



## Memorandum

**To:** Northern Water, Colorado Water Conservation Board

**From:** CASM Workgroup

**Copy to:**

**Reviewed by:** Taylor Winchell, Emily Carbone, Kate Burchenal, Jeff Deems

**Date:** 12/23/2022

**Project:** Colorado Airborne Snow Measurement Program (CASM)

**Subject:** 2022 Snow-Free Data Acquisition Activities

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## CASM and ASO

Airborne Snow Observatories, Inc. (ASO Inc.) uses paired airborne lidar and imaging spectrometer sensors to measure snow depth and albedo and coupled with a snow dynamics model to retrieve Snow Water Equivalent (SWE, the liquid depth of water stored in the snowpack) across large river basins at a high spatial resolution. The resulting data provides high-elevation snowpack measurements with detail, accuracy, and decision-support value unprecedented in water management.

The Colorado Airborne Snow Measurement (CASM) working group was formed to develop a statewide program to provide significantly improved snowpack measurements and associated streamflow forecasting throughout Colorado through widespread deployment of ASO surveys and the supporting hydrologic science. The mission of CASM is to improve water supply management and understanding of hydrology across Colorado through the widespread deployment of ASO snowpack measurements. CASM currently engages with a stakeholder group of nearly 100 agencies that serve millions of Colorado residents, hundreds of thousands of irrigated acres, and represent all major river basins.

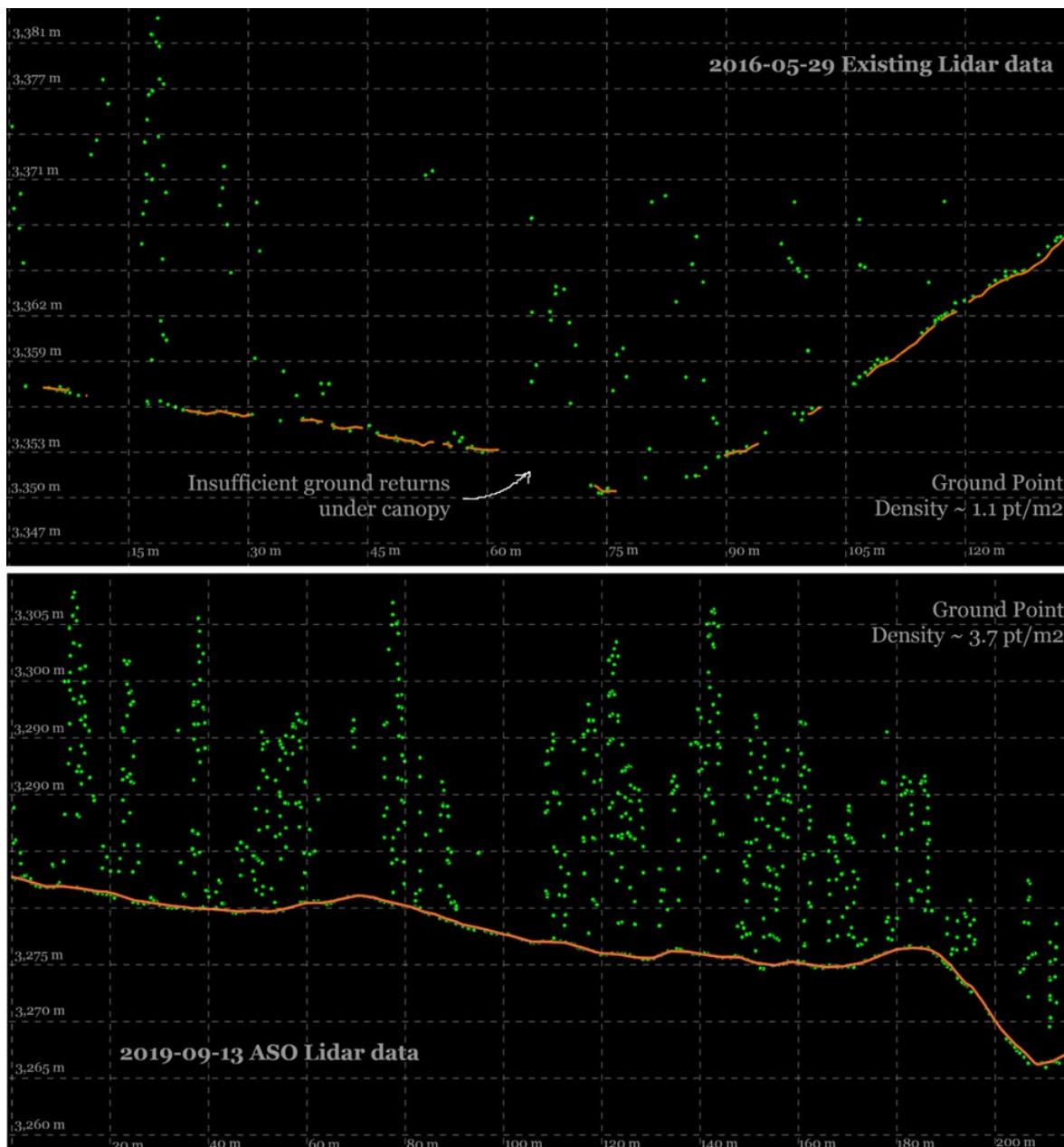
# Snow Free Data Requirements

ASO snow surveys require that a basin has had a “snow free” lidar flight conducted for the area to provide a geodetic baseline to compare to the snow survey. Snow-free data preparation is centered around development of a LiDAR dataset that has sufficient point density and homogenous accuracy throughout the basin, including under forest canopies. There is partial coverage of the State of Colorado with existing lidar products that have been collected by the CWCB, USGS and others for conventional topographic mapping purposes like floodplain delineation. These products are typically not high enough quality, or with sufficient ground point density in forested areas, to serve as a reliable baseline, so individual summertime LiDAR flights must be conducted by ASO Inc. to collect and prepare this snow free data.

In the past, ASO has used data from existing lidar mapping programs like the USGS 3DEP, or the CWCB Risk Map program. In every case, however, inconsistencies in data accuracy and sub-canopy coverage have caused major difficulties in post-processing and resulting snow depth measurement accuracy. Therefore, even in watersheds that may have pre-existing snow-free LiDAR coverage, it is generally necessary to collect a separate snow-free LiDAR collection survey with the standards and protocols of ASO Inc. **Figure 1** below shows an example of why ASO-specific snow free lidar flights are necessary to support the CASM program.

Before any basins can receive ASO snowpack measurements, that basin must have a complete “snow free” dataset flown, processed and prepared for use. Since these flights can only occur during the summer once all snow has melted, they pose a challenge in terms of timing and funding since a basin must be prepared 6 to 9 months in advance of its snowpack measurements. Once a “snow free” dataset has been completed, it may not need to be updated for several years, unless there is a major change to the basin’s physiography (ie, a new snow free dataset for the Windy Gap basin had to be collected after the East Troublesome fire).

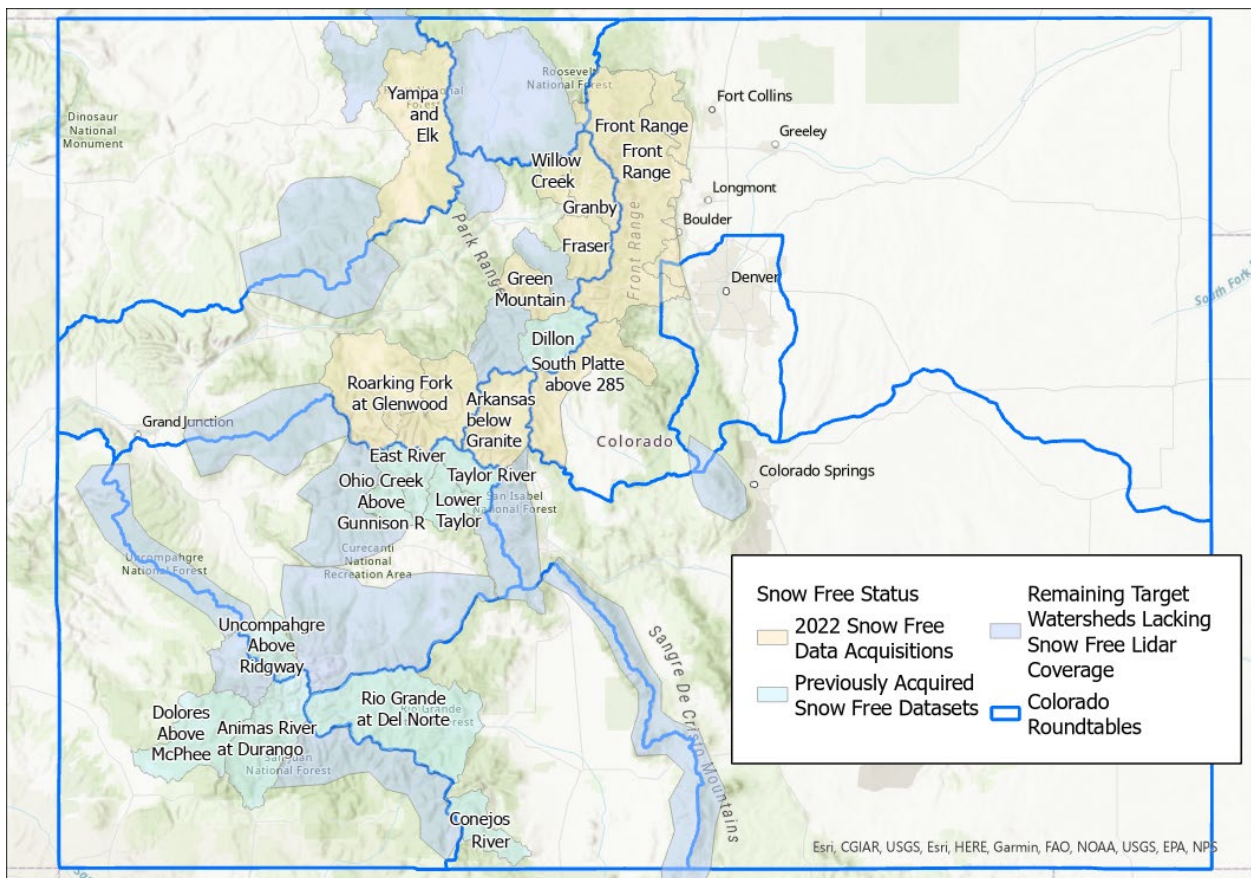
To advance the CASM program, it is necessary to complete snow-free lidar flights for all basins where ASO may eventually be flown. It is the goal of the CASM program to have snow-free data collected for every major headwater basin across the state, This memo summarizes the areas flown in 2022 and in years prior.



**Figure 1: Many existing lidar data sets have insufficient lidar point density in forested areas (top), prohibiting reliable snow depth and SWE measurement. ASO-standard data (bottom) allows complete coverage under the forest canopy, enabling accurate snow-on measurements in these important areas.**

# Snow Free Data Acquisition Statewide Summary

Snow-free data acquisitions have been ongoing by ASO Inc since at least 2016. In addition, the CASM program is targeting all headwater basins with significant springtime snow to eventually receive snow-free measurements. **Figure 2** below shows the status of the snow free data acquisitions in 2022, basins with snow-free data from previous years, and basins that CASM is targeting for snow-free flights in future years.



**Figure 2. Summary of 2022, Previous and Proposed Snow Free Coverage**

**Table 1** shows the total area of snow free data collected in 2022 and in previous years. During snowpack measurement acquisition, it is important to fly not only the basin itself, but also a bit beyond the watershed boundary to ensure complete coverage of the basin. This means that the total area acquired for each basin is slightly larger than the basin itself. As a result, the sum of the areas of all individual basins doesn't add up to the total statewide coverage acquired to date.

**Table 1. Summary of Colorado’s Snow-Free Data Acquisitions in 2022 and Previous Years**

<b>ASO Basin</b>	<b>Date Flown</b>	<b>Area Flown (sqkm)</b>
Arkansas below Granite	September 7 – 9, 2022	1,415
Colorado River at Windy Gap (Fraser, Granby and Willow Creek Subbasins)	September 6, 24 – 25, 2022	2,042
Front Range (Poudre, Big and Little Thompson, St. Vrain, Lefthand, Boulder and Clear Creek Subbasins)	September 11 – 13, 25 – 26	4,346
Green Mountain	September 11, 2022	647
Roaring Fork at Glenwood	August 31 – September 4, 2022	3,763
South Platte above 285	September 18 – 19, 24, 2022	1,663
Yampa and Elk	September 2, 5 – 6, 2022	2,708
<b>Total Area of Snow Free Data Acquisitions Collected in 2022</b>		<b>15,778*</b>
Dillon	2019	866
East & Taylor	2018	1,408
Dolores Above McPhee	USGS 3DEP Data	1,668
Animas River at Durango	USGS 3DEP Data (Needs an Update)	1,807
Conejos River	2015 (Needs an update)	724
Lower Taylor	2018	575
Ohio Creek Above Gunnison R	2018	389
Rio Grande at Del Norte	Needs an update	3,396
Uncompahgre Above Ridgway	2014/2015	685
<b>Total Area of Snow Free Data Coverage Collected Prior to 2022</b>		<b>11,518</b>
<b>Total Statewide Area of Snow Free Data Coverage as of 2022</b>		<b>28,102</b>
<b>Remaining Statewide High-Elevation Area with no Snow Free Data Coverage</b>		<b>33,057</b>

*\*The total 2022 snow free flight total is less than the sum of the areas of the component basins because of flight overlap during acquisition.*

# Acquisition Costs

Snow free flights in 2022 were funded as part of a Water Plan Grant (“Phase I of the Colorado Aerial Snowpack Measurement Study”) for Northern Water in 2022. **Table 2** summarizes the components of these activities and the required funding. Snow free activities in 2022 cost approximately \$67 per square kilometer of area flown, though that number is only useful from a planning standpoint and is variable due to flight logistics, basin size, fuel costs and various other factors.

**Table 2. 2022 Snow Free Flight and Data Processing Costs**

<b>Activity</b>	<b>Cost</b>
Aircraft mobilization / demobilization	\$50,950
Calibration flights + processing	\$61,039
Product + region prep	\$70,000
Flights + processing	\$870,422
<b>Total 2022 Snow Free Flight Cost</b>	<b>\$1,052,411</b>
<i>Area Covered (Sqkm)</i>	<i>15,778</i>
<i>Unit Cost (\$/Sqkm)</i>	<i>\$66.70</i>

## Future work

As shown in **Figure 2** and **Table 1** above, the work in 2022 is a significant step toward making the entire state “Shovel Ready” for future ASO snow-on surveys. Additional snow-free activities are anticipated in the coming year with a total remaining cost \$2-3 Million to finish the state (33,000 sqkm estimated at \$66-100 per sqkm).

While complete high-elevation statewide snow-free coverage will allow for snowpack measurements in all basins identified by CASM, occasionally basins must be re-flown to update the dataset due to recent geographic changes like significant wildfires. For example, in California, the San Joaquin basin was reflown to collect new snow free data in response to the Creek Fire.

# Watershed Monitoring

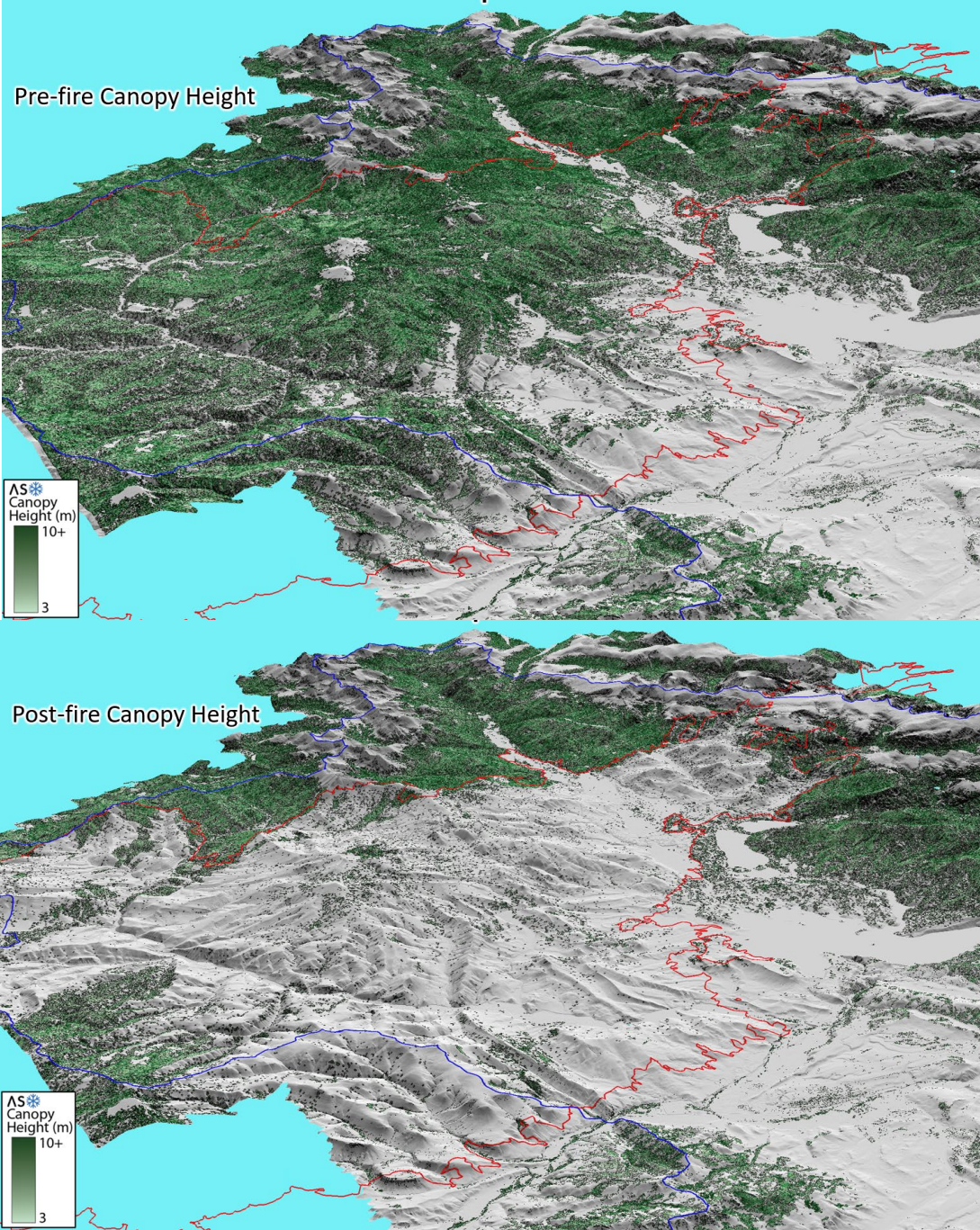
The snow free data collected by ASO, Inc. allows for other aspects of watershed monitoring in addition to the snowpack measurements it is intended for. The snow free data includes measurements over an entire basin of sufficient point density to estimate both ground elevation as well as canopy height.

While the snow-free data collected by ASO is not appropriate for every context where a lidar digital elevation model (DEM) is required, there are several use cases that have been explored in other projects, including:

- Forest stand / vegetation mapping
- Canopy change due to wildfire, beetle kill, etc.
- Land movement and erosion
- Stream morphology

**Figure 3** shows the Windy Gap basin, flown in 2022, with the boundary of the East Troublesome fire shown. The green highlighting is the measured canopy height. The top and bottom picture are the snow free coverage before and after the East Troublesome fire, showing the dramatic change in forested area.

Figure 3. Windy Gap Snow-Free data Pre- and Post- Fire





# 2022 Snow Free Data Acquisition Summaries for Individual Basins

Below are detailed descriptions of the flight coverage in each basin where snow-free data was collected in 2022:

- Roaring Fork Above Glenwood Springs
- Yampa and Elk Rivers
- Arkansas Below Granite
- Green Mountain / Lower Blue River
- South Platte Above 285
- Colorado River at Windy Gap
- Front Range (Main Fork Poudre – Clear Creek)

# Roaring Fork above Glenwood Springs

Area flown: 3763 km<sup>2</sup>

Data acquired: August 31 – September 4, 2022

Notes: This basin will have a partial snowpack measurement in 2023, with coverage of the upper third of the basin expected. The Roaring Fork watershed includes several key municipalities and multi-stakeholder projects like the City of Aspen and Ruedi Reservoir.

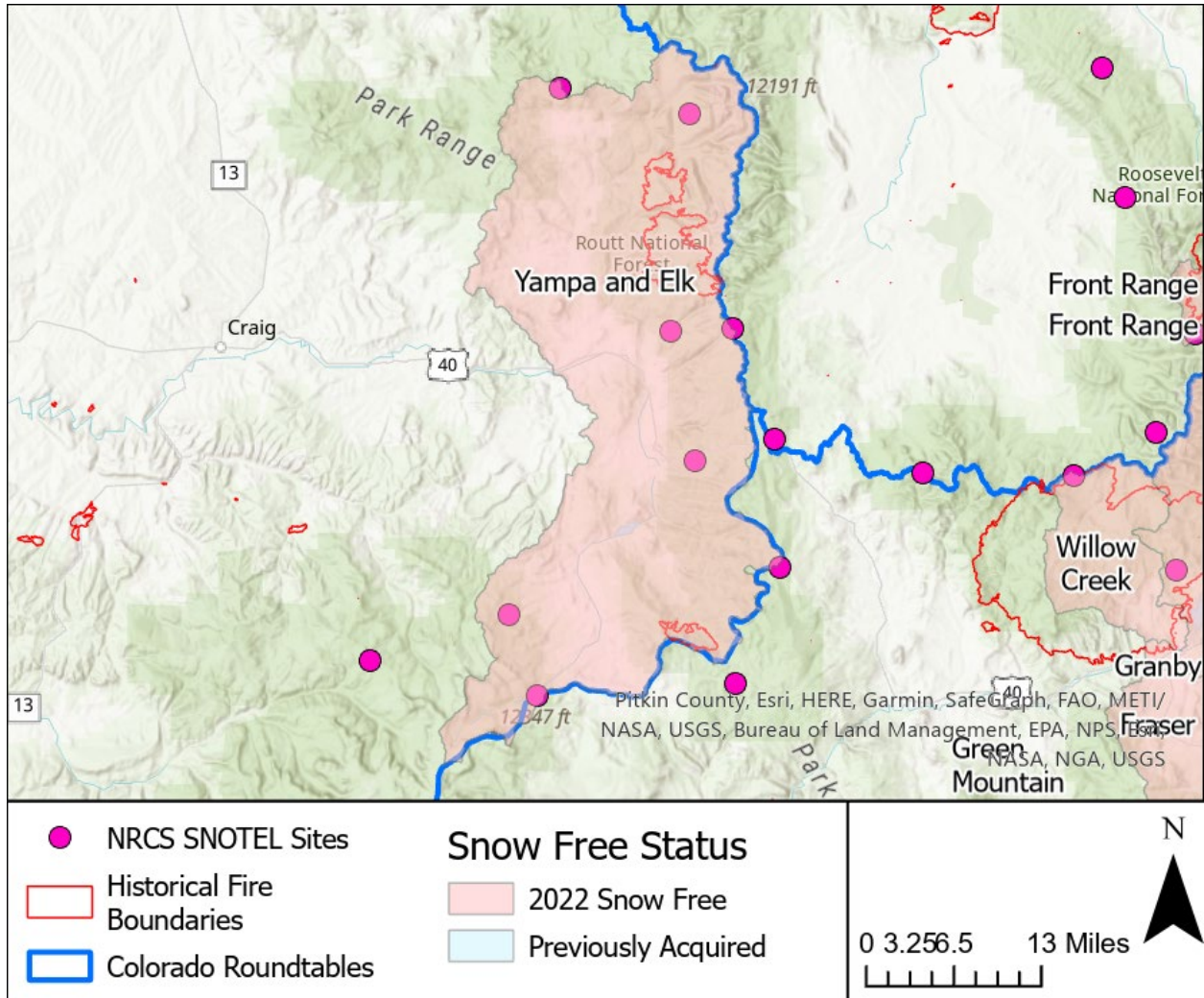


# Yampa and Elk Rivers

Area flown: 2,708 km<sup>2</sup>

Data acquired: September 2, 5 – 6, 2022

Notes: There are currently no ASO survey flights planned for these basins in Water Year 2023.

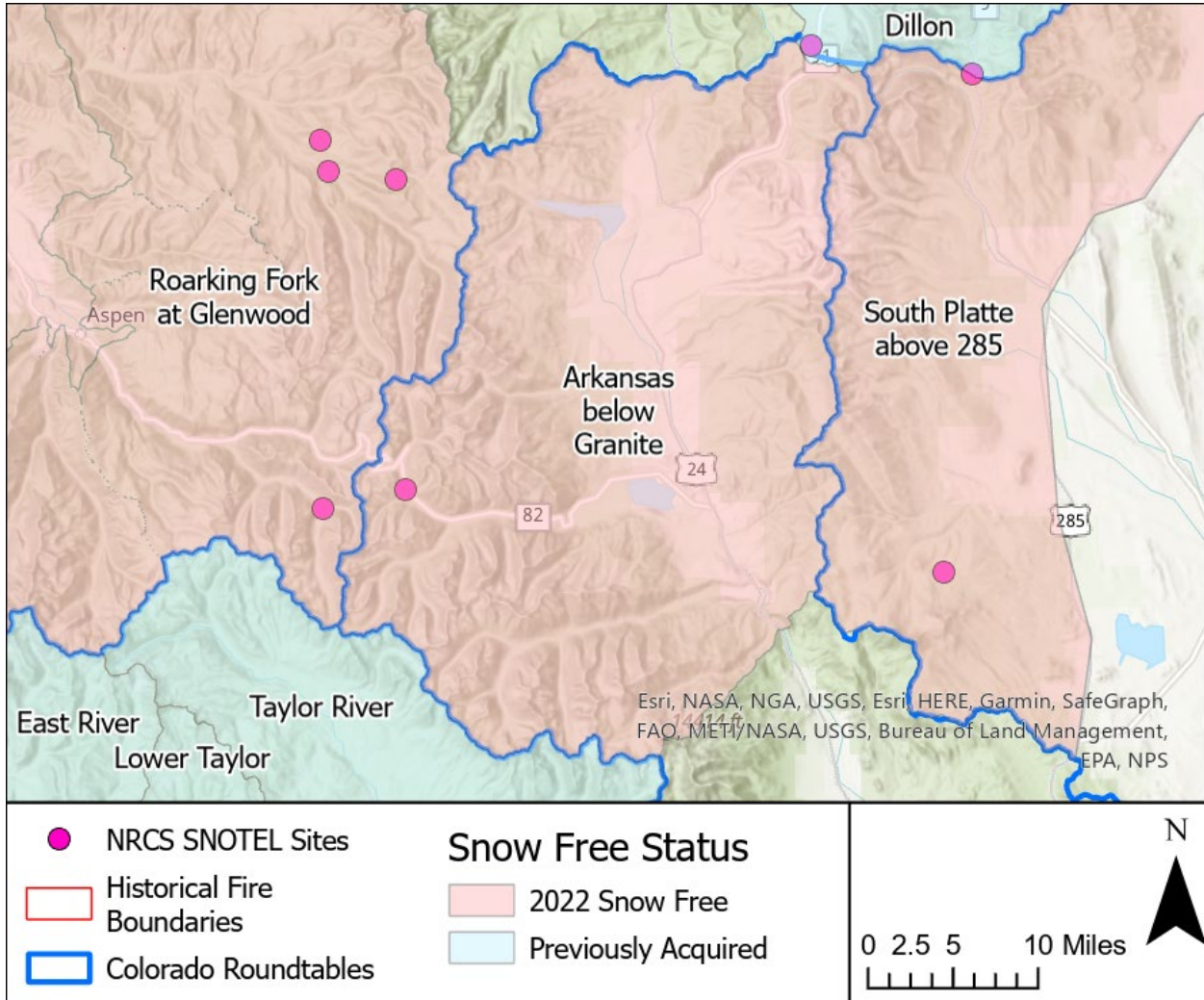


# Arkansas below Granite

Area flown: 1,415 km<sup>2</sup>

Data acquired: September 7 – 9, 2022

Notes: To address confusion around naming, “Arkansas Below Granite” is the name of the USGS Gage (ID 07087050) that the basin is based on. There are currently no ASO survey flights planned for this basin in Water Year 2023.

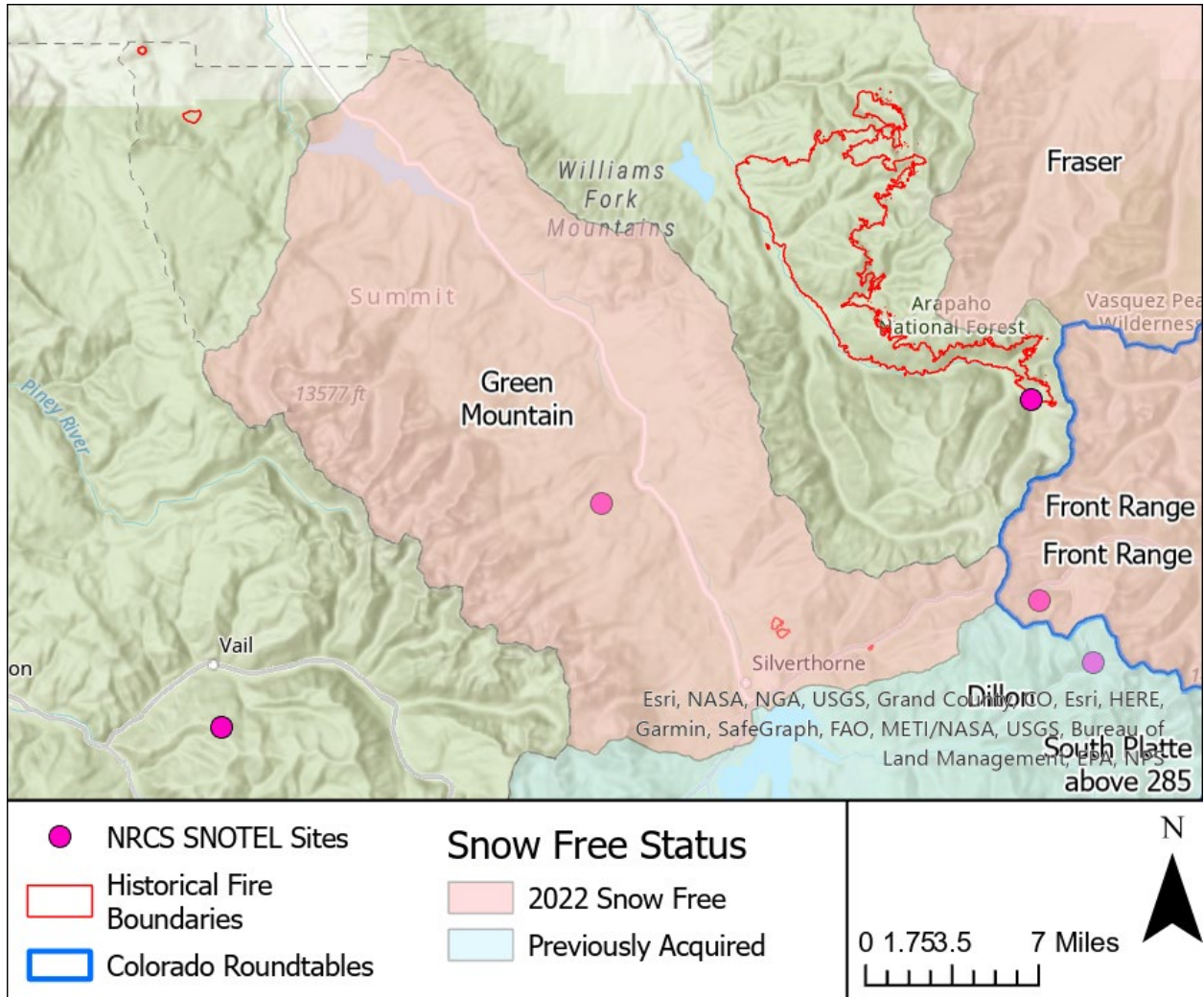


# Green Mountain / Lower Blue River

Area flown: 647 km<sup>2</sup>

Data acquired: September 11, 2022

Notes: There are currently no ASO survey flights planned for this basin in Water Year 2023.

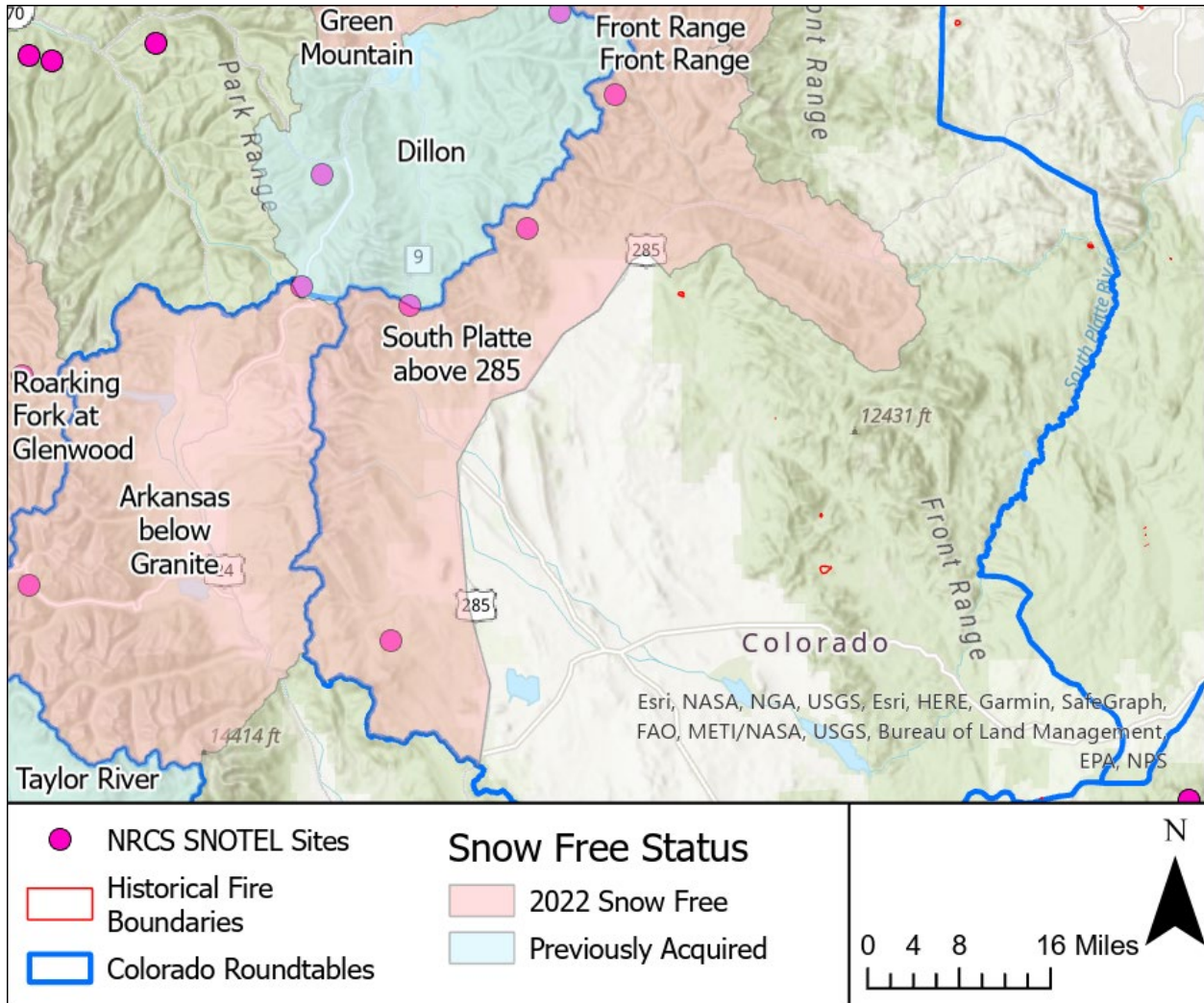


# South Platte above 285

Area flown: 1,663 km<sup>2</sup>

Data acquired: September 18-19, 2022

Notes: ASO snow measurements and WRF-Hydro forecasts are planned for this basin in Water Year 2023.

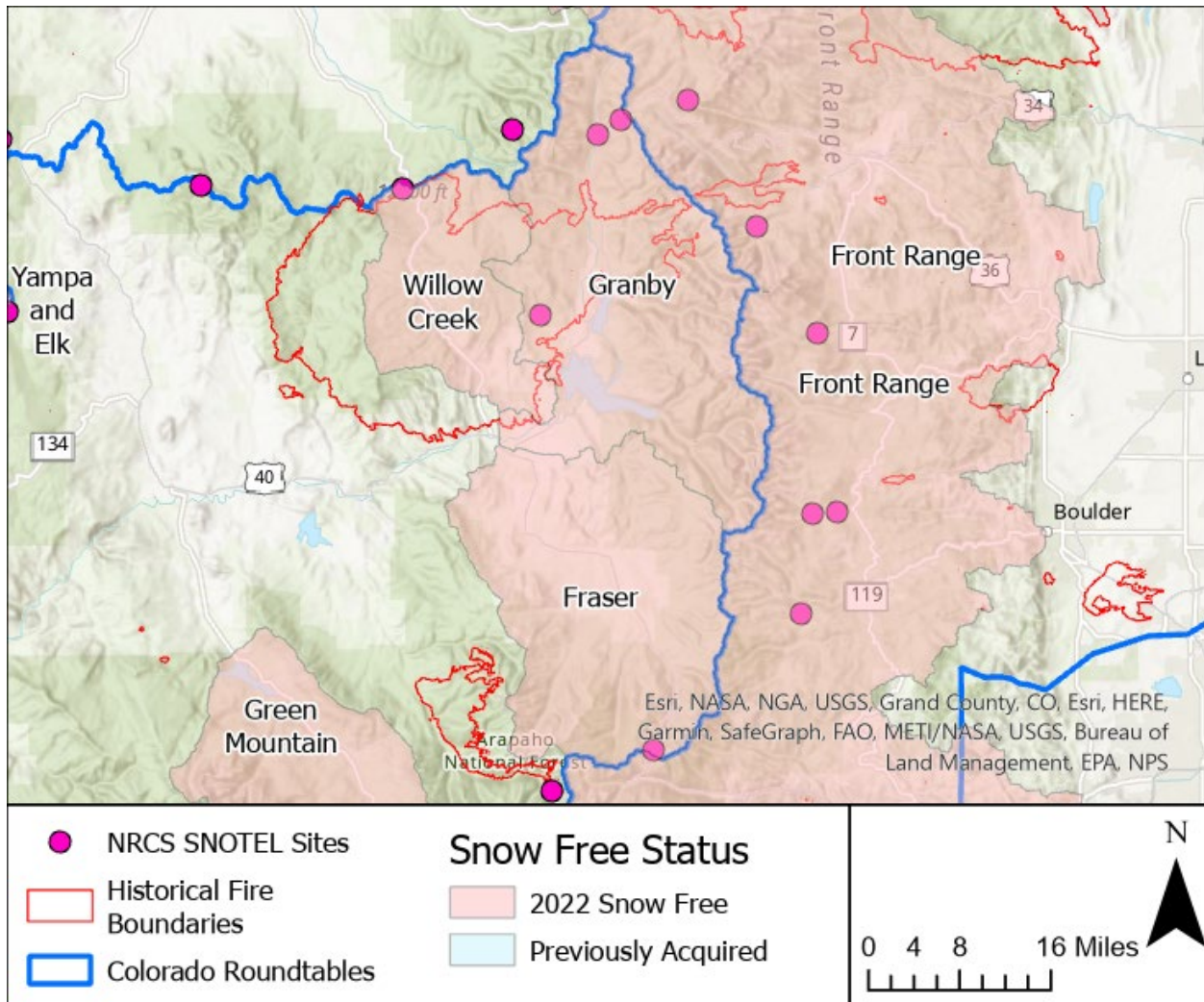


# Colorado River at Windy Gap

Area flown: 2,042 km<sup>2</sup>

Data acquired: September 6, 24 – 25, 2022

Notes: The Windy Gap basin includes the Fraser, Granby and Willow Creek subbasins. ASO surveyed these basins in Water Year 2022 and will do so again with WRF-Hydro forecasts in Water Year 2023. This basin saw one of the largest wildfires in Colorado history in the Troublesome fire in 2020. 2022 ASO surveys used existing 3DEP snow-free data as reference. The snow free lidar for this basin was reflown by ASO in 2022.



# Front Range (Main Fork Poudre – Clear Creek)

Area flown: 4,346 km<sup>2</sup>

Data acquired: September 11 – 13, 25 – 26, 2022

Notes: The Front Range coverage includes several subbasins:

- Main Fork Poudre (1053 km<sup>2</sup>)
- Big & Little Thompson (987 km<sup>2</sup>)
- St. Vrain & Left Hand (692 km<sup>2</sup>)
- Boulder Creek (591 km<sup>2</sup>)
- Clear Creek (1022 km<sup>2</sup>)

ASO snow measurements and WRF-Hydro forecasts are planned for these basins in Water Year 2023.

