National Aeronautics and Space Administration

NASA
WESTERN WATER
APPLICATIONS
OFFICE

Colorado River Basin Needs Assessment Report

Tools for managing a precious resource

September 2018

Workshop Participants and Contributors

(in alphabetical order)

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EXECUTIVE SUMMARY

WWAO's mission is to help solve important and pressing water-resource problems that the western United States faces today through the use of NASA remote sensing data and applications. Identifying the needs of those who manage water in the West is a key part of the process. WWAO conducted a workshop with participation from water management organizations in the Colorado River Basin to develop a set of needs that NASA may be able to address.

Key types of data needs identified include information related to water supply forecasting, snow properties and processes, evapotranspiration, crops and irrigation, groundwater quantification, and extreme event prediction.

Once the needs were identified, the participants developed preliminary "use cases" describing the need and the policy/decision making framework into which any improvement to the management problem would need to be inserted. Thirteen use cases related to these areas were developed during the workshop. These use cases are an important input into the next step of matching user needs with NASA capabilities.

Table of Contents

Glossary of Acronyms

ARC	NASA Ames Research Center
ARS	Agricultural Research Service
CBRFC	Colorado Basin River Forecast Center
CLIMAS	Climate Assessment for the Southwest
DOI	Department of Interior
DWR	Department of Water Resources
ET	Evapotranspiration
GRACE	Gravity Recovery and Climate Experiment
GSA	Groundwater Sustainability Agencies
GSFC	NASA Goddard Space Flight Center
JPL	NASA Jet Propulsion Laboratory
MODSCAG	MODIS Snow Covered-Area and Grain size retrieval algorithm
MODUS	Moderate Resolution Imaging Spectroradiometer
MTOM	Mid-term Operations Probabilistic Model
NAIP	National Agriculture Imagery Program
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanographic and Atmospheric Administration
NOAA-NWS	National Oceanographic and Atmospheric Administration – National Weather Service
NRCS	Natural Resources Conservation Services
RFC	River Forecast Center
RISA	Regional Integrated Sciences and Assessments
ROSES	Research Opportunities in Space and Earth Sciences
SGMA	Sustainable Groundwater Management Act
SNOTEL	Snowpack Telemetry
SNWA	Southern Nevada Water Authority
SWE	Snow Water Equivalent
TBD	To Be Determined
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WRF-Hydro	Weather Research and Forecasting and Hydrologic model
WWAO	Western Water Applications Office

INTRODUCTION

NASA's Western Water Applications Office (WWAO) was chartered to deliver customized NASA products to western water decision makers in usable formats to address real world water resources challenges. Therefore, WWAO is working hand in hand with water managers and NASA scientists to co-develop products and applications based on the needs of decision makers. As part of this process, WWAO hosted a Colorado River Basin Needs Assessment Workshop on April 9-10, 2018. The event brought together the WWAO team and a focused group of 20 Colorado River Basin stakeholders to discuss needs that WWAO could address.

The stakeholder participants (Table 1) were selected: a) on the basis of their work and/or role in management of water resources in the Colorado River Basin (Figure 1) and; b) previously identified interest in collaborating or partnering with NASA on water resource management issues and potential solutions. Workshop participants represented a diverse cross-section of Basin stakeholders, including state and city water agencies, federal agencies, regional water purveyors, water resource management efforts, university-affiliated research programs and non-profit activities.

The goal of the workshop was to identify, prioritize and catalog the needs of Colorado River Basin water resources stakeholders. WWAO will use this catalog to:

1. Identify where NASA capabilities can be used to add value and inform water management in the Colorado River Basin.

2. Develop concepts for projects that can then be formulated and implemented with support from WWAO.

Table 1: Stakeholder participants represent a cross section of organizations with a role in the management or use of water resources in the Colorado River Basin.

Stakeholder Participant	Role/Org
Mike Anderson	California Department of Water Resources, State Climatologist
Steve Bigley	Coachella Valley Water District, Director of Environmental Services
Paul Brierley	University of Arizona, Yuma Center of Excellence for Desert Agriculture, Executive Director
Jeff Deems	Western Water Assessment, Researcher
Michael Dirks	Water Research Foundation, Regional Liaison
Andrew French	USDA-ARS Arid Land Research Center, Physical Scientist
Peter Gill	Wyoming Water Development Office, River Basin Planning Project Manager
David Kanzer	Colorado River Water Conservation District, Deputy Chief Engineer

Jim S. Lochhead	Denver Water, CEO
Mohammed Mahmoud	Central Arizona Water Conservation District (Central Arizona Project), Senior Policy Analyst
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Brenley McKenna	Water Research Foundation, Subscriber Services Manager
Colby Pellegrino	Southern Nevada Water Authority, Director of Colorado River Program
Ursula Rick	Western Water Assessment, Managing Director

The Colorado River Basin (Figure 1) was selected due to its importance in the western United States, as well as the diverse range of challenges associated with managing the water extracted from the Basin.

Figure 1. The Colorado River Basin is the seventh largest drainage basin in the United States covering approximately 264,000 square miles. Water from the Basin and its tributaries feeds into the Colorado River beginning in the Rocky Mountains in north central Colorado and travels over 1,400 miles west and south, where it discharges into the Gulf of California.

Approximately 40 million Americans rely on the Colorado River and its tributaries to provide some, if not all, of their municipal water needs.

The Basin supports over 5 million acres of agricultural land responsible for producing around 15 percent of the nation's crops and 13 percent of its livestock. It is home to 22 federally-recognized tribes, 7 National Wildlife Refuges, 4 National Recreation Areas, and 11 National Parks. In addition, the Colorado River Basin provides critical habitat for a wide range of species, including threatened and endangered ones. (taken from [3])

Water supplies in the Colorado River Basin consist largely of surface water from the Colorado River and its tributaries and groundwater from underlying groundwater basins. According to a 2012 USBR study, total demand in the Colorado River Basin and outlying areas receiving surface water that cannot be met by other water supplies was projected to be 15.2 million acre-feet (MAF) annually.

Over the last century, water demand in the Basin has steadily increased while supply from the Colorado River has, on average, decreased. With so many people dependent on the Basin, declining supplies and the threat of cutbacks have brought Basin stakeholders together to develop strategies to reduce the impact of drought and to increase reservoir storage through conservation and drought contingency planning.

METHODOLOGY

Since the goal of the workshop was to identify, prioritize and catalog the needs of Colorado River Basin water resources stakeholders, with a future objective of developing concepts for projects that can then be formulated and implemented by WWAO, the workshop methodology was designed to enhance participation of the attendees as well as develop detailed descriptions of the needs that could lead to implementation.

The workshop was divided into two main parts. The first part was focused on identifying and prioritizing the needs. This part used a *facilitated brainstorming approach* (Table 2) to collect and gather the needs of stakeholders in the Colorado River Basin. The second part was focused on understanding how water-resource decisions are made and identifying data or information gaps in the decision-making process. The *use-case approach* used in this workshop is modeled after that adopted [4] by the Wheeler Water Institute based at the University of California, Berkeley, in collaboration with UC Water, the California Department of Water Resources and the California Council on Science and Technology. (See Appendix II for details on the workshop approach.)

Table 2: Workshop approach

Facilitated Brainstorming Approach	Use-Case Approach
Facilitated Brainstorming is a methodology aimed at soliciting and prioritizing inputs from a diverse team. It includes an idea brainstorming phase with a requirement for at least one "out of the box" idea from each participant to prevent self-censorship. After each person briefly explains their idea, related ideas are then grouped and prioritized using a method where each participant gets multiple votes to distribute among the ideas as they see fit.	Use-cases are brief analyses of how decision makers use data, in this case, the context is water resources management in the Colorado River Basin. The use-case approach involves identifying particular decisions and then analyzing the decision-making contexts behind them in order to gain insights into how data could be used to augment the process. Understanding the decision context as well as decision process or workflow is critical for delivering tools that can improve decision-making effectively. This analysis approach can help pinpoint the most valuable data-system functions and requirements from the perspective of an end user.

RESULTS

This WWAO Needs Assessment Workshop presented an opportunity for NASA to summarize relevant NASA research and observations and to listen to the attendees in order to better understand challenges faced by water managers and other key stakeholders in the Colorado River Basin. Thirteen use-cases within eight categories distilled from almost eighty water-resource-related topics were developed at the meeting. These use-cases speak to the importance of improving the overall understanding of the changing hydrology in the greater Colorado River Basin for water management and policy development, especially at the basin scale.

The eight prioritized categories developed by the stakeholders attending this workshop and the corresponding use case topics developed under each category are summarized in Table 3 below.

Table 3: Water Resource Categories and Corresponding Use Cases

Water Resource Category	Use Case Topics
Snow Properties and Processes	Improved Forecasts of Snowpack, Runoff, Water Demand, and Evapotranspiration
Water Supply Forecasting (< 1 year period)	Timely Streamflow Predictions at Sub-Basin Level
Evapotranspiration (ET) over Land and Water	Consumptive Use for Calculating Water Budgets
	Quantification of Reservoir Evaporation
Crops and Agriculture Properties and Processes	Crop Mapping
	Crop Monitoring
Irrigation Types and Methods	Irrigation Management
	Irrigation Mapping
Groundwater Characterization	Augmenting Groundwater Quantification
Extreme Event Prediction and Impact Assessment	Mitigation of Wildfire Impacts on Watershed Supply
	Augmentation of State-Level Drought Planning and Response
	Drought Planning and Response at the State Level
Water Supply Forecasting (≥ 24-month period)	Long-Term Water-Resource Planning: Predicting Changes in the Snowline, Snowpack Distribution, and Streamflow Forecasts

These topics and use-cases are generally consistent with the WWAO 2016 Rapid Needs Assessment [2] and a joint 2014 NASA and Western States Water Council Remote Sensing Workshop, however, the discussions in this workshop provided additional insights and details about the specific data needs and decision-making processes associated with the specific use cases.

During the workshop, participants were divided into three groups (A, B and C) and tasked with deriving use cases for each of the eight prioritized categories.

Group A addressed the topics related to snow properties and identified needs concerning improved stream flow predictions at the sub-basin level and improving forecasts of snowpack, runoff, water demand, and evapotranspiration.

Group B developed six use cases focused on the nexus of agriculture and water that included irrigation management and mapping, crop monitoring and mapping, and quantifying consumptive use, including reservoir evaporation as a component of consumptive use.

Group C identified opportunities for new methodologies for groundwater monitoring as the frequency and intensity of droughts in the Colorado River Basin increases demand for groundwater to provide additional water supplies for both agricultural and municipal uses.

In some cases, the groups determined that use cases were so closely related it was difficult to separate them. For example, Group A found that augmenting current observations of snow depth and volume, especially at higher elevations, remains a priority for water management in the Colorado River Basin for improving forecasts and streamflow predictions. However, the participants noted that these augmentations should only be considered in the context of the federal modeling framework, for example, models run by the U.S. Bureau of Reclamation and the NOAA Colorado Basin River Forecast Center (CBRFC). Even though decisions are ultimately made at the state, municipal, or irrigation-district level, the information flows from/through the Bureau of Reclamation and the CBRFC, and the models used by them would require significant modification to ingest or assimilate NASA data products directly. Furthermore, participants noted that forecasters at federal agencies are typically reluctant to make changes to operational models for a number of reasons. The group advised that in addition to developing individual use cases, WWAO should prioritize engagement with federal partners in the Colorado River Basin in order to understand the function and use of operational models for each particular use case. For all cases, the participants recommended that WWAO develop a deep understanding of how NASA information products are used now. In addition, the participants recommended that WWAO engage with the federal stakeholders and engage with NASA scientists who are currently working with NOAA to identify specific areas where NASA data and observations can play a role in improving water supply forecasts.

NEXT STEPS

The use cases gathered at the workshop form the basis of a catalogue of water management needs. This catalogue is a living document to be communicated and shared with the NASA Applied Sciences community.

Next steps fall into near- and long-term activities:

1. **Near term** – related to WWAO's mission to deliver products to stakeholders.

Actions:

1.1. Prioritize the developed needs based on WWAO objectives and inputs from the workshop;
   1.1.1. Identify NASA capabilities (people, data, and tools) that fit the needs
      1.1.1.1. This may include the development of new capabilities

1.2. Team NASA personnel with water resources stakeholders to formulate tasks to deliver tools and products meeting those needs
   1.2.1. The goal is to transfer the capability to generate the product from NASA to an operational agency for sustained operational use;

1.3. Select tasks for full development and funding
   1.3.1. The development team will include both NASA personnel and water resources stakeholders;

2. **Long term** - related to communication with the stakeholder community.

   Actions:

   2.1. WWAO will assess how NASA data and information products are currently used for decision making in the western United States, and develop recommendations and actions to streamline existing process;

   2.2. WWAO will maintain the lines of communication with the Colorado River Basin stakeholder community through regular follow-ups with workshop participants via focused telecons, meetings, and future workshops;

   2.3. Prioritize engagement with NOAA's CBRFC and the operational arm of the U. S. Bureau of Reclamation in order to better understand the function and use of operational models, and to map the flow of information in the Colorado River Basin.

Acknowledgements

WWAO would like to thank all of the attendees for their attendance, insight, and active participation. WWAO would also like to thank Arcadis U.S., Inc for their invaluable assistance in developing and facilitating the workshop, and the JPL Architecture Team (the A-Team) for facilitation and note taking.

Part of this work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Appendix I - References

1. “Colorado River Basin Study: Characterization of Water Stakeholders”, WWAO report (2017).

2. “NASA Western Water Applications Office Rapid Needs Assessment for Western Water Management” (2016).

3. United States Bureau of Reclamation Colorado River Basin Water Supply and Demand Study (2012), https://www.usbr.gov/lc/region/programs/crbstudy/finalreport/Study%20Report/CRBS_Study_Report_FINAL.pdf

4. “Data For Water Decision Making” (2018), University of California, Berkeley, UC Water Security and Sustainability Research Initiative, California Council on Science & Technology, California Department of Water Resources, *https://www.law.berkeley.edu/wp-content/uploads/2018/01/DataForWaterDecisionMaking.pdf*.

5. Raff, D., L. Brekke, K. Werner, A. Wood, and K. White (2012) Short-term Water Management Decisions: User Needs for Improved Climate, Weather, and Hydrologic Information. Technical Report, Climate Change and Water Working Group (CCAWG), https://usace.contentdm.oclc.org/utils/getfile/collection/p266001coll1/id/7161

Appendix II – Details of the Methodology

In January 2017, WWAO conducted a survey of water stakeholders in the Colorado River Basin[1]. This effort identified and characterized a representative cross-section of water stakeholders in the Colorado River Basin, and many of those stakeholders were represented at this workshop.

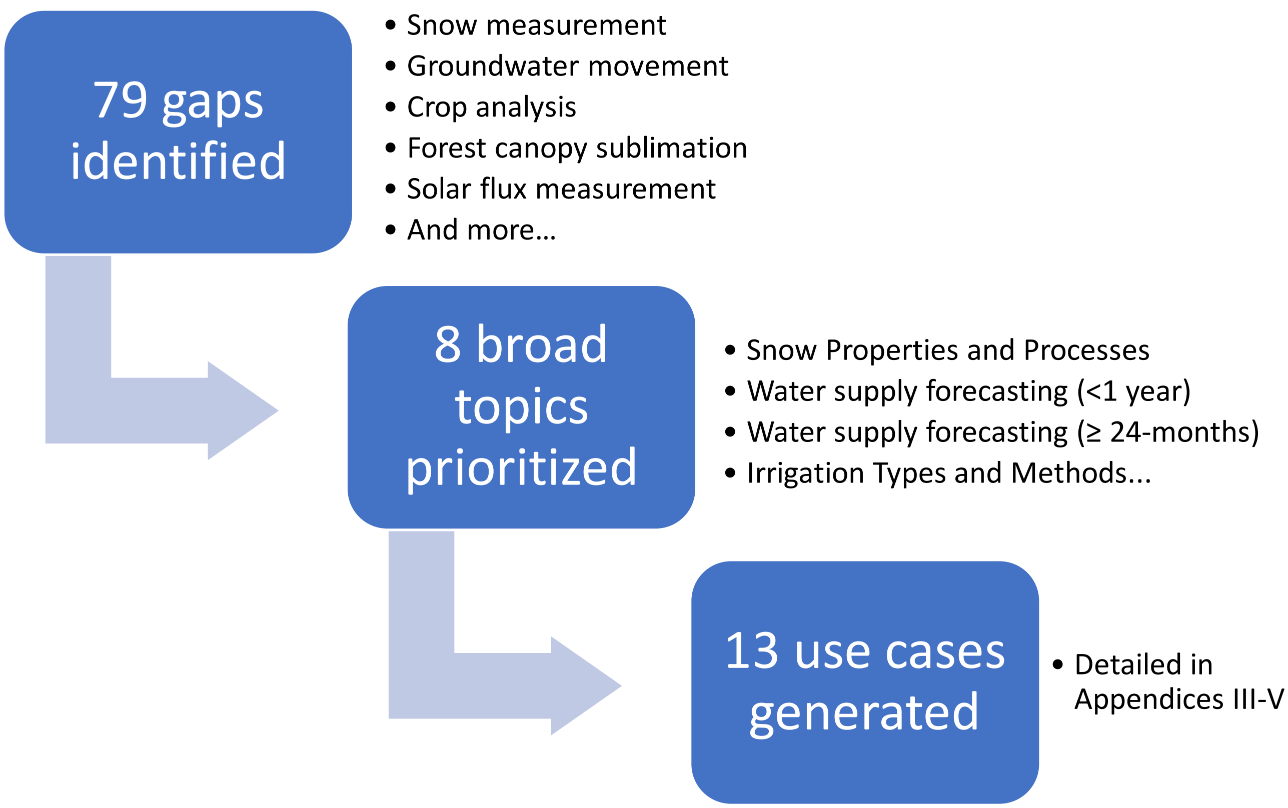
This Needs Assessment Workshop forms part of WWAO's program of strategic stakeholder engagement, which involves partnering with water-resource managers and data users from federal and state agencies, non-profit organizations, municipal bodies and academia through strategic projects, meetings, workshops, conferences, remote interactions and site visits. The workshop builds on the Arcadis report and follows on from WWAO's Rapid Needs Assessment for Western Water Management, which was published in December 2016 [2]. That assessment identified high-priority water science and management needs in the western United States and assembled a preliminary catalog of those needs. This assessment focuses on the Colorado River Basin and goes into greater depth, generating specific use cases that can be pivoted into application projects.

The study used a facilitated brainstorming approach to collect and gather the needs of stakeholders in the Colorado River Basin, with particular focus on understanding how water-resource decisions are made and identifying data or information gaps in the decision-making process. Stakeholders were asked to develop "use-cases" – short examinations of how water decision makers use data – that NASA can potentially translate into projects. The use-case approach used in this workshop is modeled after that adopted [4] by the Wheeler Water Institute based at the University of California, Berkeley, in collaboration with UC Water, the California Department of Water Resources and the California Council on Science and Technology. This group has engaged stakeholders and decision makers in the development of use cases to inform a decision-driven water data system, which forms part of the strategic plan for implementing California's Open and Transparent Water Data Act of 2016 (AB 1755).

The use-case templates that Colorado River Basin stakeholders were charged with completing for each prioritized water-resource area focus on collecting details in the following areas:

- The decision, goal or desired action in mind (the need);
- The background context to that decision;
- The main decision maker, and any other parties involved;
- Legal, regulatory and reporting requirements that drive or influence the decision;
- The decision workflow – what steps and specific actions are taken to make the decision;
- Existing data sources used and key data gaps in the decision-making process;
- Any relevant information about the characteristics of the data being considered.

In total, a significant number of ideas – 79 – were generated. These were binned into around 20 overarching thematic categories. Within each category, closely overlapping ideas were merged or combined. The stakeholder group then voted on which categories were of highest priority to their work, and the top eight were selected for further exploration in the breakout sessions during that afternoon and the next morning of the workshop. Stakeholders were divided into three breakout groups (A, B and C) and tasked with deriving use cases for each of the eight prioritized categories.



Appendix III – Use Cases Developed by Group A

Topics covered:

- **Snow properties and processes**
- **Water-supply forecasts (less than one year)**

Use cases Developed:

Use Case A1: Timely Streamflow Predictions at Sub-Basin Level
Use Case A2: Improved Forecasts of Snowpack, Runoff, Water Demand, Evapotranspiration

Stakeholder participants:

Stakeholder Participant	Role/Org
Jeff Deems	Western Water Assessment, Researcher
Michael Dirks	Water Research Foundation, Regional Liaison
David Kanzer	Colorado River Water Conservation District, Deputy Chief Engineer
Jim S. Lochhead	Denver Water, CEO
Mohammed Mahmoud	Central Arizona Water Conservation District (Central Arizona Project), Senior Policy Analyst
Colby Pellegrino	Southern Nevada Water Authority, Director of Colorado River Program

NASA participants:

Name	Role & Organization
Chet Borden	JPL A-Team Study Lead
Judy Lai-Norling	NASA WWAO / Stakeholder Engagement

Use Case A1: Timely Streamflow Predictions at Sub-Basin Level

Use Case	Timely Streamflow Predictions at Sub-Basin Level in timing and amount
Need Statement	There is a need for more interactive snow analysis products characterizing basin-distributed runoff and streamflow estimates based on snow water equivalent. Ultimately these estimates are needed to provide information related to runoff.
Description	Snowpack in the Upper Basin is a key driver for water supply. Existing streamflow/runoff models take advantage of the long historical record of snow course and SNOTEL point measurements, but there is a need for more spatially contiguous information from remote sensing to complement the existing station networks in the Colorado River Basin, particularly at locations where runoff contribution is high and forecasting skill is low.
Stakeholders/ Beneficiaries/ End Users	Data providers: • USBR • NOAA-CBRFC Decision makers: • Municipal utilities • US Army Corps of Engineers • Water contractors (e.g., SNWA) • Colorado River Basin States
Policy/Decision Context	Policy and decision contexts includes dam operations (hydro power generation, flood control, water supply delivery, groundwater recharge, and dam safety). Other policy and decision contexts include Endangered Species and Clean Water Act
Workflow	Models/processes that could benefit from this activity include models used by the CBRFC, USBR's Mid-term Operations Probabilistic Model (MTOM) and USBR's 24-Month Study.
Data Sources	Snow data for California are provided by the California Department of Water Resources (CA DWR) who together with ~50 agencies are part of the California Cooperative Snow Survey. NRCS provides snow telemetry (SNOTEL) and snow-course data and products to the other western states.
Data Characteristics	Robust techniques needed and data trends need to be understood and managed. There is a need to cover larger geographic areas than currently monitored by traditional snow survey sites. NASA's Airborne Snow Observatory project estimates snow depth and snow albedo and applies a modeling framework to derive snow water equivalent. Automated vs. manual snow monitoring • Snow data o Daily and monthly SWE, snow depth and density – current and historical (manual) o Currently, ASO is used to provide seasonal SWE estimates (automated)

	• Snow products o Reports – Snow and precipitation update reports o Maps – Snow-course SWE, depth, density o Graphs – SNOTEL water year graphs
Gaps identified / requirements	Obtain more accurate data on snowpack and snow melt and improve existing models so that accuracy goes to +/- 5%. This allows for a) better decisions on the use of this water supply; b) improved predictions of the timing and amount of streamflow at the sub-basin level.
Notes	Several Colorado River Basin stakeholders (USBR, CBRFC, SNWA, Denver Water, Central Arizona Project) have recently come together to form the Colorado River Hydrology Working Group (CRHWG). The CRHWG is also working on identifying needs in the Colorado River Basin for modernizing water management. The participants recommended participating with this group. The participants emphasized the challenge of incorporating new model into the CO River Basin decision making pipeline, there is a tendency over many years to maintain the status quo.

Use Case A2: Improved Forecasts of Snowpack, Runoff, Water Demand, Evapotranspiration

<table>
<tr><td>Use Case</td><td>Improved Forecasts of Snowpack, Runoff, Water Demand, Evapotranspiration</td></tr>
<tr><td>Need Statement</td><td>Improve medium-term forecasting (timescales of less than a year) of water supply in the Colorado River Basin, specifically of volume and timing of flow.</td></tr>
<tr><td>Description</td><td>A water supply forecast for the upper and lower Colorado basins is currently provided through a modeling infrastructure that includes a forecast component. Water managers in the Colorado Basin need to know how much snow is present, how long will it last, and where rain on snow events are occurring. However, the forecasting component is challenged due in part to the fact that relationships on which the models exist are changing. A model with improved representations of the underlying physical processes combined with spatially-distributed measurements of those processes from satellites and airborne observations will lead to improved runoff simulations and forecasts.</td></tr>
<tr><td>Stakeholders/ Beneficiaries/ End Users</td><td>Forecast data providers (to USBR) – e.g. NOAA-NWS, USGS, others
Bureau of Reclamation modelers from Upper and Lower Colorado River Basin offices
USBR Tech Group (Denver) to prototype data products or models
Colorado Basin River Forecast Center
Municipal utilities
Water contractors (e.g., SNWA)
Irrigators
Recreation industry (e.g. ski resorts, rafting and fishing companies)
Hydropower operators
Environmental compliance bodies (those assessing and controlling aquatic/watershed health, fish and wildlife presence, water quality, lead levels in water)</td></tr>
<tr><td>Policy/Decision Context</td><td>Federal regulations apply.</td></tr>
<tr><td>Workflow</td><td>Daily to Weekly: Operational determinations are made for guiding reservoir operations and release rates to maximize conservation of snowmelt runoff or to support both water supply and hydropower production. Seasonally to Annually: (1) maximize water supply allocation; (2) maintain end-of-year storage goals (mitigate drought risk).
Generic stages of weekly to annual outlook updating [5]:
Monitoring and Forecast products are provided to USBR and USACE by NOAA, NRCS, USGS and others
Information is assembled and Outlooks are updated</td></tr>
</table>

<table>
<tr><td></td><td>3. Updated Outlooks are provided to water customers and interested stakeholders
4. The basin and system conditions are monitored during the cycle*
5. Assemble information on the system conditions, service requirements (demands, constraints), and hydroclimate information (monitored and predicted) for the next Outlook update.
* Cycle is at varying temporal resolutions - fine, medium, coarse, where fine is days to weeks, medium is weeks to months, coarse is seasons to years. The models are run at daily time steps. Errors are down to 5-10% in best case, though 20% error is typical.</td></tr>
<tr><td>Data Sources</td><td>• Forecasts from operational entities – NOAA-NWS, USGS, CBRFC, USBR (MTOM ((medium term) and Colorado River Simulation System, CRSS (long term)
• Snow Water Equivalent (SWE), depth, moisture content;
• Variables affecting timing. Currently adopting MODIS products, including MODSCAG and MODDRFS, air quality data
• Snow data for California are provided by the California Department of Water Resources (CA DWR), who together with ~50 agencies are part of the California Cooperative Snow Survey.
• USDA's Natural Resources Conservation Services (NRCS) and National Weather Climate Center provide snow telemetry (SNOTEL) and snow-course data and products to the other western U.S. states.
• Automated vs. manual snow monitoring
• Snow data
    ○ Daily and monthly SWE, snow depth and density - current and historical
• Snow products
    ○ Reports - Snow and precipitation update reports
    ○ Maps – Snow-course SWE, depth, density
    ○ Graphs – SNOTEL water year graphs</td></tr>
<tr><td>Gaps/ Requirements/ Recommendations</td><td>General need for improved, robust, and more spatially explicit datasets
• With Airborne Snow Observatory data, develop a statistical spatial relationship to provide forecast improvement
• MODSCAG – apply to improve spatial performance of streamflow predictions where ground-based or airborne snow data aren't available
• Use existing data to build dust on snow projections – test w/CBRFC processes
• Explore rain on snow dynamics – Is there an increasing trend of rain on snow events in the Upper Basin.</td></tr>
<tr><td>Notes</td><td>The participants noted that:</td></tr>
</table>

	1. The importance of providing data in a usable form – with processing steps that enable the old model and the new model to use data. 2. It would be helpful for NASA to provide timely derived-data products, or raw data with the algorithms to make them operational, and to do a deep dive into how end-user are currently using existing NASA data. 3. More detail doesn't necessarily make forecasting more accurate. If the problem is broken it into sub-basins, could forecast improvement eventually get to the larger scale? 4. There is a risk that the models won't be able to operationalize NASA data. Forecasters struggle with radical change to their models. If someone were to demonstrate the value of a new model, end-users would be compelled to adopt it. Suggest engaging with WRF-Hydro model team to find specific instances where WWAO could be involved. Bureau of Reclamation has a testbed. WWAO could get NASA data to P.I.s who are proposing to NOAA for improvements to WRF-Hydro. There are agencies already tasked with this. As a general rule, WWAO and NASA should not generate new models.

Appendix IV – Use Cases Developed by Group B

Topics covered:

- **Evapotranspiration (ET) over land and water**
- **Crops and agriculture properties and processes**
- **Irrigation type and method**

Use cases Developed:

Use Case B1: Irrigation Management
Use Case B2: Irrigation Mapping
Use Case B3: Consumptive Use for Calculating Water Budget
Use Case B4: Reservoir Evaporation
Use Case B5: Crop Mapping
Use Case B6: Crop Monitoring

Stakeholder participants:

Stakeholder Participant	Role/Org
Steve Bigley	Coachella Valley Water District, Director of Environmental Services
Paul Brierley	U of Arizona, Yuma Center of Excellence for Desert Agriculture, Executive Director
Andrew French	USDA-ARS Arid Land Research Center, Physical Scientist
Peter Gill	Wyoming Water Development Office, River Basin Planning Project Manager
Brenley McKenna	Water Research Foundation, Subscriber Services Manager

NASA participants:

Name	Role & Organization
Savannah Cooley	NASA WWAO / Documentarian
Forrest Melton	NASA WWAO / Stakeholder Engagement Working Group
Randii Wessen	JPL A-Team/Facilitator

Use Case B1: Irrigation Management

Use Case	Irrigation Management
Need Statement	Provide farmers with the data they need to make irrigation decisions (when, how much to irrigate) in order to maximize crop per drop.
Description	Data are needed as inputs to irrigation-management applications. Researchers can partner with universities and cooperative extension staff, industry and non-profits to collaborate with farmers to produce an add-on to an existing system. Of central importance is fine spatial and temporal resolution data in order to optimize irrigation practices. Note that current irrigation infrastructure limits the ability to fine tune irrigation practices.
Participants	• Farmers (e.g. Yuma County Water Users' Association, Western Growers) • Water providers (e.g. Imperial Irrigation District, Coachella Valley Water District) • Researchers (e.g. USDA-Agricultural Research Services (ARS) Arid Land Research Center, Univ. of Arizona, Yuma Center of Excellence for Desert Agriculture, Maricopa County Cooperative Extension, University of California Research and Extension offices, Climate Assessment for the Southwest (CLIMAS))
Policy/Decision Context	Ensuring farmers remain within their water-rights allocation
Workflow	• Determine which crop to grow considering the following factors: environmental conditions, weather forecasts, water-rights allocation. • Make irrigation decision. Most farmers use weather reports. Some farmers augment weather reports with sensors that monitor soil moisture. However, these sensors present several limitations including cost; the expertise needed to calibrate and monitor them; the lack of knowledge of measurements in between sensors, especially in farms that have varied soil types. ET is used less frequently to irrigate than soil moisture because of the complexity associated with implementing an ET model. • Decide whether to change irrigation decision method or infrastructure (drip irrigation vs. sprinkler etc.). Changes in irrigation infrastructure happen once in a while, not necessarily every year or growing season.
Gaps identified / requirements	30-m ET every 2 days for irrigation allocation and timing. Accuracy requirements should be collected from a group of farmers.

Use Case B2: Irrigation Mapping

<table>
<tr><th>Use Case</th><th>Irrigation Mapping</th></tr>
<tr><td>Need Statement</td><td>1) Be able to distinguish, on an annual basis, between different categories of land cover – irrigated land, dry farm and non-agriculture.
2) Within the areas that are classified as irrigated, identify what type of irrigation method is being used.</td></tr>
<tr><td>Description</td><td>Use information on irrigation approach to derive consumptive estimates and forecast future irrigation demands by assessing trends in agriculture. In order to forecast trends, the irrigation mapping would need to also go back in time to create a long historic record. This information can also help policymakers identify where to focus future water-supply projects because it would show what areas in the state could benefit from additional water supplies.</td></tr>
<tr><td>Participants</td><td>State and federal agencies, water planners
State agencies (e.g. California DWR, Arizona DWR, Colorado Division of Water Resources/State Engineer, Colorado Water Conservation Board, Wyoming Water Development Office, etc.)
Federal agencies (e.g. USDA, USBR)
Regional water planners and suppliers (e.g. Central Arizona Water Conservation District/Central Arizona Project, Colorado River Water Conservation District, Metropolitan Water District of Southern California, Southern Nevada Water Authority)
Local water planners and suppliers (e.g. Coachella Valley Water District, Denver Water, Imperial Valley Irrigation District)</td></tr>
<tr><td>Policy/Decision Context</td><td>Water-rights planning in the Colorado River Basin at the state and federal levels.</td></tr>
<tr><td>Workflow</td><td>Landsat data at 30-m resolution is used to derive NDVI and other crop indices. However, this is not usually fine enough to distinguish what type of irrigation is used.
The next step therefore involves using the USDA National Agricultural Imagery Program data to digitize irrigated areas with the aerial photography. The USDA does this by hand for the Common Land Use database, but the 2008 Farm Bill prevents use of this database by another outside of USDA NASS. California creates a statewide crop type map using Landsat, NAIP (USDA) and commercial satellites.</td></tr>
<tr><td>Gaps identified / requirements</td><td>Need to estimate irrigated area and type on annual and monthly basis within +/- 5% accuracy at a spatial resolution of 30m or finer. A tool is needed to help identify irrigation areas over time in order to perform predictive analytics.</td></tr>
</table>

Use Case B3: Consumptive Use for Calculating Water Budgets

Use Case	**Consumptive Use for Calculating Water Budgets**
Need Statement	Determine consumptive use for reporting and long-term planning purposes
Description	Information on consumptive use supports the tracking of water deficits (i.e. shortfalls that occur when demand exceeds supply), as well as the tracking of which permits are actively being used. Currently each state relays on what is reported by water-rights users, in order to verify these reports, unbiased data on consumptive use is needed.
Participants	• State agencies (entities responsible for water rights administration, e.g. Arizona Department of Water Resources, California State Water Quality Control Board, Colorado Division of Water Resources, New Mexico Office of the State Engineer, Wyoming State Engineer's Office, Wyoming Interstate Stream Division). • Federal agencies (USBR)
Policy/Decision Context	Water-rights planning in the Colorado River Basin is done at the state and federal levels. This includes planning, emergency drought requirements, Indian Water Rights Settlements (legal and statutory). USBR is mandated to perform accounting of consumptive use and loss for the Colorado River Basin.
Workflow	• USBR collects consumptive use information from each state and aggregates the information it receives. • However, the 4 Upper Basin states do not use same approach for calculating ET. (Note: Calculation of consumptive use in Upper Colorado River Basin by USBR is currently being evaluated) • In Wyoming, acreage totals for different crop types are estimated. ET is then estimated for each crop and aggregate across the state.
Gaps identified / requirements	~30 m spatial resolution (field-scale), monthly, accuracy: +/- 10%

Use Case B4: Reservoir Evaporation

Use Case	Reservoir Evaporation
Need Statement	Understand how much water evaporates from reservoirs
Description	Reservoir evaporation represents a component that feeds into deriving the water budget. It also is used by reservoir managers for monitoring reservoir supplies.
Participants	• Reservoir managers • Water districts (e.g. Denver Water, Metropolitan Water District of Southern California, Southern Nevada Water Authority) • Cities • Federal agencies (USBR, USGS, Army Corps of Engineers) • State agencies (e.g. California Department of Water Resources)
Policy/Decision Context	Inter-state compacts and decree requirements, water-rights administration / management.
Workflow	• Evaporation is treated differently in the Upper vs the Lower Colorado River Basins. • In the Upper Basin, physical evaporation is allocated. However, the model is a static model that does not vary with temperature changes. Thus, there is no estimation of how increased temperatures will alter (increase) evaporation. • In the Lower Basin, evaporation is not currently accounted for because evaporation is seen as system loss, not due to an individual water use. • There are ground-based sensors on <10% of reservoirs, and ~25% of reservoir evaporation is done by "spot checks" (i.e. water-level measurements). Volume estimates are derived from these water levels. Then an evaporation model is run. Climate inputs include temperature, solar radiation and wind. • Generalize evaporation from reservoirs on a yearly basis
Gaps identified / requirements	Weekly (ideal), monthly (good) water-surface boundaries / water extent at 10-m spatial resolution or finer. This would allow the derivation of volume and could save time and effort with hydrographers who have to visit specific sites or areas that do not have monitors.

Use Case B5: Crop Mapping

Use Case	**Crop Type Mapping**
Need Statement	Determine crop types to help inform decisions related to water allocation and water policy
Description	Produce a regularly updated crop-type map in the Colorado River Basin. The temporal frequency of updates to the map would depend on region and user.
Participants	Federal, state, water suppliers, NGOs • Federal agencies (USBR, USDA) • State agencies (e.g. California DWR, Wyoming Water Development Office, water suppliers (e.g. Central Arizona Project, Coachella Valley Water District, Metropolitan Water District, SNWA) • NGOs (e.g. The Nature Conservancy)
Policy/Decision Context	Water-rights administration / management.
Workflow	• Site visits, "windshield surveys" • In Coachella Valley, "windshield surveys" happen 3 times a year • Wyoming Water Development office uses the USDA National Agriculture Imagery Program (NAIP) with 0.5-m resolution aerial photography, which they digitize to produce crop maps. Wyoming uses this information for estimating consumptive use. • Crop cover derived from the USDA's NAIP is not sufficient, especially for regions that have multiple crop types. • Need: better methods of discerning crop type
Gaps identified / requirements	Field scale (30m or ~1/4 acre pixel) to create crop-type map. Temporal frequency depends on region and user: updates should be weekly for Arizona (Sept - May), monthly for Arizona (summer), annual for Wyoming.

<u>Use Case B6: Crop Monitoring</u>

Use Case	Crop Monitoring
Need Statement	Integrate satellite data to create an agricultural recommendation system that provides early warning for disease, food pathogens, and pest detection as well as forecasts of crop yield based on projections of weather, crop type, water availability, etc.
Description	Real-time information on status of crop health (pests and stress), maturity, yield potential and food pathogens in food supply. Typically, farmers would rather over-apply pesticides than risk an infestation. If they had to hand information on early pest indications within each field, they could address those areas immediately and avoid over-application of pesticides.
Participants	Growers
Policy/Decision Context	Working within water allocations
Workflow	• Scouting (especially for high-value crops), site visits, "windshield surveys". • Farmer experience and ability to recognize conditions that are conducive to heat stress, water stress and pest infestations. • Sometimes, for instance, farmers recognize pest infestation conditions and choose to err on the side of caution by over-applying pesticides. This occurs because farmers do not have enough information to accurately determine if the observed weather conditions will actually lead to a pest infestation.
Gaps identified / requirements	Early-warning system that addresses issues of crop health (and thus can prevent over use of pesticides). Food pathogens in food supply (millions of dollars are currently spent to identify these). NOTE: if a project like this were carried out, it could potentially interfere with the perceived competitive advantage of some growers.

Appendix V – Use Cases Developed by Group C

- **Topics covered:**
    - **Extreme event prediction and impact**
    - **Water-supply forecasts (24+ months)**
    - **Groundwater characterization**

Use cases Developed:

Use Case C1: Augmenting Groundwater Quantification
Use Case C2: Mitigation of Wildfire Impacts on Watershed Supply
Use Case C3: Augmentation of State-Level Drought Planning and Response
Use Case C4: State Level Drought Planning
Use Case C5: Long-Term Water-Resource Planning: Predicting Changes in the Sierra Nevada or Rocky Mountain Snowline, Snowpack Distribution, and Streamflow Forecasts

Stakeholder participants:

Stakeholder Participant	Role/Org
Mike Anderson	California Department of Water Resources, State Climatologist
Mohammed Mahmoud	Central Arizona Water Conservation District (Central Arizona Project), Senior Policy Analyst
Patrick McCarthy	The Nature Conservancy's Colorado River Program, Deputy Director
Ursula Rick	Western Water Assessment, Managing Director

NASA-related participants:

Name	Role & Organization
Brent Alspach	Arcadis, Director of Applied Research, co-facilitator
Sarina Sriboonlue	Arcadis, Project Engineer, Documentarian

Use Case C1: Augmenting Groundwater Quantification

<table>
<tr><td>Use Case</td><td>Augmenting Groundwater Quantification (examples: Colorado, California)</td></tr>
<tr><td>Need Statement</td><td>To provide data to augment quantification of groundwater resources, in other words, to better answer questions related to groundwater production such as:
When to pump and how much?
How much can be stored?
What is the depth of the water table for recovery?
How is drought affecting the balance between surface and groundwater use? (I.e., the need for a better understanding of hydraulic connectivity.)</td></tr>
<tr><td>Description</td><td>Examples of existing gaps:
Current resolution of both spatial and temporal measurements (e.g. from GRACE satellite mission) is not sufficiently fine.
GRACE does not provide depth data – depth information is important for decision-making (e.g. whether to drill, whether to recharge and where, etc.).
There are problems with monitoring and verification of groundwater recharge pertaining to accounting of water – there is a lack of trust in the reported accounting of where the water actually went.</td></tr>
<tr><td>Participants</td><td>Entities that play a role in managing surface and groundwater resources within the Colorado River Basin e.g.
Federal (USBR, USGS)
State water resources agencies (e.g. Arizona DWR, California DWR, Colorado Water Conservation Board, Wyoming Water Development Office)
State water-rights administration agencies (e.g. Arizona DWR, CA State Water Quality Control Board, Colorado Division of Water Resources, etc.)
Local water agencies (e.g. Coachella Valley Water District, City of Phoenix, etc.)
Example 1: Colorado Groundwater Commission (reports to Colorado Division of Water Resources) responsible for establishing "designated groundwater basins" and Groundwater Management Districts.</td></tr>
<tr><td>Policy/Decision Context</td><td>State-level groundwater regulations (e.g. SGMA, Colorado Water Courts, Colorado Groundwater Commission).

Example 1: In response to issues surrounding interstate compacts and intra-basin concerns, the State Engineer promulgated rules regarding the measurement of ground water for certain river basins in Colorado.

Example 2: California's Sustainable Groundwater Management Act (SGMA)</td></tr>
</table>

	provides the framework for CA to manage the use of groundwater. sustainability.
Workflow	**Example 1:** Data include estimated thickness of saturated sands, well logs, and groundwater levels. Data are provided to users through Colorado Division of Water Resources HydroBase Online Tools. Users such as Ground Water Management District and individual property owner/groundwater producer can access data through DWR's website. **Example 2:** Data include groundwater level data and water quality data. Data are provided to users (e.g. Groundwater Sustainability Agencies (GSAs)) through DWR's data portal such as the Water Data Library. DWR is required to develop BMPs and guidance documents for groundwater management.
Data Sources	Data are provided by various state-level agencies e.g. Department of Water Resources, State Water Engineer's Office, Water Rights Office, groundwater management agencies. **Example 1:** Colorado Division of Water Resources in cooperation with various local groundwater management districts and partners, operates a statewide network to monitor groundwater levels. It provides data portal for water users on its website. "HydroBase Online Tools" includes Aquifer Determination Tools (determine volume of water located beneath a parcel of land, using estimated thickness of saturated sands), well logs, and groundwater levels. **Example 2:** California DWR provides various data portals. - The Water Data Library contains hydrologic data (groundwater level data and some groundwater quality data) for over 35,000 wells in California. The data is collected by DWR Region Offices and dozens of local and federal cooperators. - DWR's SGMA Portal allows local agencies, groundwater sustainability agencies (GSAs), and water masters to submit, modify, and view the information required by SGMA.
Data Characteristics	GRACE (spatial resolution would need to be addressed / overcome), well logs, groundwater levels, GIS maps, groundwater accounting data, climate data.

Use Case C2: Mitigation of Wildfire Impacts on Watershed Supply

Use Case	**Mitigation of Wildfire Impacts on Watershed Supply (example: Rio Grande Water Fund)**
Need Statement	To better prepare for and respond to a wildfire; to support building of forest resiliency and assist with priority setting and overall decision-making.
Description	The Rio Grande Water Fund program involves 63 partners to help reduce risk of catastrophic wildfire. The goal of the water fund is to protect storage, delivery and quality of Rio Grande water through landscape-scale forest restoration treatments in tributary-forested watersheds, including the headwaters of the San Juan Chama Project. This group needs information on the condition of forest in the watershed to inform fire setting activity, collection of baseline data, and monitoring of burn areas, how much area was treated, and to verify whether or not contractors were in compliance at burned areas. There is also a need to assess the vulnerability of the region. Use remote sensing data to set priorities, implementation monitoring, water security
Participants	• Federal agencies (e.g. US Forest Service, US Environmental Protection Agency) • State- and local-level forestry • Rio Grande Water Fund partners (60 signatories - public and private, e.g. US Forest Service, Army Corps of Engineers, USDA NRCS, Albuquerque Bernalillo County Water Utility Authority, University of New Mexico, The Nature Conservancy)
Policy/Decision Context	Regulations related to managing forest fires and managing forest in the aftermath of a fire event.
Workflow	TBD
Data Sources	TBD
Data Characteristics	TBD

Use Case C3: Augmentation of State-Level Drought Planning and Response

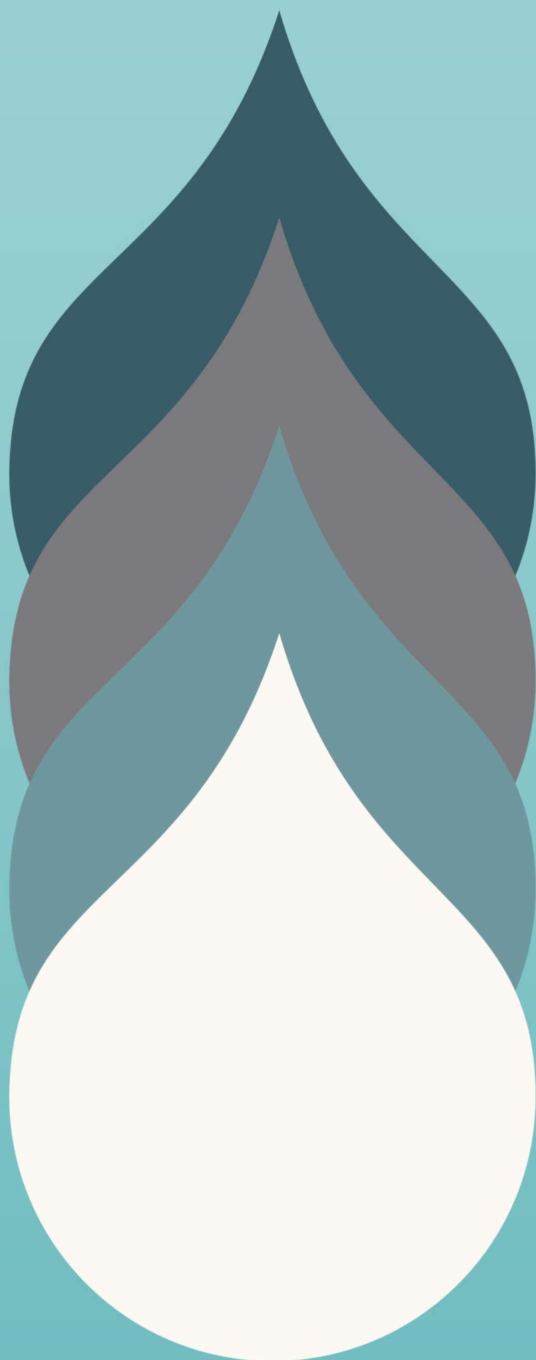
Use Case	**Augmentation of State-Level Drought Planning and Response**
Need Statement	Create data/a tool to augment drought planning and response at the state level that specifically provides supplemental drought indices and triggers. Better prepare for and respond to drought at the state level by being able to better answer questions such as: • How and when to prepare for and respond to drought? • What defines the end of a drought? • What are the impacts of a pluvial on drought mitigation? • How should a pluvial be defined? **Example**: Augmentation of NOAA's National Integrated Drought Information System (NIDIS) Drought Early Warning System (DEWS).
Description	• Supplement current triggers that are being used for drought contingency planning • Provide drought-related indices that are useful at the regional-, state- and basin-wide levels
Participants	• State-level decision makers • Water-resource managers (such as an individual state's Department of Water Resources or equivalent)
Policy/Decision Context	Regulations related to drought planning and drought response are regulated by state agencies e.g. California State Water Resources Control Board.
Workflow	Not yet known
Data Sources/Characteristics	Data comes from NOAA, CLIMAS, RISA centers. Data types include: • Land-based station data • Satellite data • Paleoclimate data • Model-derived information.
Gaps identified / requirements	• Need for more spatial information instead of amalgamated/ aggregated information • More direct measurements of land • Existing approach is to wait for impact and then respond • Goal is to be able to anticipate impact, be more proactive and better prepare

Use Case C4: State Level Drought Planning

Use Case	Drought planning and response at the state level (example: California)
Need Statement	Understand and support California's drought preparation efforts. Gather information to inform state-wide declaration of the beginning/end of a drought and inform overall drought planning and responsivity.
Description	What information is fed into a drought completion report? (E.g. precipitation, reservoir levels, snowpack characteristics, extent, timing, other drought parameters, water-rights holders / allocations / water districts.)
Participants	• California Department of Water Resources • California Governor's Office • Water agencies that respond to declaration of drought or receive drought-related aid.
Policy/Decision Context	Beginning/end of drought declaration.
Workflow	Not yet known
Data Sources/Characteristics	Data types: • Reservoir levels • Precipitation data • Agricultural water-allocation needs • Snowpack status • Allocations and needs • Urban water users Data sources: Weather stations, snow pillows/courses, reservoir-level gauges, streamflow gauges.

<u>Use Case C5: Long-Term Water-Resource Planning</u>: Predicting Changes in the Sierra Nevada or Rocky Mountain Snowline, Snowpack Distribution, and Streamflow Forecasts

Use Case	**Long-Term Water-Resource Planning: Predicting Changes in the Sierra Nevada or Rocky Mountain Snowline, Snowpack Distribution, and Streamflow Forecasts in 24+ month time scales**
Need Statement	Predict key elevation thresholds for snowline to improve current and future water-supply forecasts against the backdrop of a changing climate.
Description	Develop an Integrated Water Resources Management system (IWRM) in states that rely heavily on snow as the primary water resource; model the changes in snow-elevation thresholds using satellite and in situ data records, linked with climatology; project how this might change in the future.
Participants	Central Arizona Project, California Department of Water Resources (CA DWR), others.
Policy/Decision Context	Varies by state (e.g., CA DWR California Water Plan, updated every 5 years)
Workflow	TBD – need follow-up conversation.
Data Sources	California currently uses Bulletin 120 and *in-situ* data from stations or snow courses/pillow to predict streamflow. Arizona – Central Arizona Project Hydrology model
Data Characteristics	In situ snow data, stream-gauge data



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