MEMORANDUM  
10/3/2018

TO: BOARD OF DIRECTORS
ANDY MUELLER, GENERAL MANAGER
PETER FLEMING, GENERAL COUNSEL

FROM: DAVE KANZER, P.E., DEPUTY CHIEF ENGINEER

SUBJECT: NOAA-CIRES Presentation on NASA-sponsored Airborne Snow Observatory

No Action Requested – For Information Only

STRATEGIC INITIATIVE(S): 3.B. & C.

Attached are several documents as background information for Dr. Jeffery Deems presentation on the NASA sponsored Airborne Snow Observatory.

Dr. Deems is a research scientist specializing in mountain snowpacks and hydrology with the National Snow and Ice Data Center and the CIRES/NOAA Western Water Assessment at the University of Colorado at Boulder, and leads the Lidar and Field Operations components of the NASA JPL Airborne Snow Observatory. Dr. Deems has pioneered the use of lidar snow depth mapping in support of hydrologic science, water management, and avalanche mitigation. His interests in avalanche and snow hydrology research combine field data collection, modeling, and remote sensing in midlatitude mountain locations in the western US and around the globe.

Attachments
**Airborne Snow Observatory update:**

*mapping mountain snowpacks to enable next generation water management*

Operational runoff forecasting and water management in snowmelt-dominated watersheds currently relies on index measurements of snow accumulation and melt from a small number of point locations or geographically-limited manual surveys. These data sources cannot adequately characterize the spatial variation of snow depth and snow water equivalent (SWE) – the primary determinant of snowmelt runoff magnitude and timing.

The NASA JPL Airborne Snow Observatory (ASO) uses an airborne laser scanning system to map snow depth at high spatial and temporal resolutions, providing an unprecedented snowpack monitoring capability and enabling a new operational paradigm.

Beginning in 2013, the ASO has mapped snow depth and SWE, and provided low-latency snow depth and SWE maps to water management partners. These products enable more accurate runoff simulation and optimal reservoir management, even in years with unusual snow conditions.

ASO activities in Colorado in recent years include participation in the Rio Grande Headwaters Project and multiple flights in the Upper Gunnison River. This presentation will provide an overview of the ASO program, discuss recent results from Colorado operations, and outline planned and future activities.
California’s Opportunity to Lead

Hydrologists and water managers at state, regional, and local levels agree that ASO offers an unparalleled opportunity to improve the management of our shared resources, but California’s ability to adopt this technology and harness its benefits on a wide scale is uncertain.

At present, NASA and research funding for ASO surveys has ended. A growing coalition of local and regional water users with a strong belief in the value of the technology has emerged to provide gap funding through the 2019 snow season for ASO surveys of the Tuolumne, San Joaquin, and Kings river basins. This same water-user coalition intends to broadcast the successes experienced by the ASO program and explore opportunities to leverage the range of benefits ASO could provide if implemented statewide.

California’s History of Leadership in Snow Monitoring

In 1929, the State of California initiated a novel water supply forecasting program that relied on measurements of snow in select locations to predict spring and summer runoff into the state’s reservoirs. This investment was motivated by the “Tahoe Water War,” where the forecasting techniques helped end the long-standing litigation over operation of Lake Tahoe by reducing errors and professional judgement in reservoir operations. Today, this forecasting technique has matured into an indispensable tool for balancing the operations at California’s major reservoirs for the benefit of our economy, environment, and public safety. The snow program currently includes 359 monitoring locations that span the watersheds of the Sierra Nevada and Trinity Alps.

Why Upgrade a Working Program?

Conventional snow surveys have served an indispensable role in California water management for almost a century, but the state has also changed dramatically over the same period. The demand for water has grown along with the population, which has doubled in the past 40 years alone. We have altered our landscape, with urban and suburban growth replacing floodplains. Changes in social values have required that reservoirs be operated not just for people, but also for downstream species and habitat. With the implementation of the Sustainable Groundwater Management Act, highly precise infrastructure operations will be required to maximize groundwater recharge. Finally, the climate appears to be changing in ways that further strain the state’s water resources and how we manage them.

As a result of these changes, mistakes in water management have become more expensive than ever. The conventional snow survey and forecast methods rely heavily on professional judgement, which is prone to errors and miscalculations. As a result, water managers have had to make difficult decisions based on limited information.

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ASO technology was developed at the NASA Jet Propulsion Laboratory to map the snow water equivalent (i.e. the volume of water stored as snow) and snow albedo (i.e. the reflection of incoming radiation) completely and accurately across mountain basins. ASO measures snow depth and snow reflectivity using plane-mounted light detection and ranging (LiDAR) technology. LiDAR is similar to radar but relies on near-infrared light to measure the distance of objects. Because the measurements are being taken continuously overhead through a wide geographic area, ASO is similar to putting a snow depth sensor in every square meter of snow in the mountains. When data obtained through the ASO surveys are combined with computer-based snowmelt models, they can provide runoff forecasts for up to 10 days in the future for entire seasons for any point on a river.

ASO technology was developed at the NASA Jet Propulsion Laboratory OBSERVATORY TECHNOLOGY.

MEASURING SNOW FROM THE AIR: HOW ASO WORKS

Aircraft flies over snow-free mountains and uses laser pulses to measure reflected light bouncing back from the surface.

Laser pulses shot toward ground.

Laser light reflected measures distance and is used to create a map of the surface.

Aircraft flies over same area to measure reflected laser light bouncing from snow on surface.

Laser pulses shot toward ground.

Laser light reflected measures distance and is compared to summer survey data to show snow depth.

Bare Earth Survey

Snow-On Survey

THE PROOF

ASO performance at Helch Water: near perfect predictions over 5 years

THE AIRBORNE SNOW OBSERVATORY TECHNOLOGY

This figure compares point locations for conventional snow monitoring versus the snow coverage that exists in the Sierra Nevada and Trinity Alps which could be fully mapped by ASO.

Conventional Snow Monitoring

- Wilderness Area
- Active Surveys
- ASO Summer Survey Complete
- ASO Summer Survey Needed

2018 Estimated Snow Cover

High

Low

Moving from Pixels to a Full Screen

ASO data (orange) reveals significantly more snow remains in the higher elevations much later into the year than conventional data collection methods (blue) were previously able to accurately quantify. ASO’s methods give greater confidence in making decisions, such as allocations in drought years such as 2014. The same holds in wet years with flood management.

BENEFITS FROM ASO

No matter what type of hydrologic year California is experiencing – wet, normal, or dry – in addition to water supply and flood forecasting, ASO is useful for assessing many on-the-ground conditions that support forest health, fire management, and recreation.

Flood Management

Throughout the year, and especially in the winter and spring, flood managers apply their professional judgment to information about snow and runoff in upper watersheds to determine when and how much flood space will be needed in reservoirs to protect public safety. By providing more precise and accurate data, ASO helps eliminate this “guessing game” and:

- Prevents over-releasing water from reservoirs, impacting water supply storage
- Reduces property loss because large-scale runoff events with potential for flooding will be easier to anticipate
- Avoids false alarms to the downstream public

Water Management

Water supply allocations are frequently delayed as water managers cast dubious eyes on conventional snow pack measurements. Highly precise and accurate ASO data can allow for:

- Earlier and larger groundwater recharge deliveries in wet years
- Avoided losses from overly conservative forecasts in dry years
- More balance among competing demands at reservoirs during the refill season
- Earlier and more confident management decisions for allocating and managing environmental flows

Additional and Indirect Benefits

Data from ASO can also provide value to California through:

- Improved runoff forecasts that can help with detection of hydropower generation opportunities
- Snow assessments that could assist in supporting ski area management, Caltrans efforts, park maintenance, and avalanche risk assessments
- Imagery of forests that can improve forest and fuel management, and surveys of tree mortality and ecosystem health
- Imagery of the terrain, including seismic fault systems, that can help identify and assess landslide risk
THE AIRBORNE SNOW OBSERVATORY TECHNOLOGY

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MEASURING SNOW FROM THE AIR: HOW ASO WORKS

The airborne snow observatory (ASO) was developed at NASA to track snow cover and depth across vast geographic areas. ASO uses LiDAR technology to map snow depth and albedo, providing accurate data for runoff forecasts and water management decisions.

- **ASO Technology**: Developed at NASA Jet Propulsion Laboratory, ASO uses LiDAR to measure snow depth and albedo continuously overhead.
- **Data Integration**: Combined with computer-based snowmelt models, ASO data can predict runoff forecasts for up to 10 days in advance.
- **Widespread Coverage**: Capable of mapping entire seasons for any location on a river.

**ASO How It Works**
- **Aircraft Missions**:
  - **ASO Summer Survey**:
    - Snow-free mountains used for calibration.
    - Laser pulses reflect back with distance measured.
  - **ASO Winter Survey**:
    - Snow on surface acts as calibration point.
    - Laser pulses reflected to assess accuracy.

**Benefits from ASO**
- **No Matter What**:
  - Water supply for flood management.
  - Flood forecasting, including wet and dry years.
  - Water management decisions.
- **Highly Precise**:
  - Confident forest, fire, and avalanche management.
  - Increased water supply during drought years.
  - Water management decisions.
- **Enabling Benefits**:
  - Restoration of wetland ecosystems.
  - Flood protection.
  - Forest and wildlife management.

**ASO vs. Conventional**
- **Comparison**:
  - ASO data provides more accurate snow cover data.
  - Improved water management decisions.
  - Enhanced flood forecasting.

**Deleted Content**
- Imagery of the terrain, including seismic fault systems.
- Imagery of forests that can improve forest and fuel management.
- Snow assessments that help identify and assess landslide risk.

**Moving from Pixels to a Full Screen**
- Using ASO data, managers can make informed decisions regarding water supply, flood management, and forest health.

**BENEFITS FROM ASO**

No matter what type of hydrologic year California is experiencing — wet, normal, or dry — in addition to water supply and flood forecasting, ASO is useful for assessing many on-the-ground conditions that support forest health, fire management, and recreation.

**Flood Management**
- ASO helps prevent over-release of water from reservoirs, protecting public safety.
- Provides accurate data for forecasting flood events.
- Avoids false alarms downstream.

**Water Management**
- Data from ASO allows for timely water releases and allocations.
- Reduces water supply storage needs.
- Prevents false alarms to downstream communities.

**Additional and Indirect Benefits**
- Provides high-confidence data for forest and fuel management.
- Enables earlier and more confident management decisions.
- Prevents over-releasing water from reservoirs.
- Reduces property loss associated with large-scale runoff events.

**ASO Summer Survey Needed**
- Data from ASO can provide value to California through various applications.

- **Caltrans efforts, park maintenance, and avalanche risk assessments**
- **Hydropower generation opportunities**
- **Allocating and managing environmental flows**
- **Supporting water supply storage needs**

**ASO Summer Survey Complete**
- Data from ASO provides a comprehensive view of snow cover across California.

**ASO Summer Survey Needed**
- Data from ASO is crucial for informing water management decisions.

**ASO Winter Survey Needed**
- Data from ASO helps in assessing snow conditions across the state.
**PARALLEL MISSIONS: ASO WOULD ADVANCE SEVERAL CALIFORNIA GOALS**

**California’s Open and Transparent Water Data Act (AB 1755)**
ASO propels California towards achieving the Legislature’s vision of AB 1755. This law positions California to lead the nation in fostering public investment to demystify the complexity of water and ecological resources. The terabytes of information collected through ASO will be underpinning of accessible, discoverable, and usable data that will foster entrepreneurship, innovation and scientific discovery by the public.

**Integrated Regional Water Management**
ASO is a critical link between Regional Water Management Planning Act of 2002 and the Sustainable Groundwater Management Act of 2014 (SGMA). Development and renewal of Integrated Regional Water Management (IRWM) plans is expected to escalate in response to SGMA. Accurate and timely snowpack data builds relevancy for future IRWM planning efforts.

**Efforts to Modernize Advanced Observation Systems**
For more than a decade, advanced observation systems have been implemented by DWR to address conventional snowpack measurement systems, particularly in situ monitoring at high elevations. ASO fills these challenges and supports DWR’s evolution in a warming world.

**Central Valley Flood Protection Plan**
ASO helps achieve the Central Valley Flood Protection Plan’s goal to implement flood management solutions that use an Integrated Water Management (IWM) approach before focusing on “harder” engineering solutions. IWM is a proven solution that enhances system understanding by reducing labor costs, avoids implementation of localized solutions, and minimizes unintended consequences to nearby regions.

**California’s History of Leadership in Snow Monitoring**

**CALIFORNIA’S OPPORTUNITY TO LEAD**

Hydrologists and water managers at state, regional, and local levels agree that ASO offers an unparalleled opportunity to improve the management of our shared resources, but California’s ability to adopt this technology and harness its benefits on a wide scale is uncertain.

At present, NASA and research funding for ASO surveys has ended. A growing coalition of local and regional water users with a strong belief in the value of the technology has emerged to provide gap funding through the 2019 snow season for ASO surveys of the Tuolumne, San Joaquin, and Kings river basins. This same water-user coalition intends to leverage the range of benefits ASO could provide if implemented statewide.

**WHY UPGRADE A WORKING PROGRAM?**

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As a result of these changes, mistakes in water management have become more expensive than ever. The conventional snow survey and forecast methods rely heavily on professional judgement and extrapolation with a large margin for error because they use a few point locations to estimate water held in tens of thousands of square miles of snow cover. In the past, water managers have helped imprecise in the surveys by over- or under-estimating water forecasts to avoid flood damage or shorting deliveries. These once-acceptable practices have begun to pose problems for meeting demands of our urban, agricultural, and environmental water users.

**ASO provides invaluable information that is not otherwise available, most importantly 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

**“What you’ve done is created new reservoir space and water supply without any impacts to the current physical or environmental paradigms.”**

Dave Rizzardo, Chief of Snow Surveys and Water Supply Forecasting, Department of Water Resources

**“Having used this technology, it is hard to imagine a future without it.”**

Was Munroe, Chief Hydrologist, Turlock Irrigation District

**“Advanced observing systems are critical elements needed to support integrated water management in the 21st Century.”**

Mike Anderson, State Climatologist, Department of Water Resources

**Download a PDF of this brochure, here:**