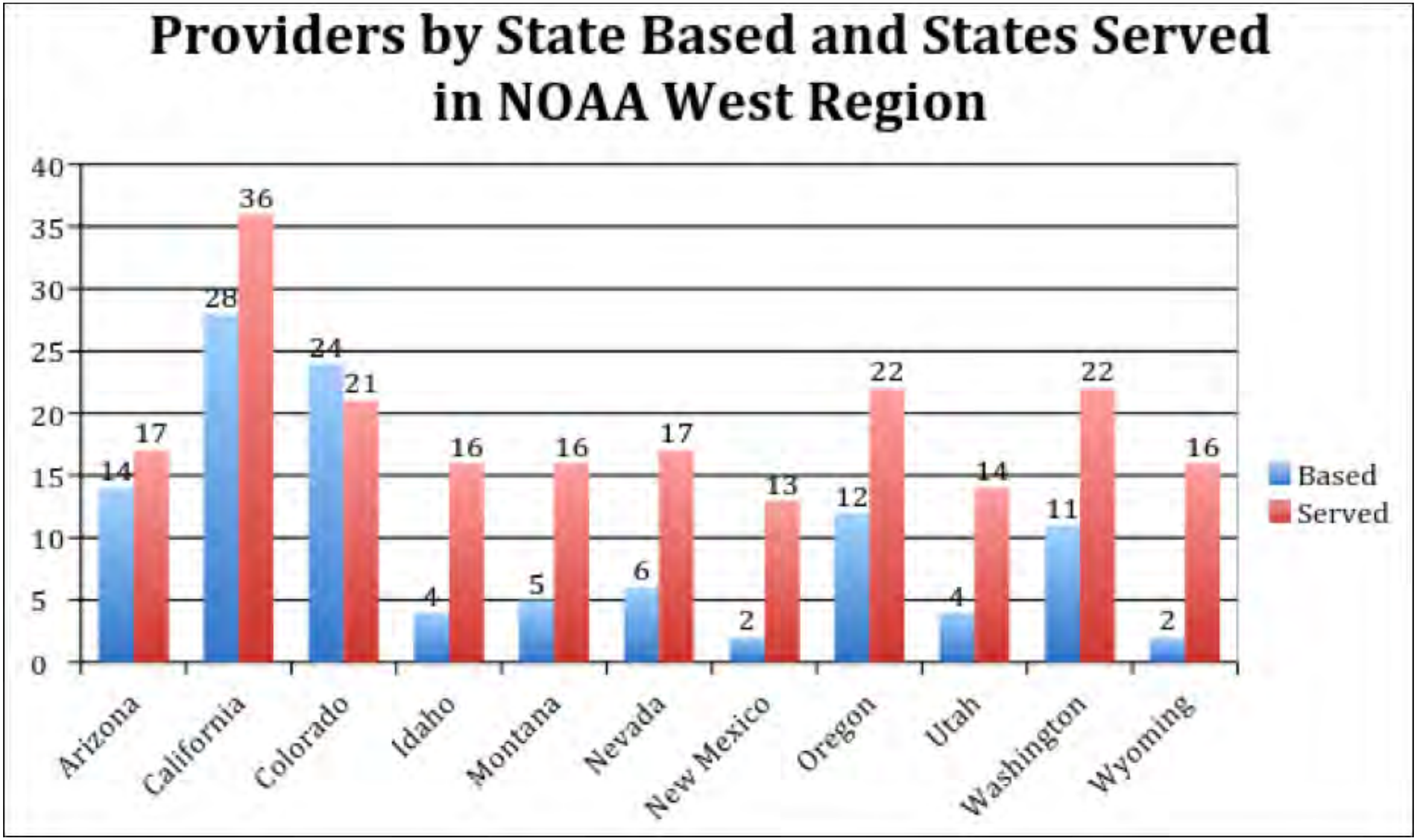
- Service provider information
- Provider level
- Funding source
- Sectors served
- Scales served
- **Services provided** →
- Stakeholders served

Convening
Coordination
Data
Decision-Support Tools
Monitoring and Evaluation
Newsletters
Peer-Reviewed Pubs
Presentations
Reports/White Papers
Scenarios/Models
Training and Education
Vulnerability Assessments
Webinars
Workshops

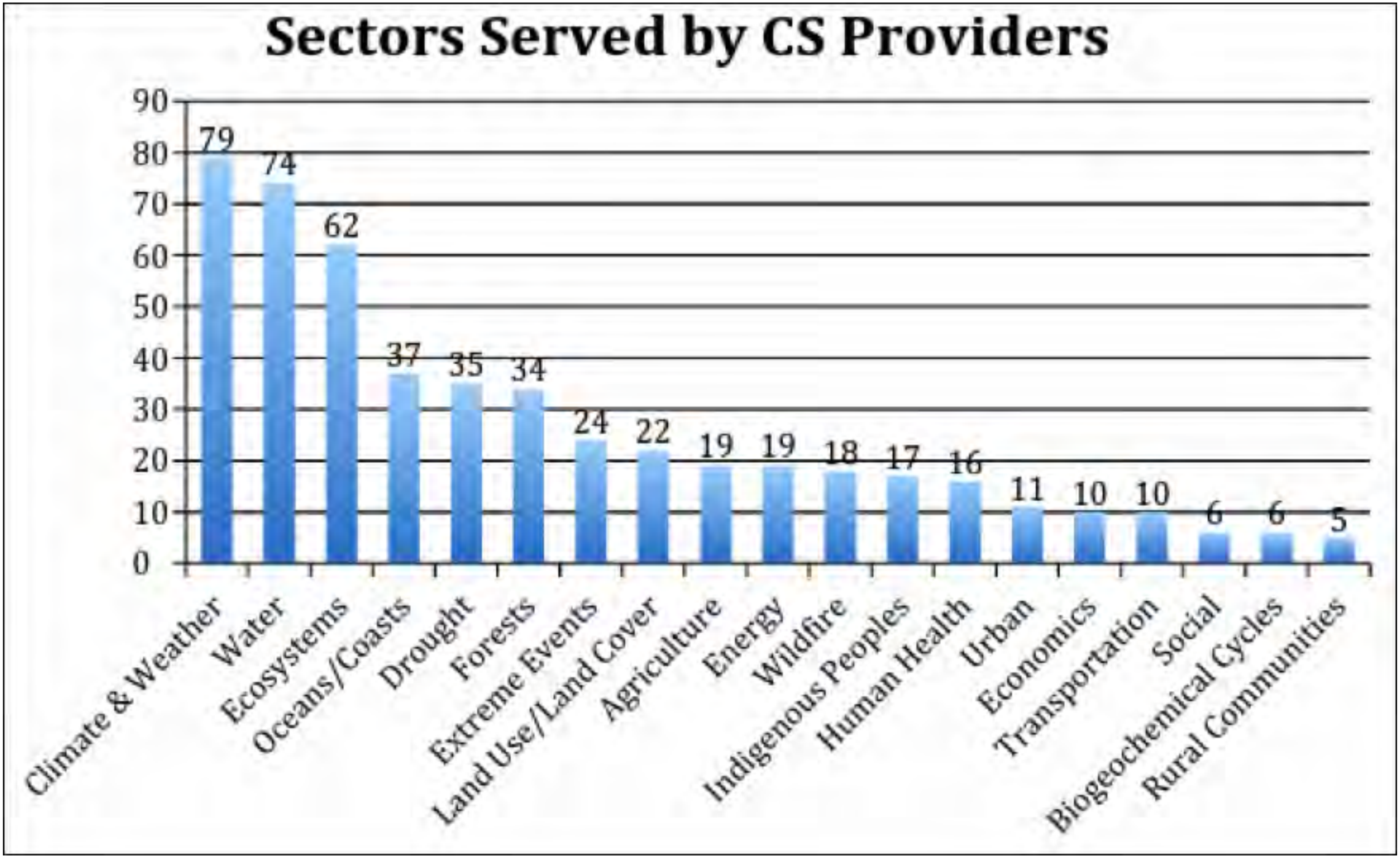
Information Collected

- Service provider information
- Provider level
- Funding source
- Sectors served
- Scales served
- Services provided
- Stakeholders served

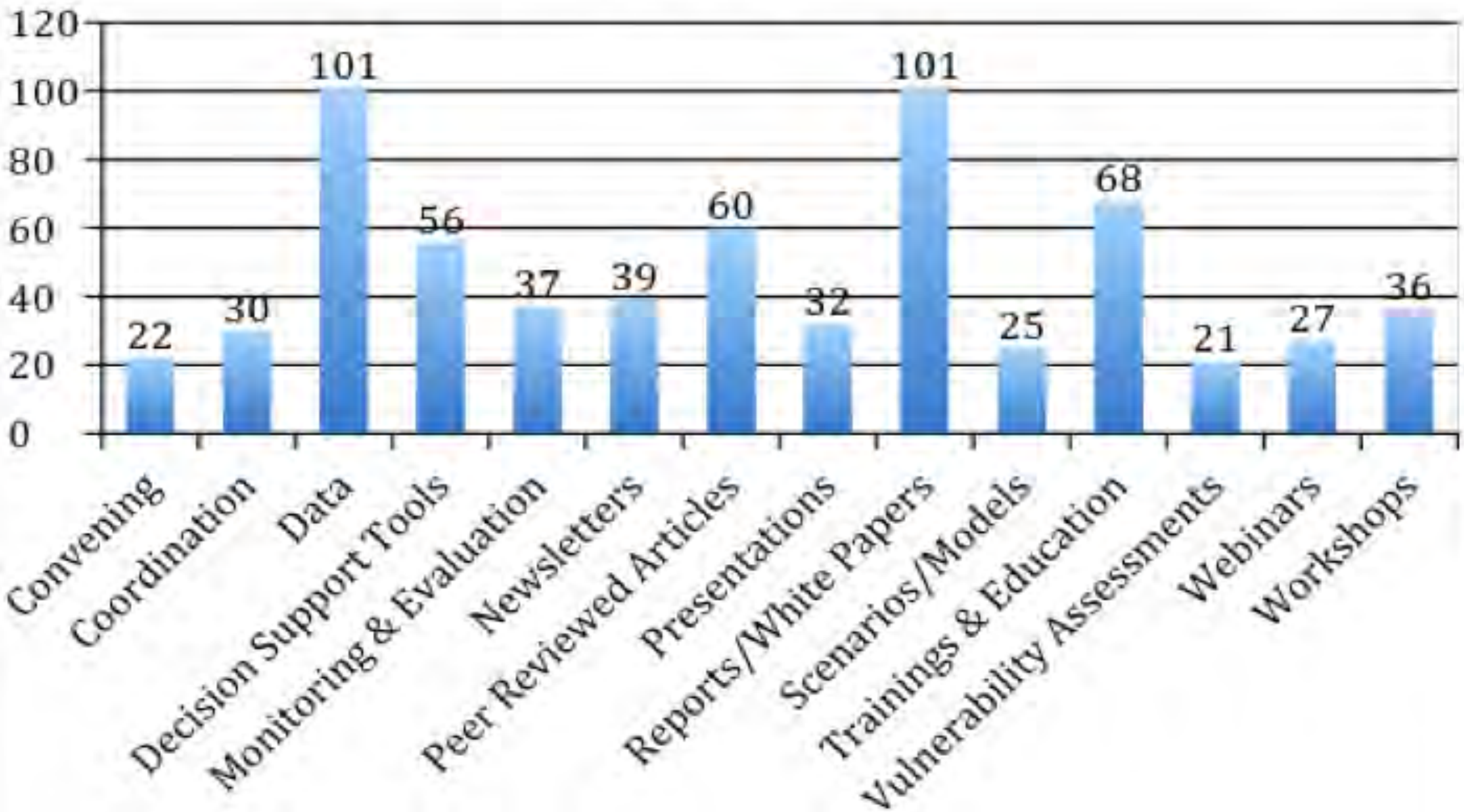
Government
Public
Private Sector
Researchers
Resource Managers
Tribes


Providers by State Based and States Served in NOAA West Region
40
35
30
25
20
15
10
5
0
14
17
28
36
24
21
4
16
5
16
6
17
2
13
12
22
4
14
11
22
2
16
Arizona
California
Colorado
Idaho
Montana
Nevada
New Mexico
Oregon
Utah
Washington
Wyoming
Based
Served

Scale Served	Provider Count
International	16
National	29
Regional	77
Tribal	18
State	92
Municipal	45

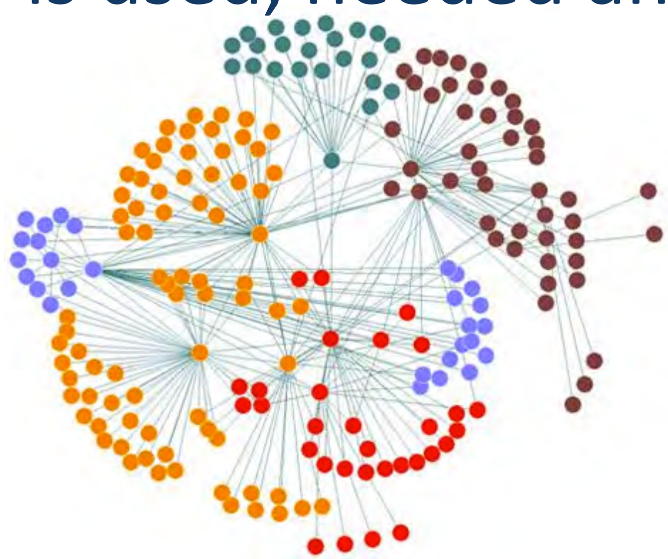

Sectors Served by CS Providers
90
80
70
60
50
40
30
20
10
0
79
74
62
37
35
34
24
22
19
19
18
17
16
11
10
10
6
6
5
Climate & Weather
Water
Ecosystems
Oceans/Coasts
Drought
Forests
Extreme Events
Land Use/Land Cover
Agriculture
Energy
Wildfire
Indigenous Peoples
Human Health
Urban
Economics
Transportation
Social
Biogeochemical Cycles
Rural Communities

Number of Providers by Services Offered



Next Steps:

- Institutional Network Analysis of Providers
- Survey
- ID what info is used, needed and services provided



Lunch

Partnership with Northern Plains Regional Climate Hub and North Central Climate Science Center

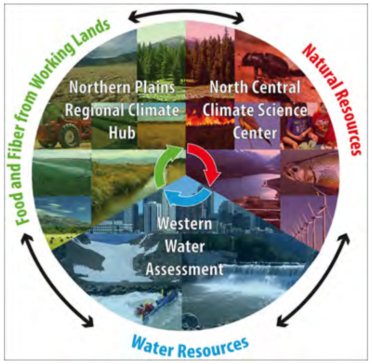
- Joint projects
  - Drought decision-making
  - Ecological drought
  - Climate & agriculture tools
  - National Climate Assessment

- Joint retreats twice per year to facilitate collaboration

- Publishing a paper on cooperation among regional climate entities

NORTH CENTRAL CLIMATE SCIENCE CENTER
UNIVERSITY CONSORTIUM

USDA




EARTH LAB
Accelerating discovery with a view from Space
Geography, Applied Mathematics, Cooperative Institute for Research in Environmental Sciences, Ecology & Evolutionary Biology, Environmental Sciences, Ecology & Evolutionary Biology, Environmental Studies, Geological Sciences, Institute of Behavioral Science, National Snow and Ice Data Center, and Research Computing
Digital Globe, Lockheed Martin, Ball, aWhere
University of Colorado Boulder
Grand Challenge

Key pieces of Earth Lab

Analytics Hub

Science Projects

Education Initiative