Airborne Snow Observatories
and the
Colorado Airborne Snow Measurement Program

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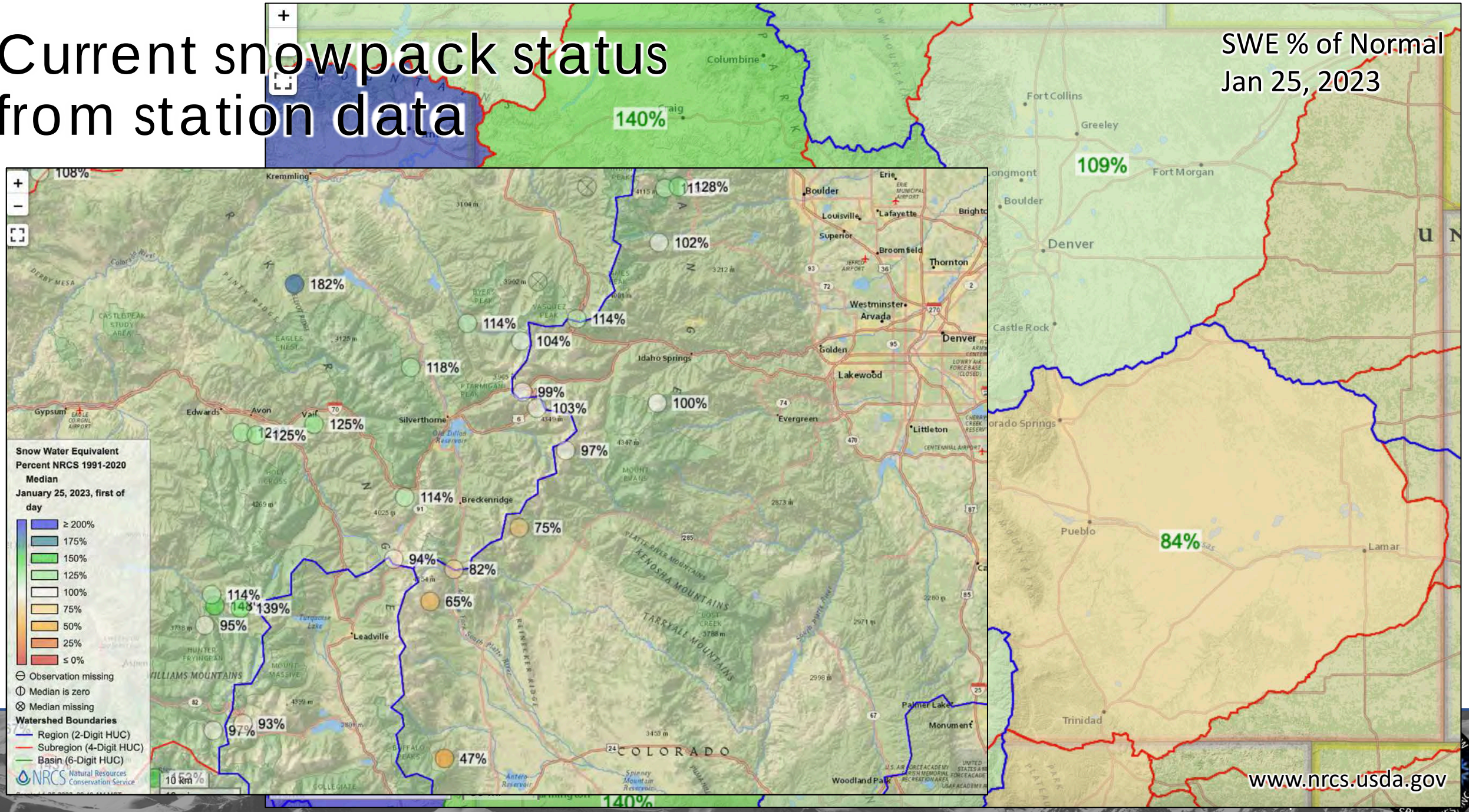
ASO 3m Snow Depth
Quandry Peak, CO
18 April 2021

Current snowpack status from station data



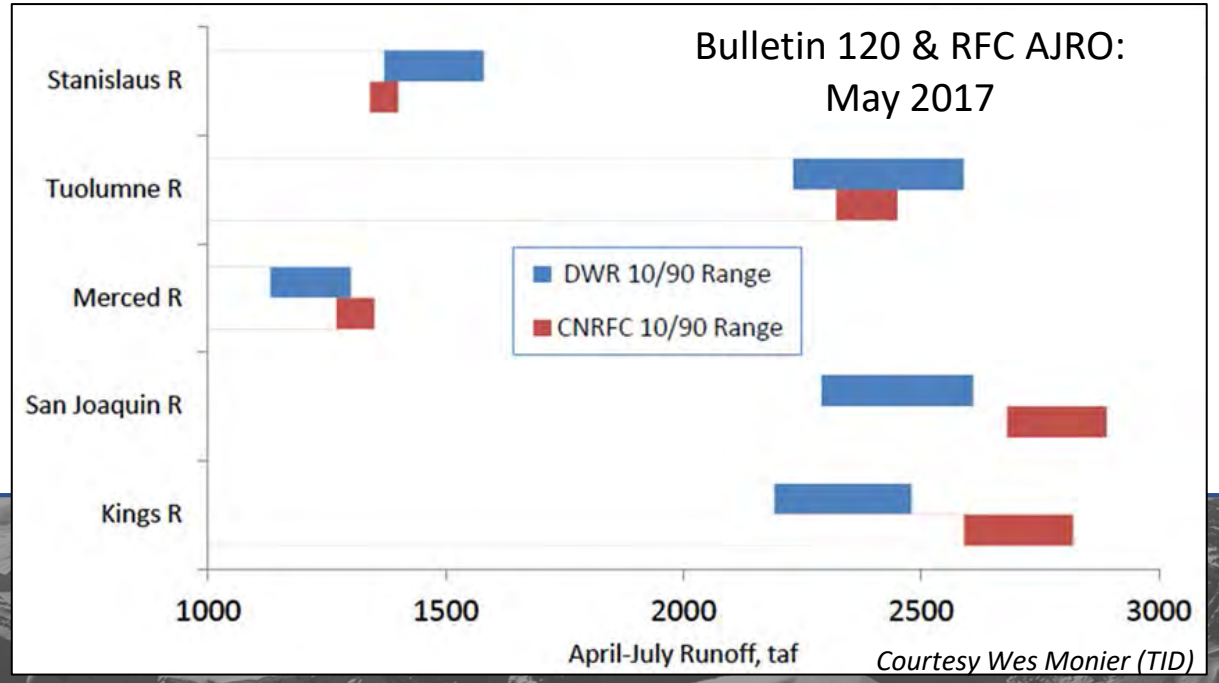
Basin snowpack indexed using station data

Elk Range
ASO Snow Depth
April 2019

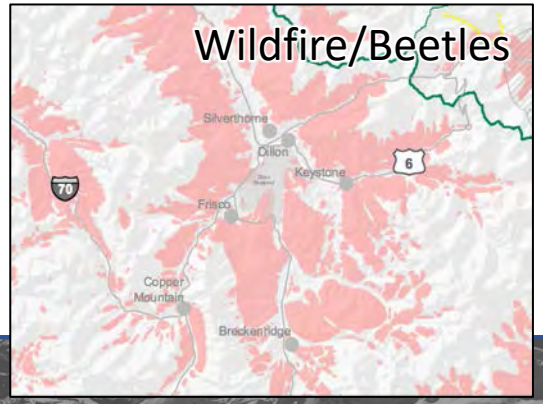
Snow Depth (m)
0 5+

History is an increasingly poor guide to the present

- forecasts based on historic data assume that calibrations apply to current conditions
- forecast uncertainty requires a wide margin
- accurate & complete SWE mapping is a foundation for reduced forecast uncertainty



Courtesy Wes Monier (TID)



Airborne Sno

	April Forecast	Obs Inflow	% Difference
1999	120	197	-39%
2000	155	159	-2%
2001	150	146	3%
2002	59	57	4%
2003	170	173	-2%
2004	100	78	28%
2005	125	120	4%
2006	210	176	19%
2007	150	177	-15%
2008	200	195	2%
2009	180	192	-6%
2010	120	142	-15%
2011	225	272	-17%
2012	100	64	56%
2013	100	134	-25%
2014	250	242	3%
2015	166	202	-18%
2016	167	157	7%
2017	195	184	6%
2018	137	117	17%

Forecast > 10% Low | **Forecast > 10% High**

Airborne Snow Observatories, Inc.

mapping the two most critical snow properties to forecast runoff volume & timing

Snow Water Equivalent

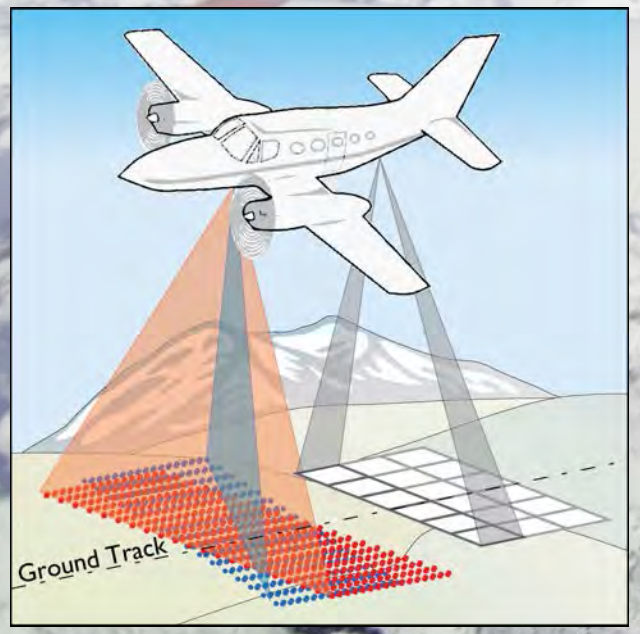
Snow depth from lidar elevation

SWE from coupling with obs & modeled density

Snow Albedo

HySpex VSWIR spectrometers

Albedo & surface properties



Physical Modeling

Coupled lidar & spectrometer

Physical snowpack & runoff modeling

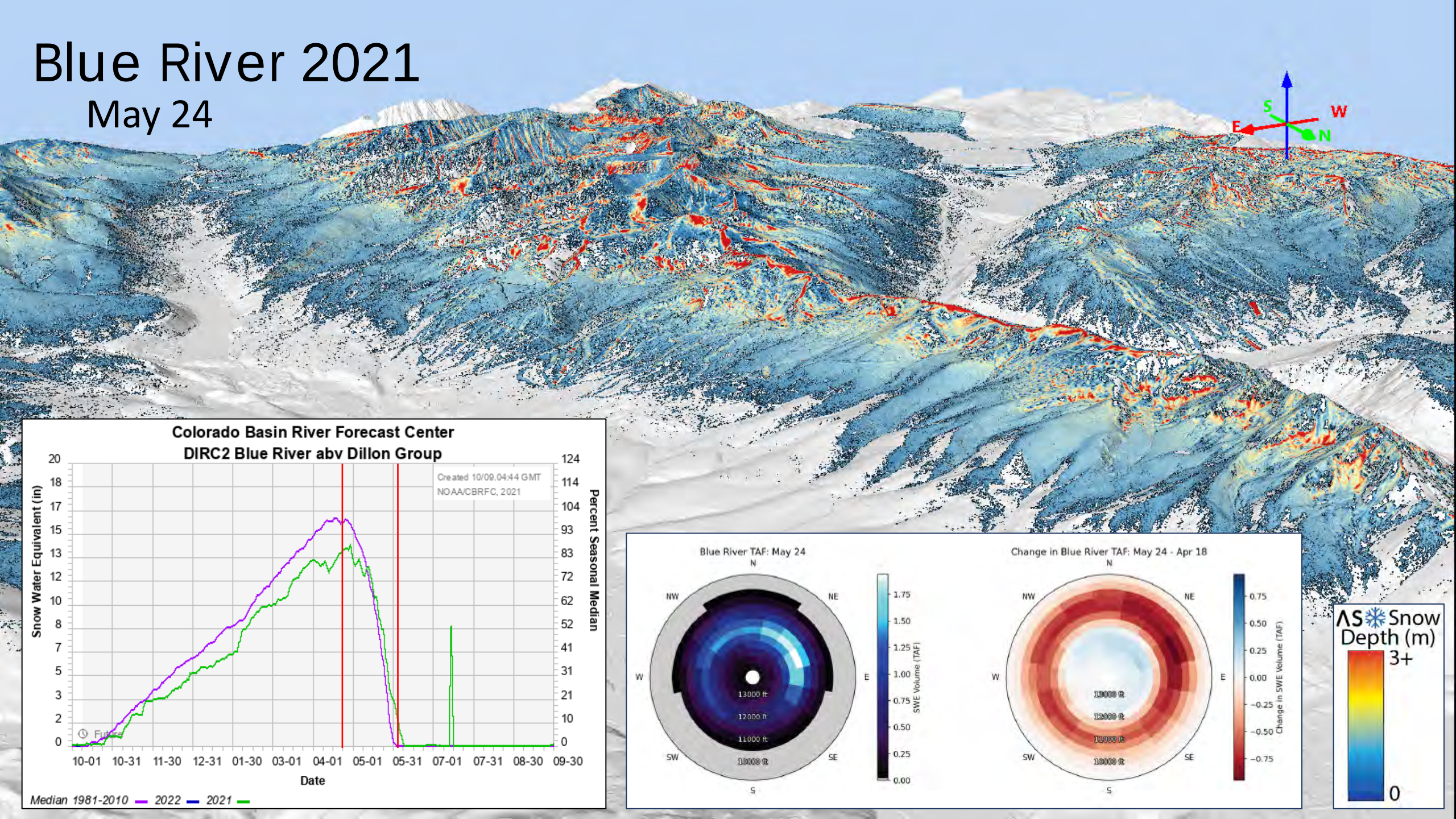
Operations

Unique high-altitude operations

Unique rapid product turnaround

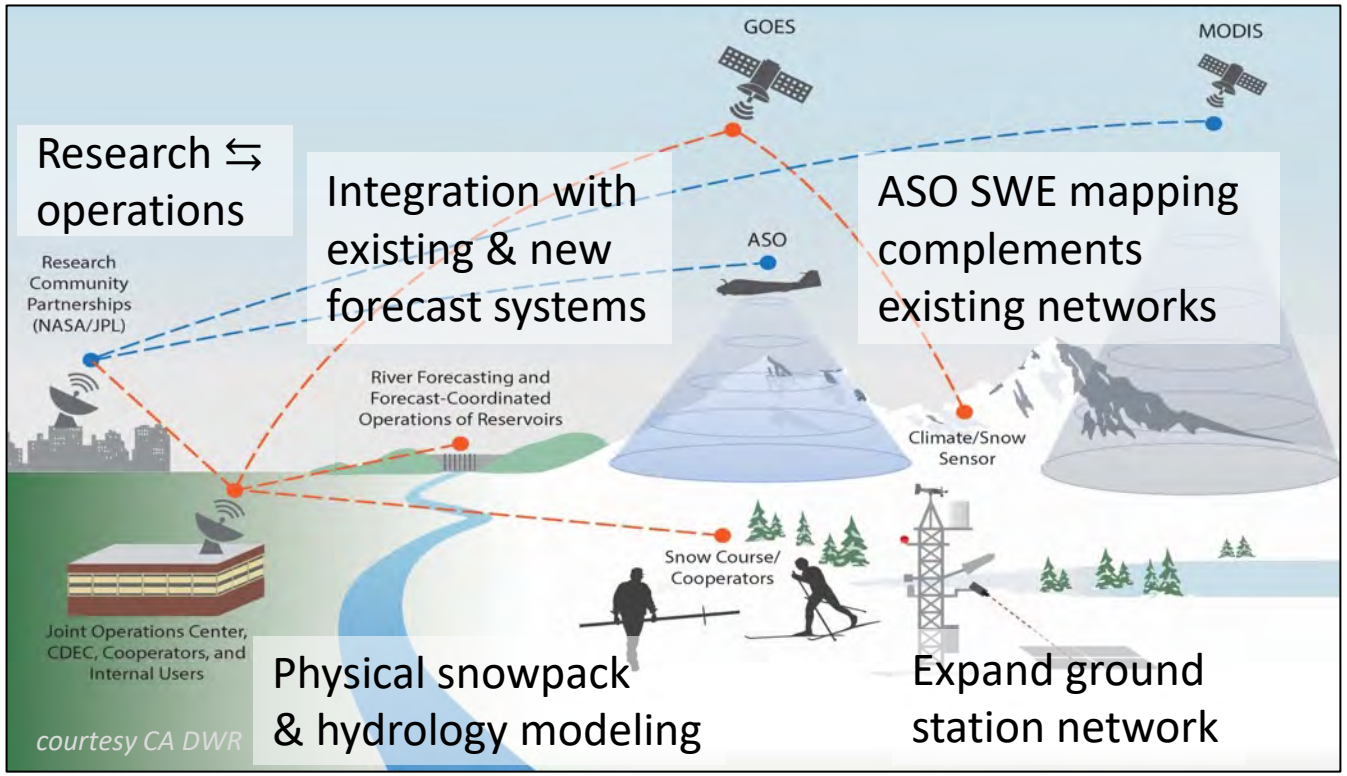
Blue River 2021

May 24



Enabling a resilient & responsive water management paradigm

An integrated monitoring & forecasting system



Evolving challenges & programs

- enabling **adaptation** to changing hydroclimate & watershed conditions
- providing **accurate & complete** snowpack data to experienced forecast teams
- allowing physics-based forecast models to be **responsive** to watershed dynamics

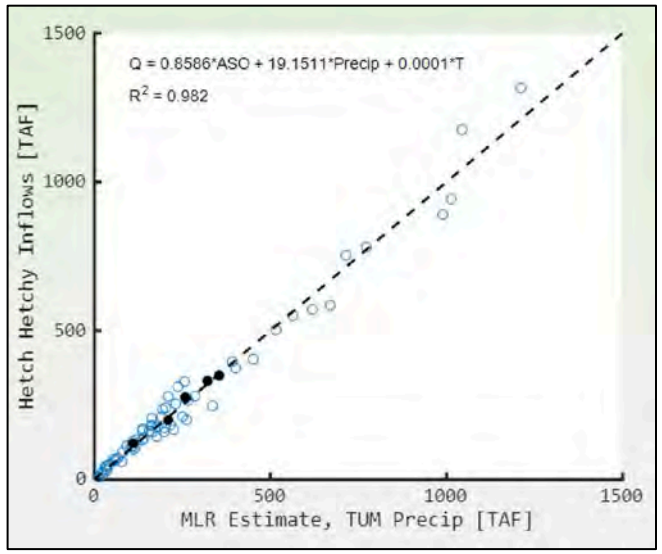
ASO is the cornerstone of this vision

- the only **highly-accurate, full-coverage** measurement of snow depth, SWE, & albedo
- forecast improvement & **decision support**

Wide-range of decision-support applications

Reservoir operations

- Robust AJRO predictor
- lower bound confidence allowed ecology flows in drought years



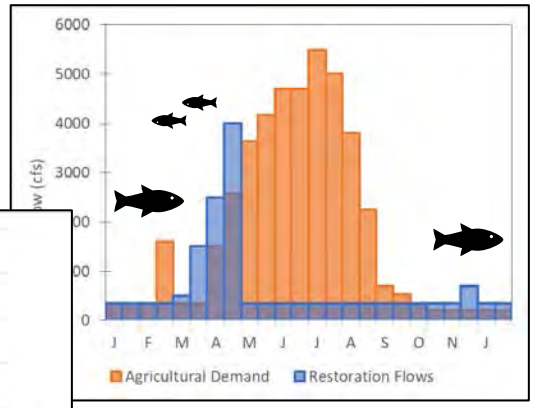
Proactive flood management

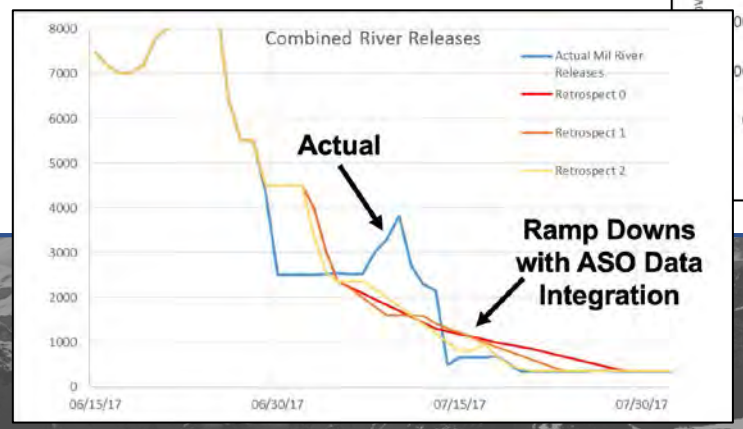
- Kings River, CA – 2019: flood designation avoided using ASO SWE volume guidance
- met supply obligations
- avoided costly water lease

Forecasts	Apr-Jul Runoff Forecast Exceedance		
	10%	50%	90%
CA DWR	2.1 MAF	1.8 MAF	1.6 MAF
NOAA RFC	2.3 MAF	2.1 MAF	1.9 MAF
ASO		2.5 MAF	

Ecologic & In-stream flows

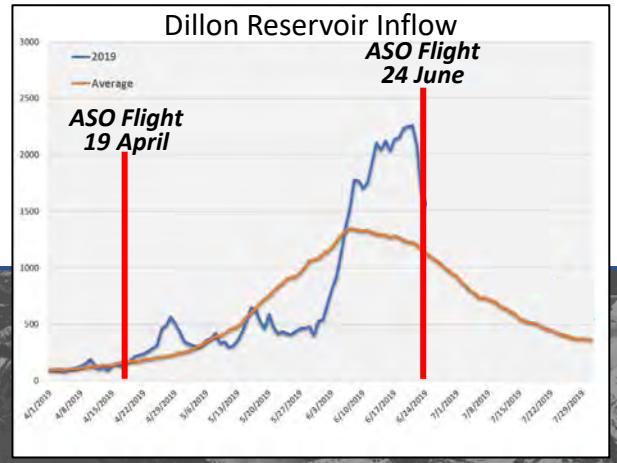
- fish flow timing
- dam release ramping

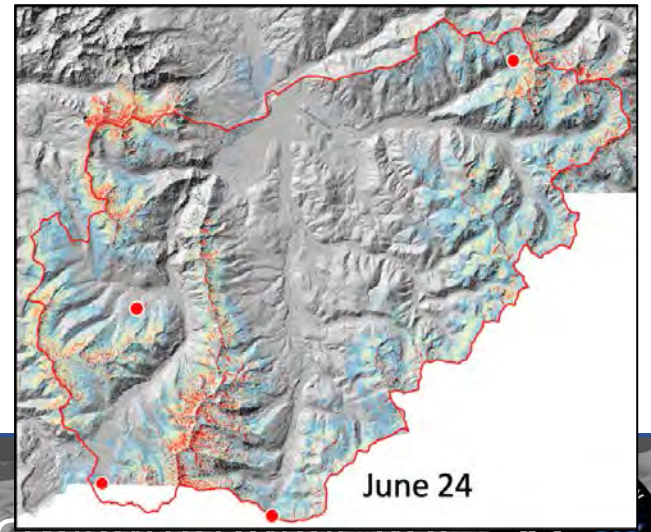




Reservoir operations timing

- Dillon Reservoir 2019
- captured 2nd runoff peak



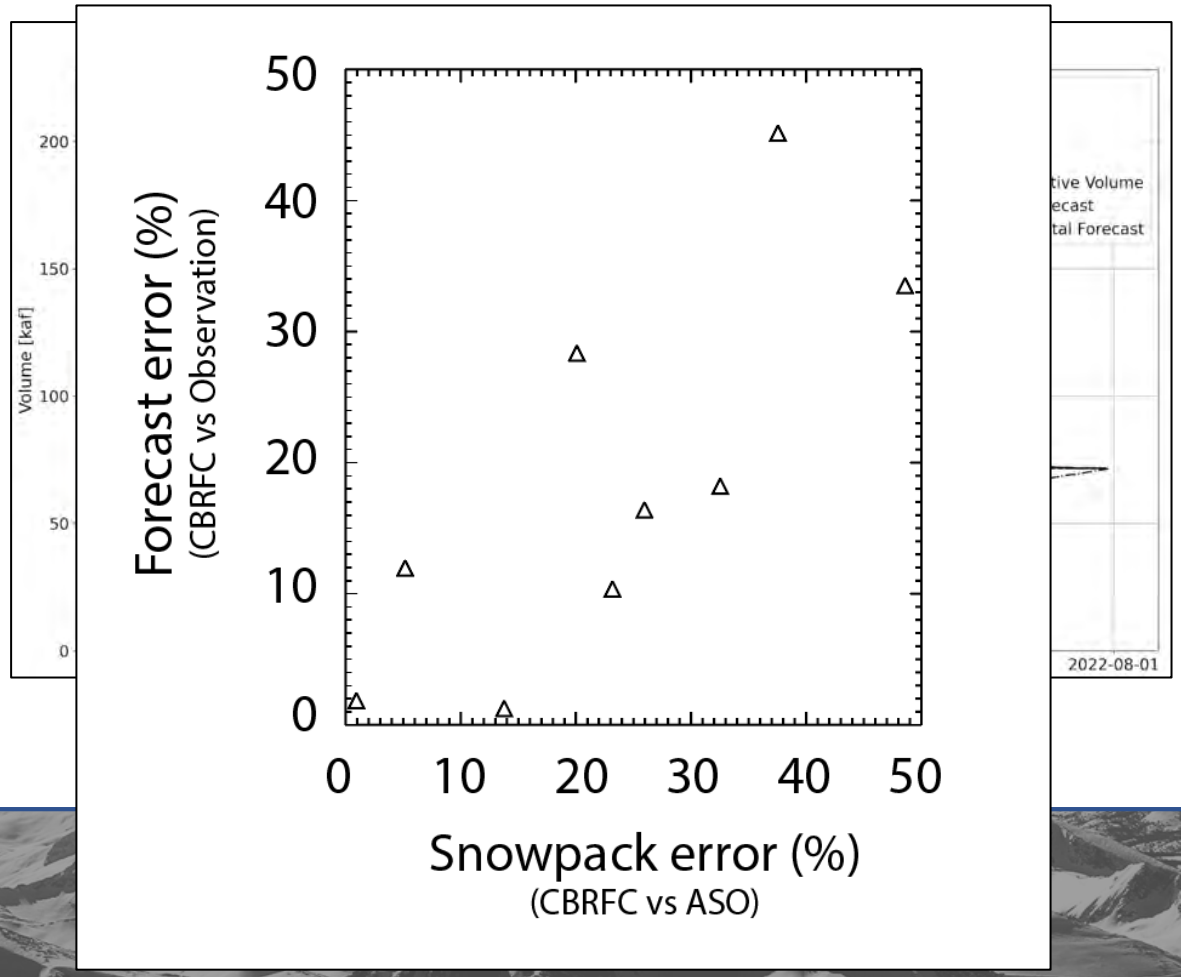


Observatories, Inc.
A Public Benefit Corporation

Operational forecast integration

NWS River Forecast Center testing/evaluation

- experimental SNOW-17 forecasts with ASO ingest
- ASO validation of RFC SWE volumes

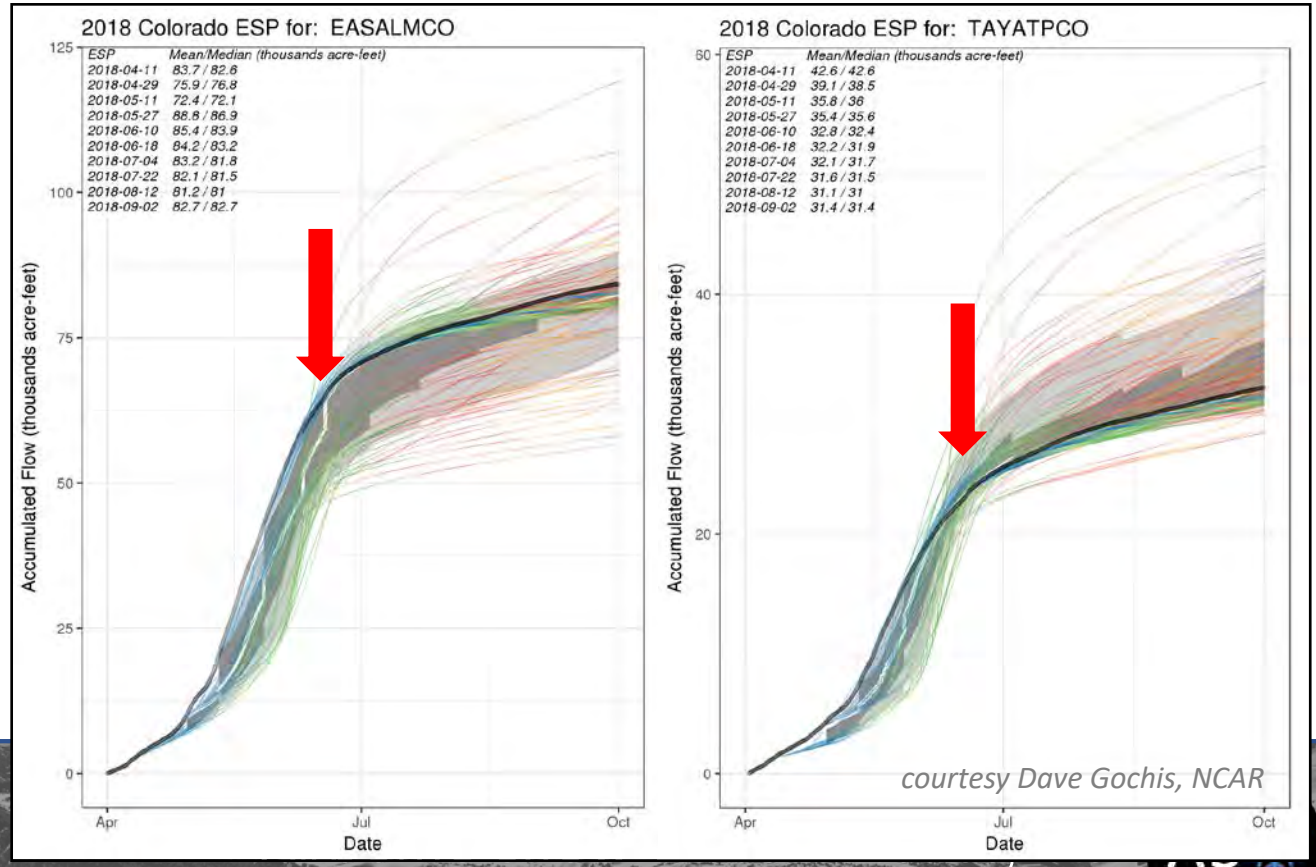


WRF-Hydro forecast with ASO data assimilation

- distributed, physics-based model
- ASO SWE ingest enforces spatial distribution of snow

East River @ Almont

Taylor River @ Taylor Park



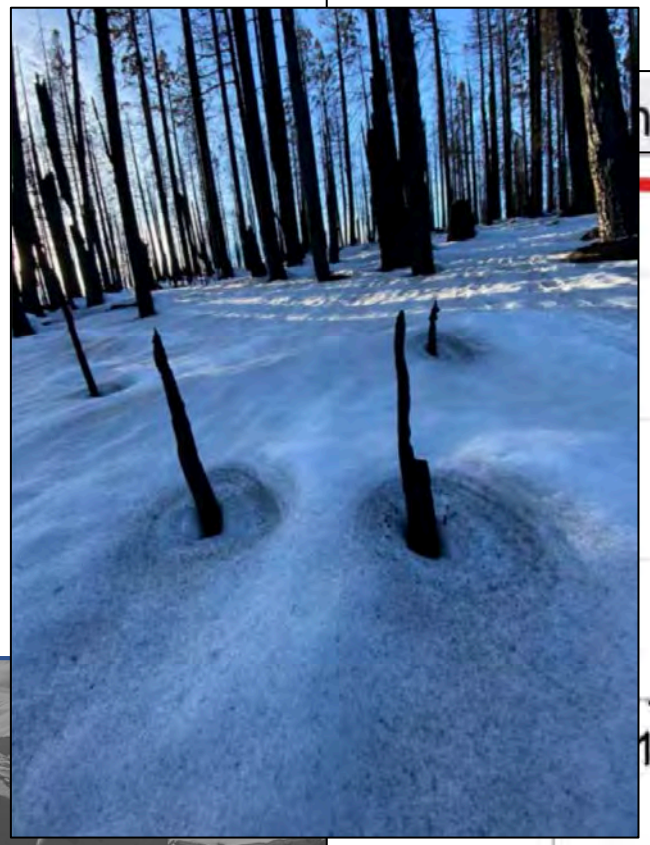
Adaptation in practice: Feather River, CA, 2022

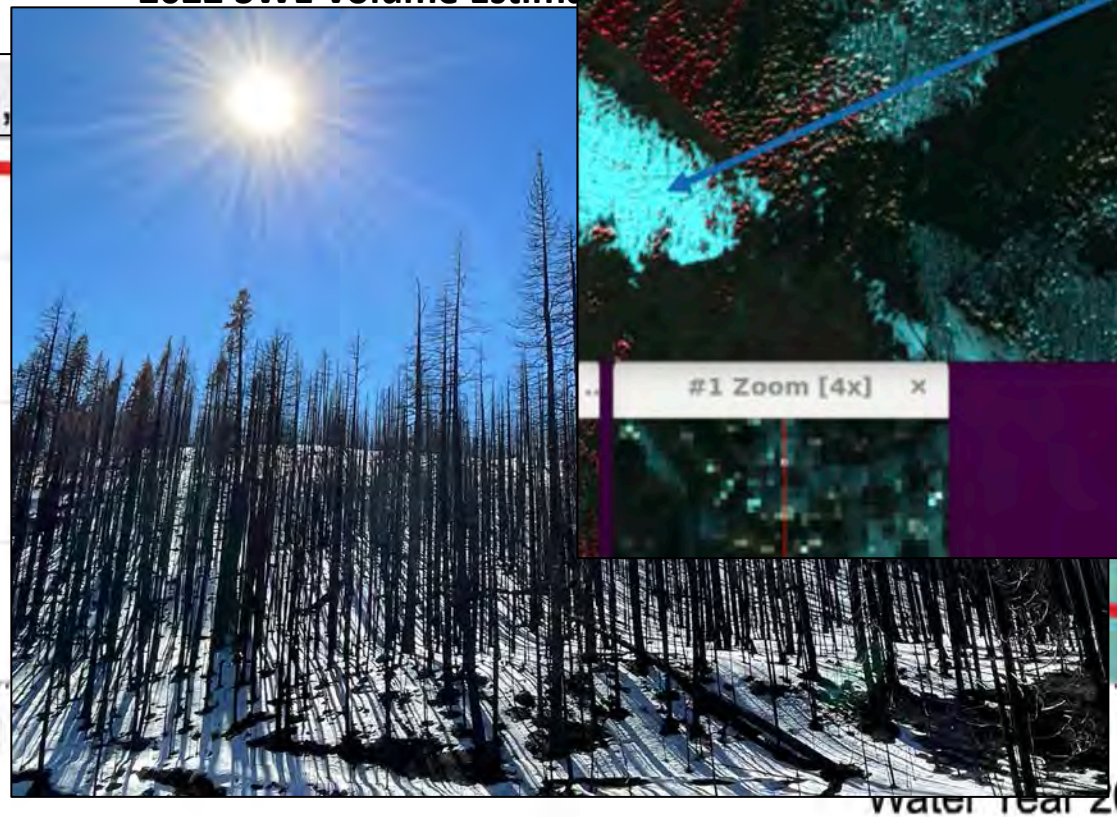
Early warning of low snowpack

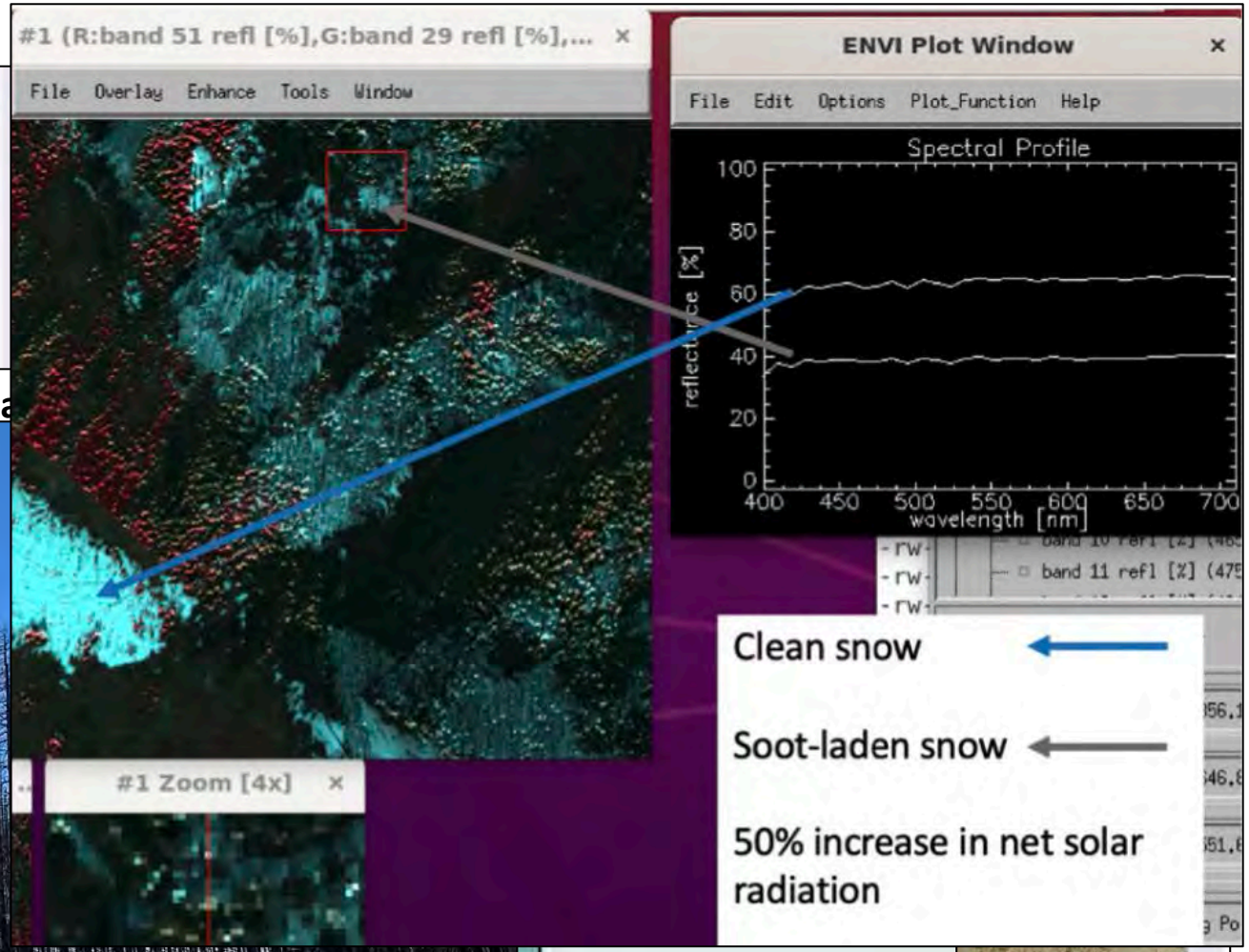
- snowpack peaked Jan 1st
- overestimated by conventional products

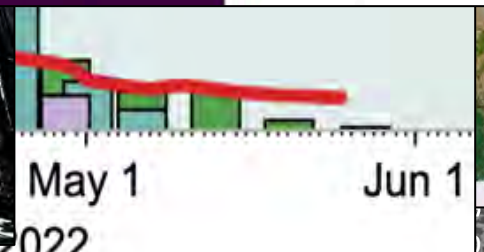
Wildfire impacts on hydrology

- >60% of basin burned in 4 years
- Large snow albedo reduction from soot









Water Year 2022

Colorado wildfire impacts – East Troublesome

ΔS Canopy Height (m)
10+
3

ΔS Snow Depth (m)
3+
0

Realizing value in accurate snowpack monitoring

operational resilience & reliability:

- minimize runoff forecast uncertainty
- optimized/increased hydropower
- in-stream flow reliability
- groundwater recharge

avoided costs:

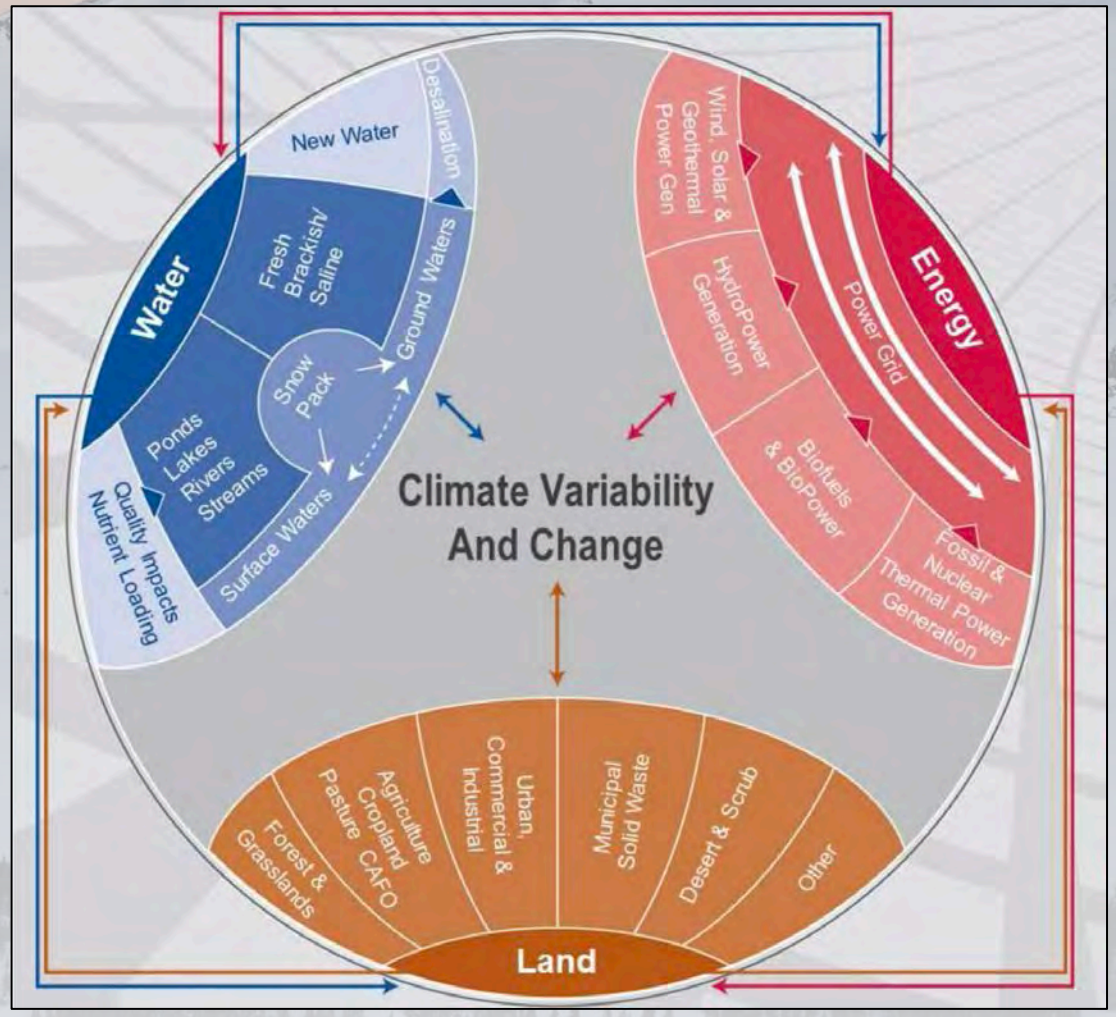
- reducing/avoiding flood impacts
- unforeseen curtailment or water leasing
- water temp & quality impacts from low flows

effective policy implementation:

- measurement is fundamental to planning
- equitable & effective response to shortage
- proactive water management
- wildfire planning & response

***NOT** measuring the snowpack reservoir is the expensive option!*

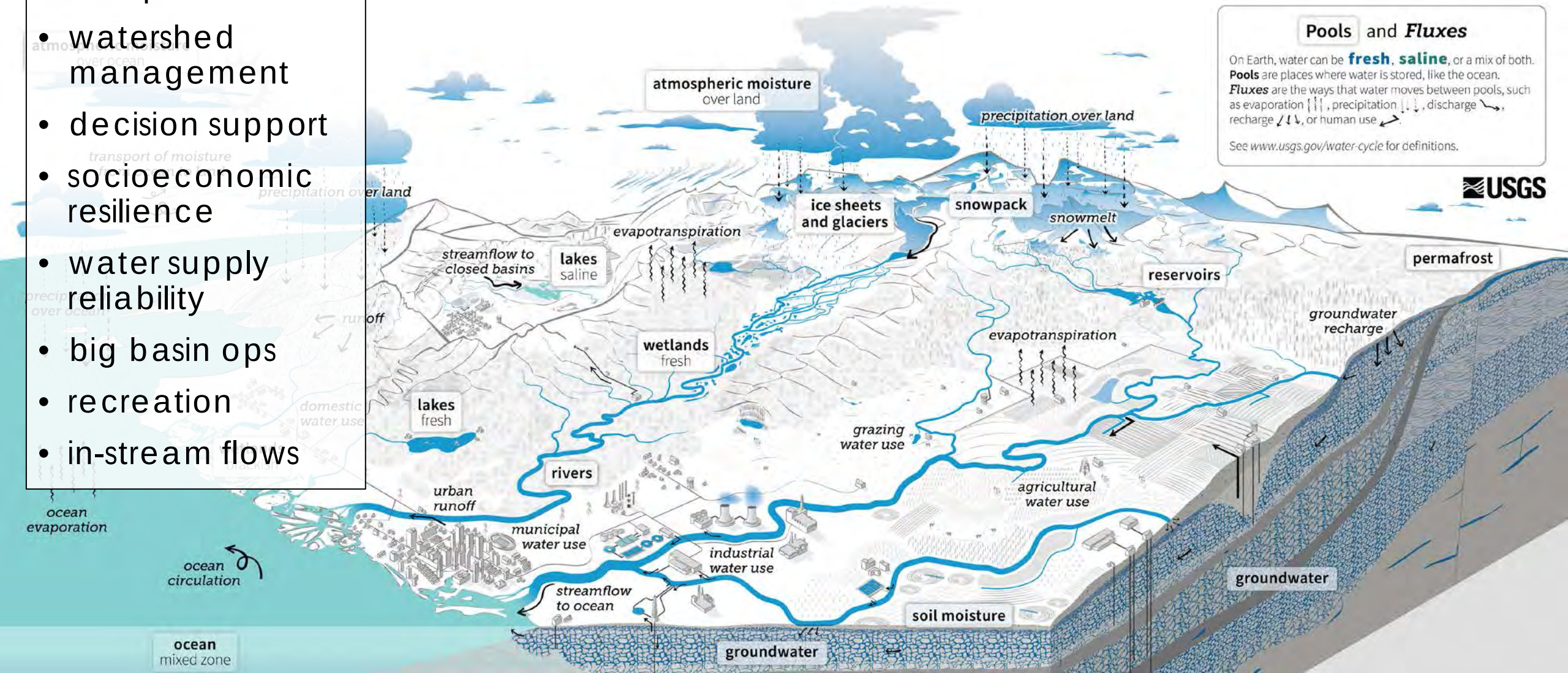
Energy/Water/Land Nexus



www.energy.gov

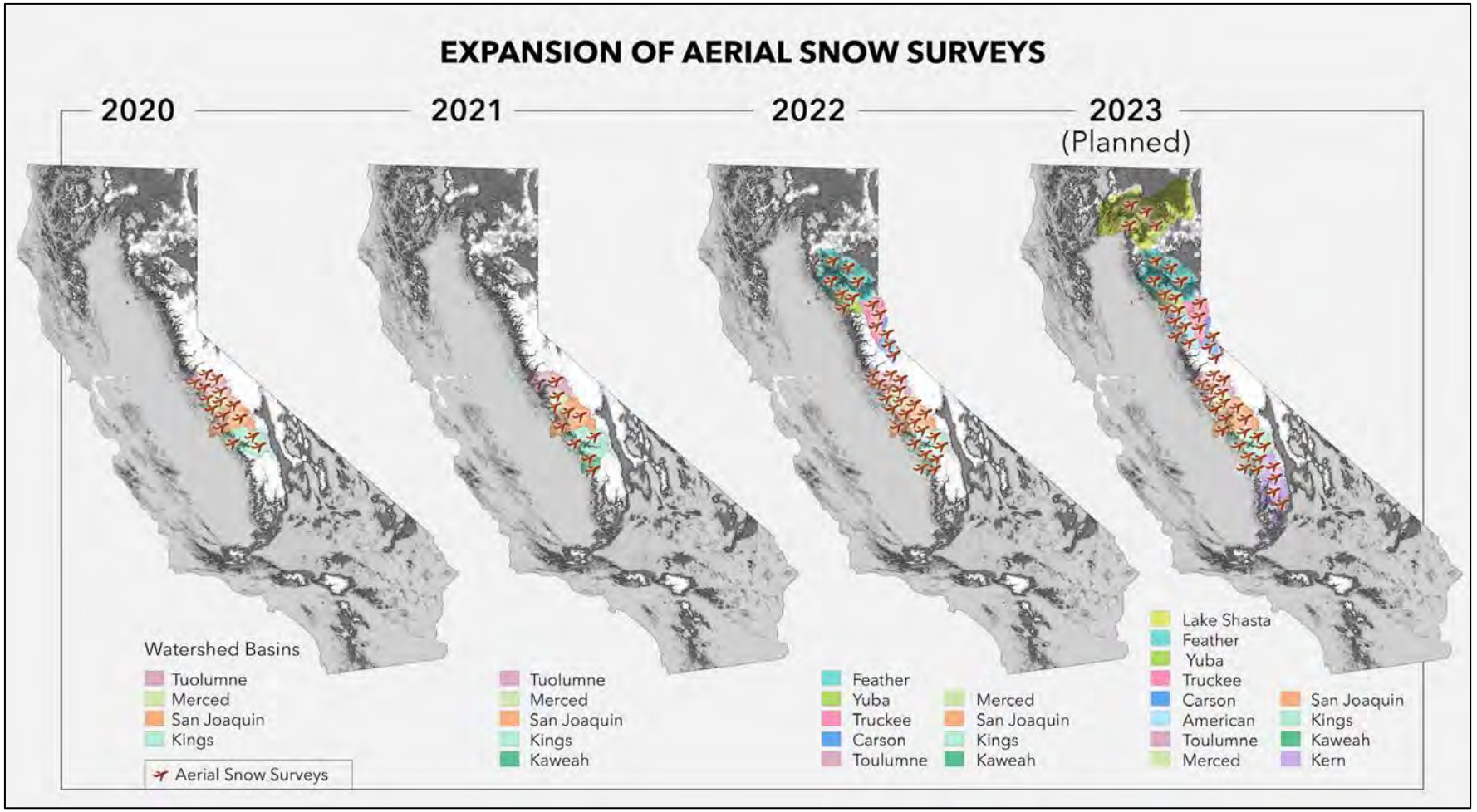
Cascading impacts of better information

- other H_2O budget components
- watershed management
- decision support
- socioeconomic resilience
- water supply reliability
- big basin ops
- recreation
- in-stream flows



Building towards a sustained California program

- program growth reflects stakeholder demand
- local, state, & federal funding
- science & decision support
- 2023: base funding for sustained program
  - 4 flights/basin in 2023
  - add remaining basins & build towards 8 flights
- benefits for expansion in CO & westwide



ASO + CASM:

Building & sustaining a statewide program

ASO ➜ ASO, Inc.

- CO legacy since 2013
- Forecast Improvement Project began 2015

WRF-Hydro runoff forecasting

- CWCB support

Colorado Airborne Snow Measurement Program (CASM)

- $1.9M WPG in March 2022
- 2022 snow flights
- snow-free coverage
- stakeholder coordination
- survey schedule coordination

CASM Program

Planning Team

DENVER WATER

COLORADO
Colorado Water Conservation Board
Department of Natural Resources

Northern Water

COLORADO RIVER DISTRICT
PROTECTING WESTERN COLORADO WATER SINCE 1937

LRE WATER

ST. VRAIN & LEFT HAND WATER CONSERVANCY DISTRICT

AIRBORNE SNOW OBSERVATORIES, INC

DOLORES WATER CONSERVANCY DISTRICT DWCD

Stakeholder Workgroup

100+ member workgroup from diverse sectors and geographies

Flight Coordination Committee

25+ member committee

COLORADO AIRBORNE SNOW MEASUREMENT PROGRAM CASM

CASM Vision

Vision 1 - Water Management and Decision-Support Applications

Improved snowpack measurements and water supply forecasts that empower better water management decisions

Vision 2 - Hydroclimate Science

Contributes to the advancement of watershed sciences

Vision 3 - Program Structure and Cooperative Management

CASM is co-led by CWCB staff, with local stakeholders cooperating on flight decision-making and program subcommittees

Vision 4 - Funding

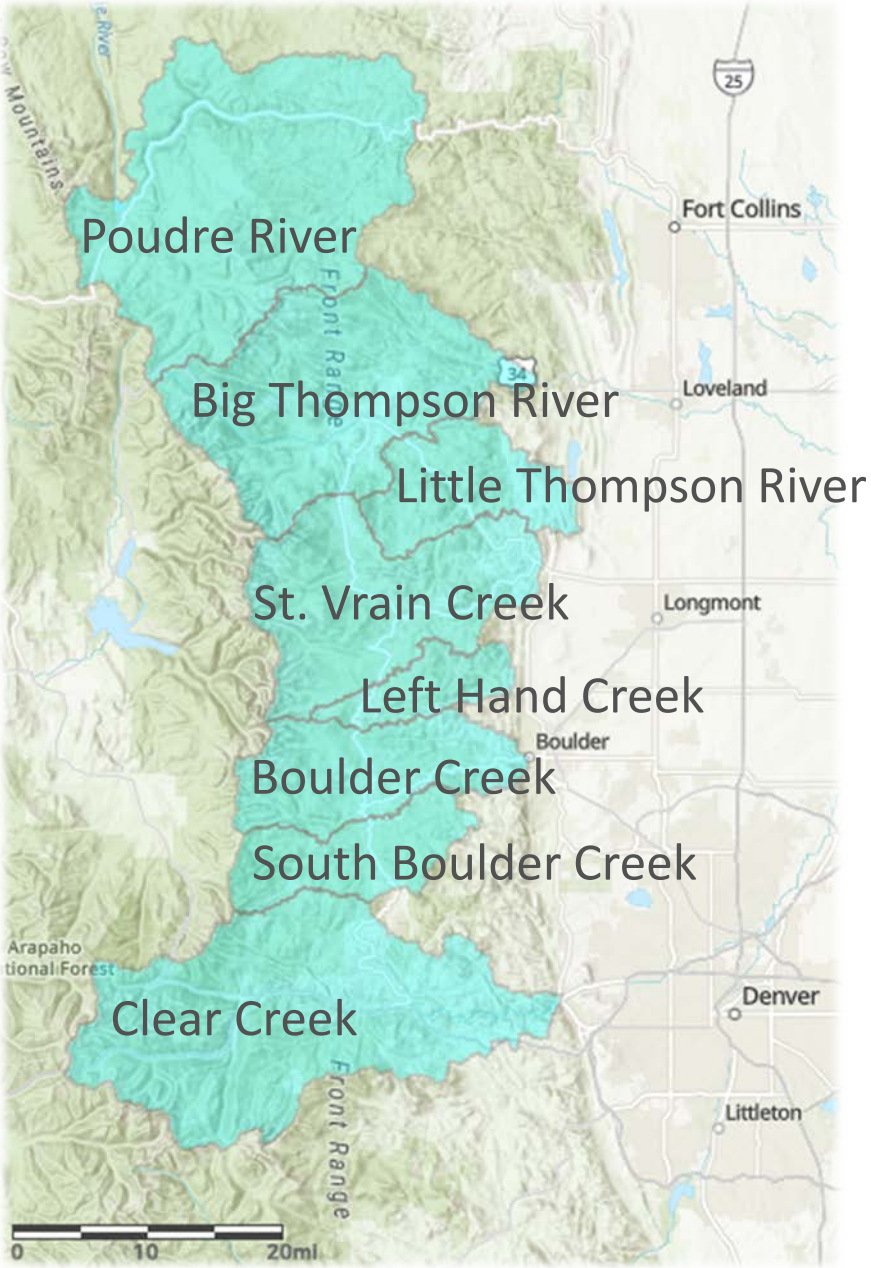
Sustainable CASM program will require consistent state and/or federal funding.

Executive Summary & Report available at coloradosnow.org

Priorities for Program Development

- **Funding**
  - 2023 Committed & Potential: $2.4 million
    - Local Agencies: 23 agencies giving from $1K to $250K totaling over $1 million
    - State Funding Pools: $1.13 million
    - Federal Partners: $250K
  - Widespread Adoption: $8.6 million
  - Maximum spatial/temporal coverage: up to $26.6 million
- **Simplified Contracting Mechanism**
- **Expanding Snow Free Coverage**
  - 10.3M acres of 25.5M acres completed
  - Approximately $5 million to reach full coverage

Successes & Challenges in Front Range Funding



City of Fort Collins

City of Greeley Colorado

Northern Water

City of Loveland

St. Vrain & Left Hand Water Conservancy District

CCWCD Where the Future Flows

Highland Ditch Company

City of Thornton

Left Hand Ditch Company

Westminster Colorado

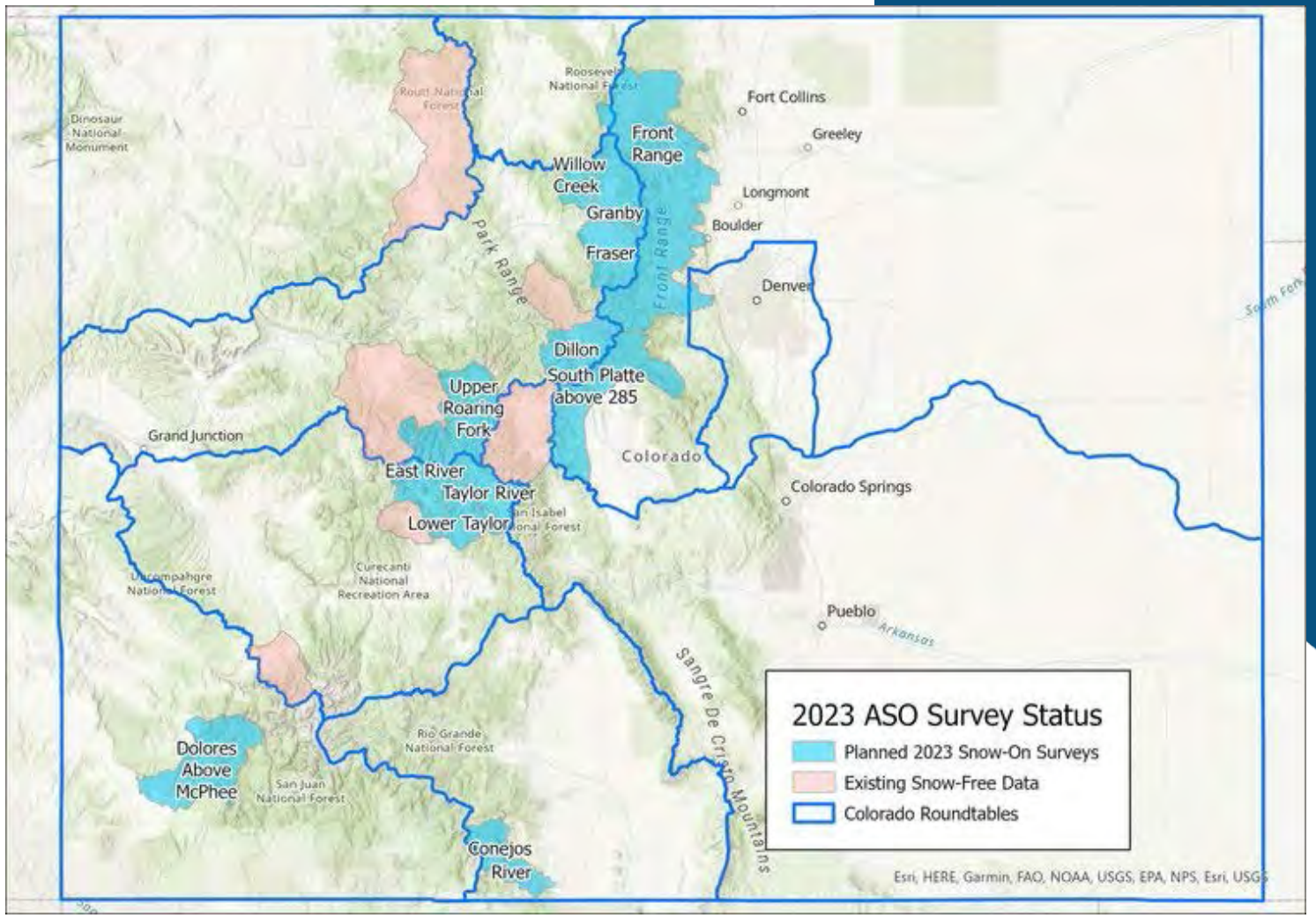
City of Boulder

City of Golden

Colorado Airborne Snow Measurement Program CASM

CASM in 2023

- 24 flights across 11 basins
- WRF-Hydro forecasting
- Weekly flight planning committee
- Stakeholder update emails
- Monthly stakeholder meetings
- Continued CWCB engagement
- Expanded engagement with:
  - California, Media, Researchers, Basin Partners, Federal Partners, additional stakeholders



Water Manager Perspectives

"ASO data can significantly enhance the accurate predictability of these future streamflows and provide Colorado with a better ability to meet these compact obligations while also fully utilizing the water that is allocated to Colorado users under the compact."

- Craig Cotton, CO DNR, Division Engineer Division 3

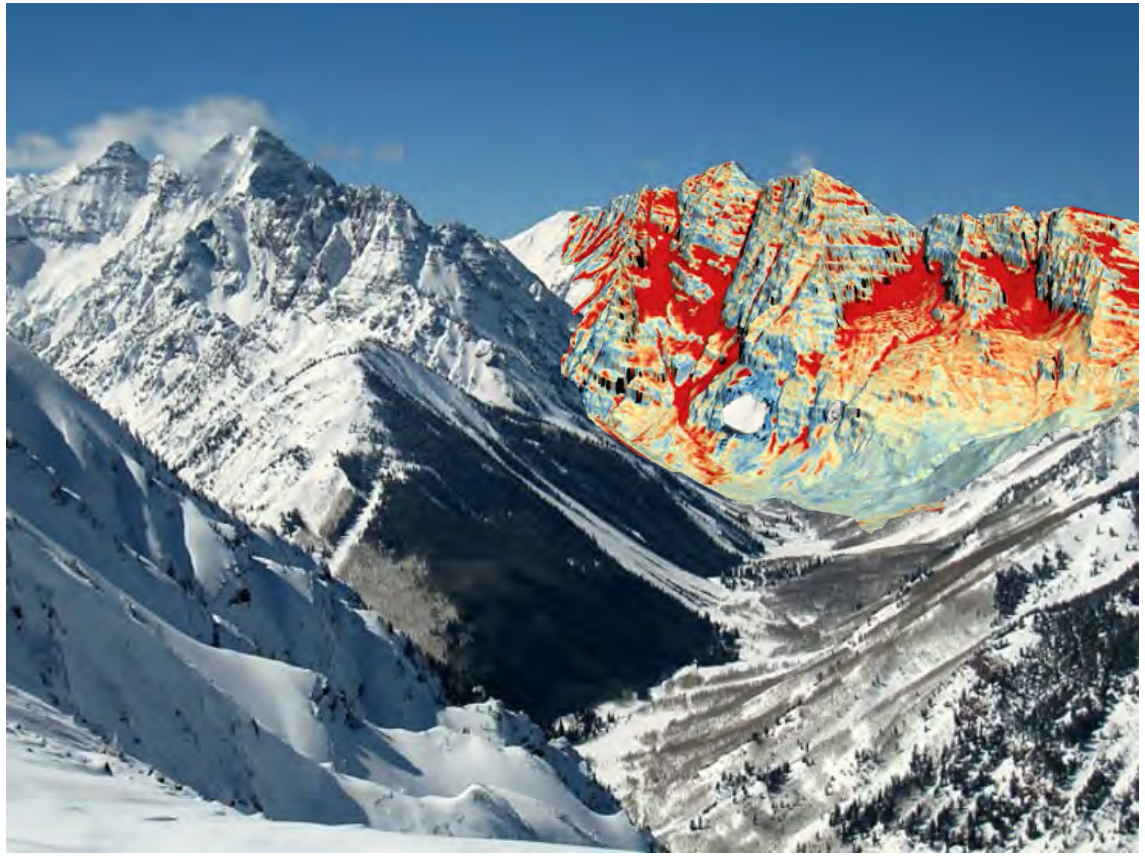
"ASO provides detailed information into the snowpack like we have never seen before. The information gained from ASO flights allows for a finer level of water management and provides more opportunity to benefit more users and get the maximum benefit out of every drop."

- Nathan Elder, Raw Water Operations Manager, Denver Water

COLORADO AIRBORNE SNOW MEASUREMENT PROGRAM
CASM

Measuring Reservoirs

wikipedia



PlanetWare

"Accurate snowpack/SWE monitoring and streamflow forecasts are critical to Colorado's ability to meet its compact obligations on the Rio Grande."

Craig Cotten
Colorado Division 3 Engineer

"What you've done is created new reservoir space and water supply without any impacts to the current physical or environmental paradigms."

Wes Monier
Chief Hydrologist - Turlock Irrigation District

"Having used this technology, it is hard to imagine a future without it."

Dave Rizzardo
Chief of Snow Surveys & Water Supply Forecasting, CA DWR

"ASO provides invaluable information about the rate of melt that provides a real opportunity to optimize reservoir operations for water supply, flood control, and instream requirements."

Steve Haugen
Watermaster, Kings River Water Association

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