

NASA Western Water Applications Office

Annual Report

2019

NASA Jet Propulsion Laboratory



Credit: Carlee McClellan, Navajo Nation Department of Water Resources.

Where there is water, there is life. With its fleet of satellites and remote-sensing expertise, NASA has a unique set of eyes over our planet that can help solve water challenges affecting people's lives. NASA's Applied Science Program's Western Water Applications Office (WWAO) is on a mission to improve how water is managed in the arid western U.S. by getting NASA data, technology, and tools into the hands of water managers and decision makers.

WWAO does this by:

1. **Identifying Needs in western water management** for information and decision support;
2. **Making Connections between stakeholders and NASA** scientists, technology, tools, and data;
3. **Building Projects tailored to meet those Needs**, engaging with stakeholders from beginning to end;
4. **Transitioning water applications** and technology into an operational, sustainable state for long-term impact.

WWAO is part of a larger effort within NASA to forge an "applied-science mindset" that maximizes the societal benefits of NASA's capabilities and projects.

In 2019, WWAO continued its focus along these four main thrusts, as elucidated below.

1. WESTERN WATER NEEDS

Partner-driven tools start with relationships. And as in all relationships, listening is key. In 2019, WWAO continued to listen to the needs of western water managers, decision makers and stakeholders, through both formal Needs Assessments and ongoing strategic partnerships.

Following on from its previous work in the western U.S., WWAO undertook a Needs Assessment in the Columbia River Basin (CRB) to identify, catalog and understand high-priority needs of water stakeholders in and around the basin, as well as the obstacles to meeting those needs. The assessment was part of WWAO's ongoing push to catalog water needs in the west using a basin-by-basin approach. By the end of 2019, WWAO had surveyed four of the ten major river basins – California, Upper Colorado, Lower Colorado and Columbia – in the continental western U.S. (west of the 100th meridian), and other basin assessments will continue apace in 2020.

Columbia River Basin Needs Assessment



WWAO's CRB Needs Assessment commenced in March 2019 with a study that summarized publicly-available information about stakeholders in the CRB who could potentially benefit from NASA's remote-sensing research and data. In April and May, a series of interviews were conducted with twenty-two stakeholders who made up a representative cross-section of policymakers, planners, water management officials, and end users in the CRB. These interviews helped establish a greater understanding of stakeholders' water responsibilities and the limitations they currently face in providing maximum value to their clients, customers, members or constituents. The surveys were used to identify, at a first pass, important water management and data challenges within the CRB and information gaps that impede decision-making progress.

Then in September 2019, WWAO convened a two-day Needs Assessment Workshop with stakeholders in Portland, Oregon to dig deeper into the issues identified. At the workshop, a variety of NASA resources and capabilities were presented. Stakeholder representatives collaborated to identify and prioritize key water management issues, coming up with an initial set of 54 needs. These needs were then organized into four broad categories: Agriculture, Water Quality, Water Supply, and Watershed Health. Discussion and analysis resulted in a shortlist of 14 'Use Cases' to move forward for further study:

- **Agriculture**
 - Crop Mapping
 - Evapotranspiration / Consumptive Use
 - Irrigation
- **Water Quality**
 - Cyanobacteria
 - Stream Temperature
 - Turbidity
- **Water Supply**
 - Evapotranspiration
 - Groundwater Recharge & Storage
 - Snow Water Equivalent
 - Streamflow Monitoring
- **Watershed Health**
 - Habitat Management
 - Land Use & Land Cover
 - Surface & Groundwater Interaction
 - Stream Temperature Dynamics

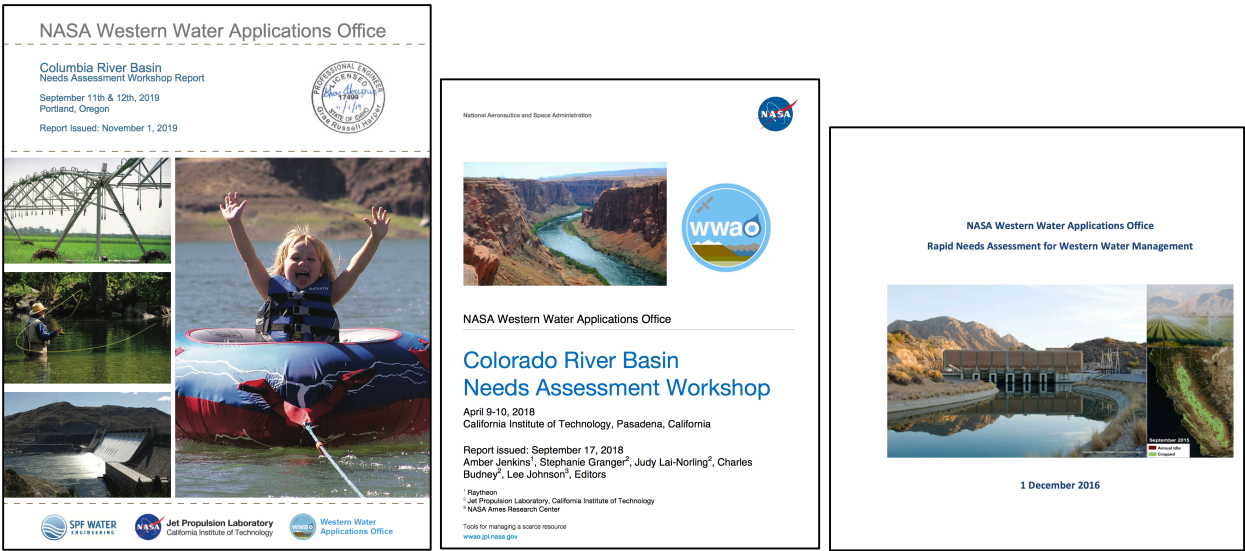
Via breakout groups, these Use Cases were fleshed out by the stakeholders with sufficient detail to enable WWAO to potentially develop strategies and technical Water Projects based around those needs. Akin to WWAO's 2018 Needs Assessment for the Upper and Lower Colorado River Basins, the findings are summarized in a WWAO technical report.

Notably, the Agriculture and Water Supply groups both developed Use Cases based on evapotranspiration (ET), and the Water Quality and Watershed Health groups both developed Use Cases based on stream temperature. ET is a critical element in water management within the CRB and, indeed, within other western U.S. river basins. From an agricultural perspective, accurate estimation of ET is crucial to the proper administration of water rights for irrigation. Agricultural irrigation is a major consumptive use of water within the CRB, and different crops, climatological conditions, and irrigation methods can create enormous variability in agricultural ET values. On a larger scale, however, accurate estimates of ET are important for determining water availability throughout entire regions and for large-scale water use planning and forecasting. It was therefore not surprising that ET was selected as a Use Case by two different stakeholder groups at the workshop, and ties in to one of the key priorities identified in the Colorado River Basin in 2018 – ET over land and water – which is now being pursued through an FY19 project concept.

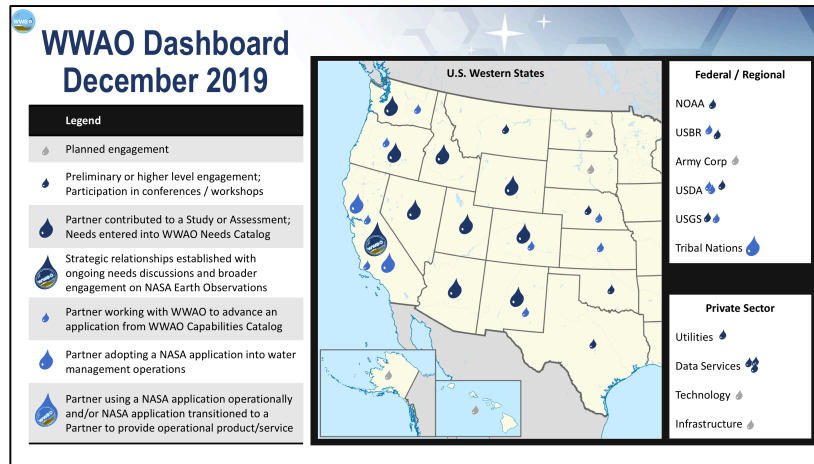
Drought monitoring and forecasting was also identified by stakeholders as an important need throughout the CRB, but was not developed into a Use Case at the WWAO workshop. (The prediction and impact of extreme events are an important issue, too, in the Colorado River Basin.) A deeper dive and / or folding in the perspective of other stakeholders in the CRB region may be needed to explore this and other topics.

Water Needs Catalog

With four river-basin-based Needs Assessments (California, Upper and Lower Colorado, and Columbia basins) under its belt, as well as a Rapid Needs Assessment that was performed soon after WWAO’s launch, WWAO has amassed a Water Needs catalog containing around 150 high-priority Water Needs and 40 detailed Use Cases. An important thrust in the coming months will be to build an online database to house these data, to share internally and externally and to help shape the development of future Water Projects in 2020 and beyond.



2. BUILDING CONNECTIONS WITH STAKEHOLDERS



Headquartered at NASA's Jet Propulsion Laboratory in Pasadena, California, WWAO is well placed to build meaningful relationships with water managers in the west. In 2019, the team continued to be intentional in expanding its reach into the public and private sectors.

Public Sector Partnerships

As of the end of 2019, WWAO is engaging 15 states in the western U.S. and the most relevant federal agencies. This engagement takes various forms: joint participation in conferences, workshops and working groups; stakeholder contributions to WWAO's formal Water Needs Assessments; nurturing of strategic partnerships via ongoing needs discussions and broader engagement on NASA Earth Observations; specific WWAO partners adopting a NASA application into water management operations. WWAO's federal and regional partners include the National Oceanic and Atmospheric Administration, the U.S. Bureau of Reclamation, the U.S. Army Corps of Engineers, the U.S. Department of Agriculture, the U.S. Geological Survey, and tribal nations.

Private Sector Partnerships

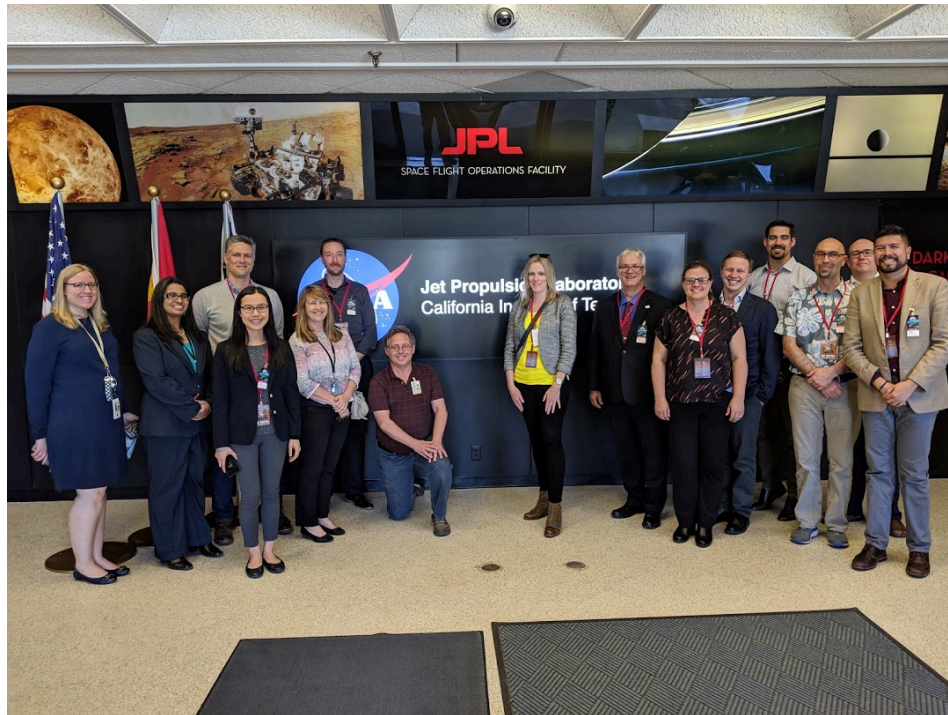
WWAO's strategic engagement with the private sector gained momentum in 2019 through its Water Alliance (details below) and through the Water Funder Initiative. The Water Funder Initiative is a collaboration of leading philanthropic groups (such as the S. D. Bechtel, Jr. Foundation, Gates Family Foundation, and William and Flora Hewlett Foundation) seeking to deliver promising water solutions through strategic investments in the U.S. Their focus, which starts in the American west, where the scarcity and reliability of clean water are urgent issues, aligns well with WWAO's strategy and vision.

Strategic Working Groups and Efforts (Selected Highlights)

➤ With California:

- In April 2019, WWAO hosted a very successful meeting with the California State Water Resources Control Board (CA SWRCB) at NASA Jet Propulsion Laboratory. The two parties discussed ways in which NASA capabilities might prove helpful in the Water Board's work and both groups found the discussions enormously helpful towards efforts to identify high-impact applications for satellite data. After the event, Joaquin Esquivel, Chair of the Board, said, *"We're at an incredibly exciting and singular time in our fields of work, where the strong investments in science and technology are quickly coming to bear on our most wicked resource*

challenges.” The SWRCB emphasized its commitment to continuing the discussion and collaboration between the Water Boards and NASA.



WWAO and the California State Water Resources Control Board at NASA Jet Propulsion Laboratory, April 2019.

- WWAO provided recommendations on data science planning efforts to the CA SWRCB's Data Science Advisory Board, which is offering guidance on this and other topics related to the CA SWRCB Open Water Data Initiative. Priority areas include data literacy, machine learning and computer vision, and development of standard data models.
- WWAO delivered a Tools and Data document to Mike Anderson, California State Climatologist, as part of its participation in the Hydrology Observations and Prediction Advisory Council for the State of California. This engagement represents a longer-term effort that may result in future projects or initiatives.
- WWAO continued to be very actively engaged with the California Department of Water Resources (CA DWR), and was asked to join the CA DWR Data Acquisition Round Table Committee.
- WWAO continued to pursue an MOU with the Metropolitan Water District of Southern California in support of multiple water-resource management efforts.
- With Texas, WWAO engaged with the Harris-Galveston Subsidence District to discuss the feasibility of measuring subsidence in the Houston, Texas area using satellite data. Satellites could potentially provide valuable information to fill in the gaps between the roughly 200 Global Positioning System (GPS) sites that the district currently uses to monitor subsidence rates, which can reach 2 cm a year.
- WWAO hosted a meeting at NASA Ames Research Center with scientists from the U.S. Geological Survey Water Mission to explore potential collaboration opportunities.
- WWAO connected with the U.S. Army Corps of Engineers (USACE), specifically its Chief Water Resources lead and Columbia River Basin lead, to explore potential partnerships. WWAO also engaged the USACE Collaboration & Public Participation Center of Expertise and Institute for Water

Resources to discuss stakeholder engagement approaches.

- WWAO took part in the NASA Harvest Conference as well as Harvest domestic strategy discussions. NASA's WWAO and Harvest teams will continue to work together to identify areas of strategic overlap, particularly around the use of water in agriculture.

Workshops and Events (Selected Highlights)

- In January, WWAO participated in the Aspen Institute Roundtable on Water Data for the Colorado River Basin in Salt Lake City, Utah. The workshop provided important insights into water data needs in the Colorado River Basin, and mechanisms used to share data between state and federal water management agencies in the western U.S. One key outcome was a request from the Western States Water Council to WWAO to co-host a workshop on technology transfer from NASA to operational partners, which WWAO held in August 2019 (see section 4).
- WWAO attended the Spring American Water Resources Association Conference in Omaha, Nebraska, in March. The team made promising connections with players such as the Nebraska Department of Natural Resources. Insights into Integrated Water Resource Management, as well as how NASA could contribute to water-resource management in Nebraska and beyond, were gleaned.
- In July, the office took part in the Second National Drought Forum in Washington, D.C. There, WWAO explored NASA's involvement in the National Drought Resilience Partnership, reached out to various private-sector partners, and held strategic discussions on projects relevant to drought.
- WWAO was part of the 2019 National Water Use Data Collaboration Workshop, a joint effort between the WSWC Water Information System (WIMS) and the USGS, in September. The goal of the gathering was to focus on the status of water-use data science and state agency strategies for getting to high-quality water use information, including through online reporting, automated data checking, and remote-sensing tools. WWAO gave an invited talk on its work as part of a session on Regional Water Use Data Efforts.
- In October, WWAO was asked to give a keynote speech at the World Water-Tech Summit North America Summit in Los Angeles to a primarily private-sector audience, which was well received. Fruitful connections with water companies were forged and folded into the WWAO Water Alliance activities (details later).



WWAO Manager Indrani Graczyk gave a keynote speech on the value of satellite data in solving critical water issues at the World Water-Tech North America Summit in Los Angeles, October 2019.

- And in December, WWAO was invited to present a series of posters on its work at the Colorado River Water Users Association (CRWUA) meeting in Las Vegas. The meeting, which is an annual gathering

of the water management movers and shakers up and down the Colorado River from Wyoming to Mexico, touched upon topics such as how Drought Contingency Plans are working.



One of several WWAO posters invited to showcase the program's work at the Colorado River Water Users Association meeting in December 2019.

WWAO Water Alliance

In 2019, WWAO continued its momentum in establishing a Water Alliance of private and non-profit water partners focused on common goals. The Alliance is a group of hand-picked private companies and non-profit groups involved in western-water management and infrastructure that can potentially partner with WWAO to 1) forge innovative collaborations and 2) help transition WWAO's Water Projects out of NASA to sustainable, long-term states.

Following efforts in 2018 to define a shortlist of target organizations, identify synergies, and reach out to a variety of players, in 2019 WWAO recruited ten mainly private-sector-based entities to take part in its Industry-Based Water Needs Assessment. These are Esri, Tetra Tech, WaterStart, AECOM, Quantum Spatial Inc., California Water Services Group, Parsons Engineering, Jacobs Engineering, Maxar Technologies, and the Freshwater Trust. Together, they focus on everything from geospatial data and analytics, to infrastructure services and solutions, to water treatment and flood management, to water conservation and ecosystem restoration, and to technology and innovation acceleration.

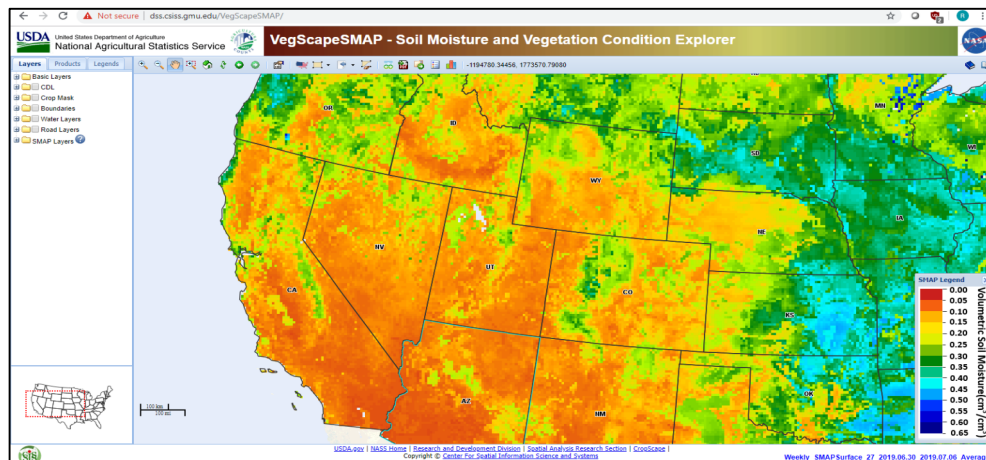
Akin to the Needs Assessments that WWAO has been conducting in the public-sector sphere, the private-sector process will first involve carrying out a detailed Water Needs Survey for each potential partner organization via a series of in-depth interviews. The results will be compiled in a technical report in Q1 of 2020. Following analysis by the WWAO team and depending on the potential synergies identified, WWAO plans to host either an Industry Water Needs Assessment Workshop for multiple Alliance partners or hold a

number of one-on-one meetings to identify specific areas of collaboration with NASA and potential pilot activities.

3. WATER PROJECTS

In 2019, WWAO continued to fund six Water Projects in implementation phase. These projects reported significant technical achievements and end-user interactions, highlighted below. WWAO's Water Projects address core issues facing the western U.S. now and in the future – water availability, water consumption, drought, and water forecasting. Project partners include farmers, local and tribal communities, and water managers, decision makers and agencies at the federal, state and local levels.

i) High-Resolution Soil Moisture



Goal: Harness soil-moisture data from satellites to improve measures of soil moisture at both ground-level and in the root zone for agricultural and other partners.

Lead: Rajat Bindlish, NASA Goddard Space Flight Center

Partners: U.S. Department of Agriculture's National Agriculture Statistics Service (USDA NASS); University of Virginia.

Capability: Mapping surface soil-moisture at 1-km spatial resolution

Applications: Crop-yield forecasting; Drought monitoring and impact assessment.

Achievements & Highlights:

- A thermal-inertia-based algorithm was developed to disaggregate SMAP soil moisture using land surface temperature and vegetation data to a scale of 1 km. An operational platform was built to host the new high-resolution data, and implemented in a NASA high-performance computing system. The soil moisture outputs were validated using in-situ measurements from the USDA's Agricultural Research Service's SMAP core validation sites. A paper describing the approach has been submitted to a peer-reviewed journal.
- Data gaps result from the thermal inertia approach due to cloud cover in the MODIS data employed. To bridge these gaps, a new approach based on soil texture distribution was developed. A second technical paper describing this approach is being prepared.
- A fruitful meeting was held with the USDA NASS western region office in Sacramento, which is linked to almond, pistachio and farming groups in California. As a result, the USDA regional directors wish to use the data next growing season.
- High-resolution soil moisture products from April 2015 to December 2019 were delivered to the USDA NASS for the purpose of evaluating soil condition during planting season and identifying areas that could prevent successful harvesting next season.

- USDA NASS has ingested the high-resolution soil moisture into its online VegScape system. A beta version of the system is now available at <http://dss.csiss.gmu.edu/VegScapeSMAP/>.



In late 2019, the project team had a fruitful meeting with USDA regional directors to demonstrate the value of integrating their improved soil moisture product into the NASS VegScape system.

ii) Satellite-Based Drought Reporting on the Navajo Nation

Goal: Use satellite data to improve the way the Navajo reports and manages drought, specifically through the Navajo Nation Department of Water Resources Drought Report, which is presented to emergency managers and used to allocate drought-relief dollars to each chapter in the Navajo Nation.

How: Build a Drought Severity Evaluation Tool (DSET) that combines satellite Earth observations and in-situ data in a user-friendly web application. The app is run through Climate Engine, which uses Google's Earth Engine to do on-demand processing of satellite and climate data through a web browser.

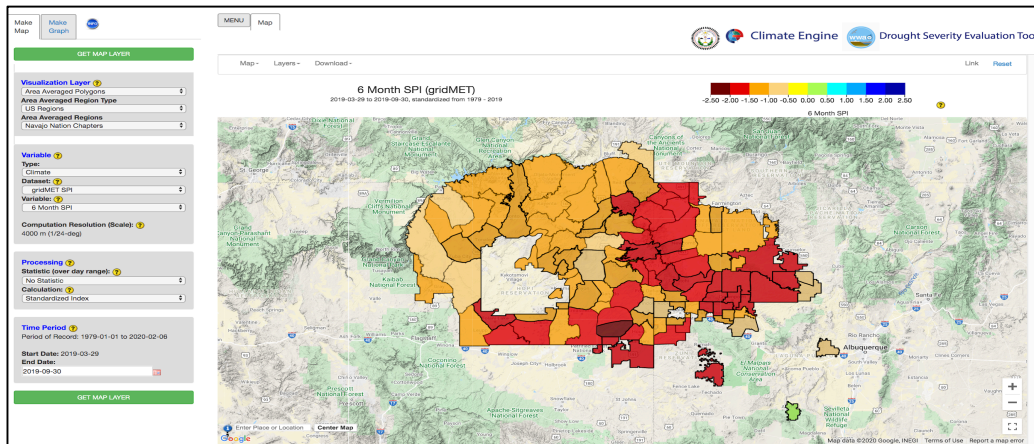
Lead: Amber Jean McCullum, Bay Area Environmental Research Institute / NASA Ames Research Center

Supporting Investigators: Britta Daudert and Justin Huntington (Desert Research Institute); Henrietta Marks (Navajo Nation Department of Water Resources).

Partner: Carlee McClellan (Senior Hydrologist, Navajo Nation Department of Water Resources (NN DWR), Water Management Branch)

Capability: Mapping drought indicators

Applications: Quantification of drought severity at local scales; Allocation of drought emergency funds / resources for drought mitigation.



Map from WWAO's Drought Severity Evaluation Tool displaying area-averaged 6-month Standardized Precipitation Index values for Navajo Nation Chapters.

Achievements & Highlights:

- Technical advances:
 - A beta version of the DSET beta was completed: <https://app.climateengine.org/dset>.
 - NN DWR rain-gauge data were incorporated into the DSET. This step, the first achieved within the Climate Engine computing interface, allows the user to view all 85 rain-gauge locations and historical data across the Navajo Nation to compare alongside NASA data in map and time-series formats.
 - The team developed the capability to generate area-averaged geocomputing of 3-, 6-, 9- and 12-month drought indices for Navajo administrative boundaries on-the-fly in map and time-series format.



Navajo Nation Natural Resource Management at a Remote Sensing and Climate Engine Training, April 2019, Flagstaff, Arizona.

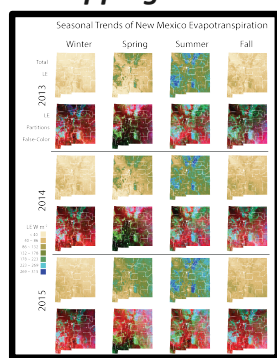
- Stakeholder Engagement and Tool Transition:
 - In April 2019, an in-person technical workshop and feedback session for tool improvement was held in Flagstaff, Arizona, with 14 participants from Navajo Natural Resource Management agencies and regional partners. The training was held in collaboration with the Desert Research Institute and NASA's Indigenous Peoples Capacity Building Initiative (IPI). It focused on an introduction to remote sensing, DSET beta testing, and feedback discussions.
 - Another in-person capacity-building workshop, held in December 2019 in Window Rock, Arizona, was led by the project's Navajo Nation DWR intern and partner, with 16 participants from the Navajo Nation Department of Agriculture and students from Dine College.
 - An NNDWR intern joined the team to help with tool testing and transition to the partner agency.

- Community Outreach: A feature story highlighting the project was published in collaboration with WWAQ; a training highlight was published in collaboration with NOAA's National Integrated Drought Information System (NIDIS); an article was published on the Space for U.S. website; a presentation on the work featured at the Tribal Leaders Summit in collaboration with NASA's IPI; and the project was highlighted in three talks at the 2019 American Geophysical Union Fall Meeting, including at the Google booth.



Left: WWAQ feature story on Navajo Nation project. Right: Project partner Carlee McClellan (left) and P.I. Amber McCullum (right) attending the American Geophysical Union Fall Meeting in 2019.

iii) Evapotranspiration Mapping in New Mexico



Seasonal ET trends, which were provided by the project for inclusion in New Mexico's State Water plan.

Goal: Develop operational evapotranspiration (ET) data for New Mexico so it can better monitor drought conditions, process water-rights applications, and refine its water-budget modeling.

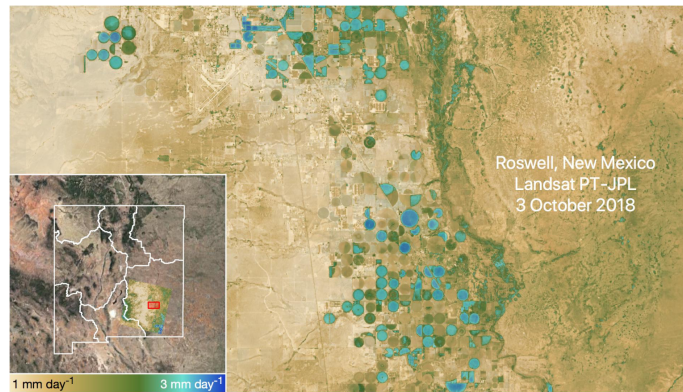
How: Operationalize production of NASA Earth-Observing-System-based drought monitoring data for New Mexico water management. Develop access to and a dissemination mechanism for the drought product suite.

Lead: Josh Fisher, NASA Jet Propulsion Laboratory

Partner: New Mexico State Engineer's Office; Interstate Stream Commission.

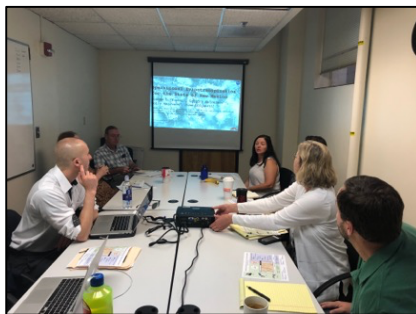
Capability: Field-scale mapping of ET

Applications: Administration of water rights; Wildfire risk assessment; River basin studies.



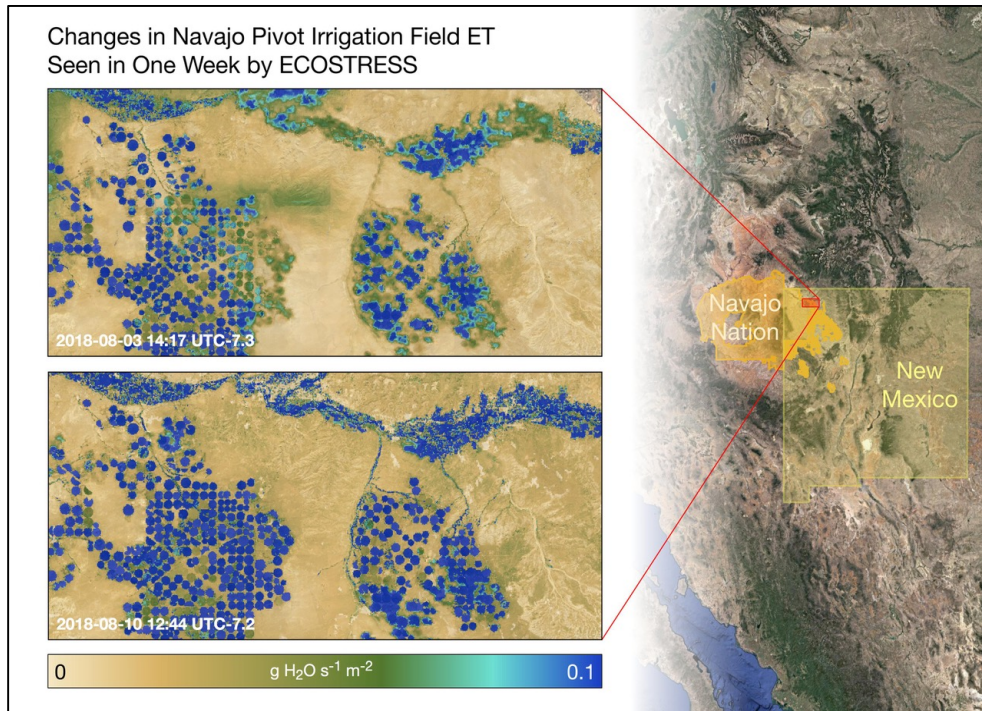
Achievements & Highlights:

- The team demonstrated the ability to process the Landsat Analysis Ready Data record to meet the requirements of water rights and forestry Use Cases in New Mexico. Successful delivery of daily PT-JPL ET data for use in water management has been achieved.
- Notably, the project has shown it can offer a significant advance in water-rights management, by offering the ability to provide water managers with actionable evidence – historical, multi-decadal, satellite-based records of field-scale ET and beneficial use at the field scale.



Numerous in-person meetings, teleconferences, and interactions were held with state and local representatives.

- Seasonal ET trend figures were delivered to New Mexico for inclusion in its State Water plan.
- Development began on a data browser to help end-users access the ET data, and cloud storage and cloud services have been identified as a data delivery mechanism and a potential element of a transition plan.
- Testimonials from partners in the New Mexico Office of the State Engineer have been enthusiastic. “I am extremely interested in the data and can’t wait to see the [maps],” said Jerri Pohl, Statewide Projects Supervisor. Frank Scott, Statewide Projects Lead, said “I am really proud to be a part of this project.”
- Discussions were held with Jake Collison of the University of New Mexico about his floating evaporation pans, which are able to provide an accurate accounting of the evaporative losses within a water system. This inspired a flurry of development at NASA and interactions with partners about the development of water-surface evaporation capabilities to remotely sense changes in reservoir water height.



iv) Satellite-Based Irrigation for Better Crop Management

Goal: Help farmers in California and beyond grow food in more sustainable ways, with less water and fertilizer, using NASA satellite data inputs.

How: 1) Enhance NASA's Satellite Irrigation Management Support (SIMS) system to reliably provide real-time data for the CropManage decision support system within 48 hours of satellite overpass; 2) Upgrade CropManage to improve model skill and strengthen satellite data incorporation; 3) Fully build out a beta version of the CropManage-SIMS application programming interface (API).

Lead: Alberto Guzman, NASA Ames Research Center

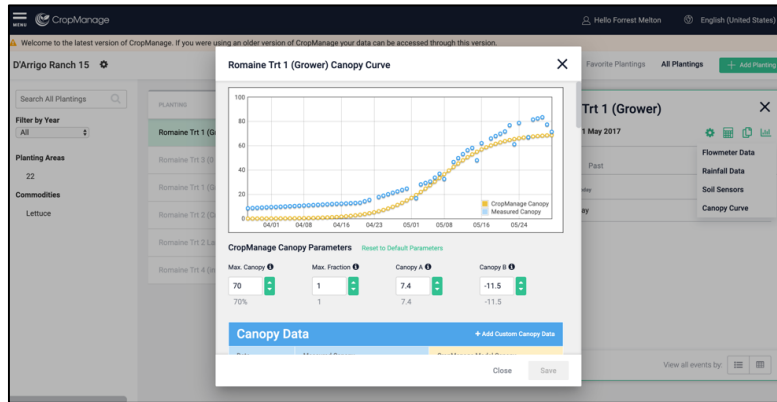
Partner: University of California Cooperative Extension



The team has been meeting with growers in the field to discuss expansion of the CropManage-SIMS application to additional high-value crops.

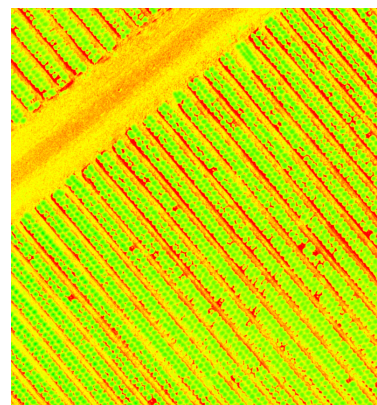
Achievements & Highlights:

- NASA's SIMS system and the CropManage-SIMS API were integrated into Google Earth Engine.



SIMS data are now integrated with the new version of CropManage via the SIMS API, and are being used by growers to evaluate crop-canopy development and irrigation recommendations.

- Fractional cover data were analyzed for the period 2016-2018 to identify any crops that may require crop-specific relationships.
- UAVs are being flown to collect high-resolution aerial imagery that will be combined with satellite data to develop crop-specific data.
- The commercial sector was engaged and an ongoing collaboration is being pursued with Ceres Imaging to evaluate SIMS fractional cover for almonds, walnuts, and vineyards. Ceres was given access to the SIMS API for the purposes of site evaluation and review of aerial remote-sensing data.
- Rapid atmospheric correction routines were implemented to further reduce data latency from the time of satellite overpass to data being available in CropManage.



- The project held two CropManage training workshops in May and June, as well as various meetings with growers in the field to discuss expansion of the CropManage-SIMS application to additional high-value crops and to plan demonstration projects. In March, an invited presentation was given at the Salinas Valley AgTech Summit to hundreds of growers and agriculture technology companies.

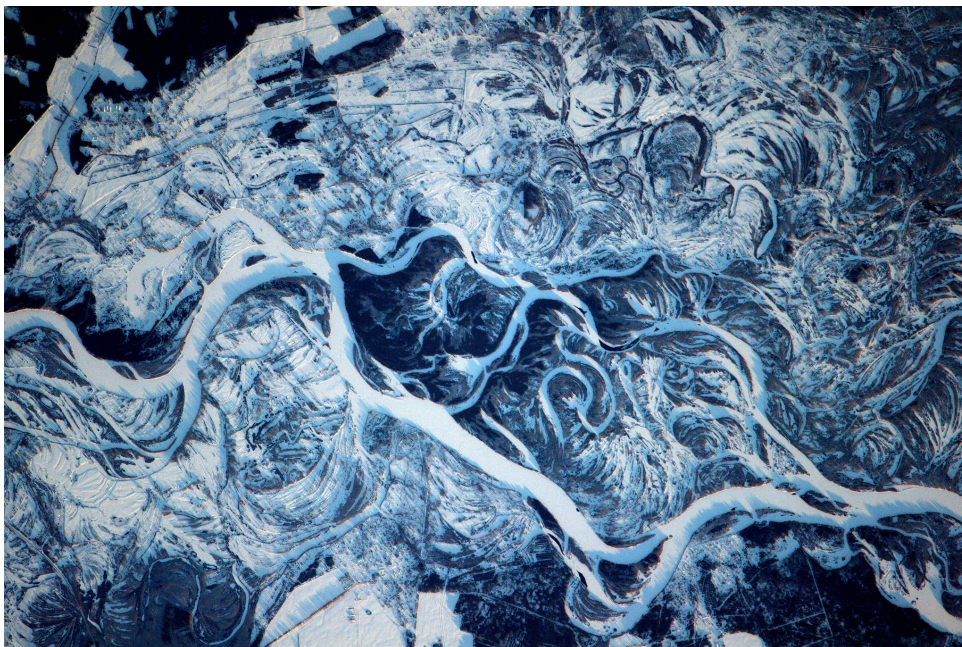
- Scheid Vineyards approached the team in April to partner on expanding the CropManage-SIMS framework to support vineyards, building on the extensive data network Scheid has already developed. The Almond Board of California invited the team to provide input into their Strategic Plan.



Deployment and maintenance of flux towers at validation sites for vineyards and celery.

- NASA Administrator Jim Bridenstine made note of CropManage-SIMS in his February address (<https://blogs.nasa.gov/bridenstine/2019/02/19/nasa-is-everywhere-talking-to-the-farm-community/>).
- Towards the end of the year, the project team met with over 40 staff from the CA DWR to discuss a transition plan for the project. A two-day workshop organized jointly with the CA DWR is being planned to determine a technology transition strategy.

v) NASA's Airborne Snow Observatory and Automated Water Supply Model



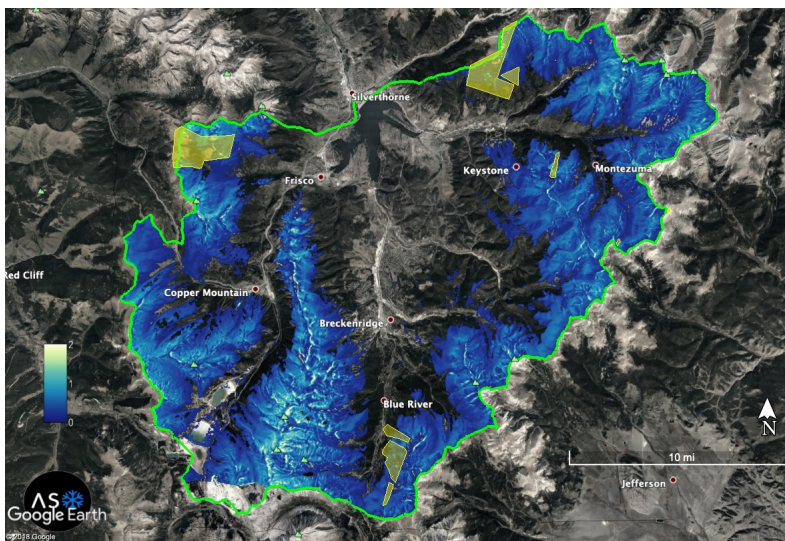
Goal: Incorporate data from NASA's Airborne Snow Observatory (ASO) into precipitation runoff models to improve forecasts of runoff in California's Sierra Nevada and Colorado's Rocky Mountain ranges. Such predictions help reservoir managers make informed decisions about water allocation and reservoir operation, balancing often conflicting needs for drought planning, ecological flows, groundwater recharge and flood prevention.

Lead: Tom Painter, University of California Los Angeles

End Users / Decision Makers: California Department of Water Resources; USDA Agricultural Research Service; San Francisco Public Utilities Commission; Irrigation districts.

Achievements:

- 2018 saw the automated integration of ASO's snow-depth data products into the USDA Agricultural Research Service's Automated Water Supply Model (AWSM), which forecasts the supply of many water basins.
- In February 2019, WWAO participated in the first CA DWR ASO Steering Committee meeting. The purpose was to discuss status and priorities for ASO activities during the 2019 snow season, as well as to shape planning for the 2020 snow season. The committee was set up to help ensure that a concept of operations is developed for 2020 that facilitates the successful transition of ASO to an operational snow-survey capability outside NASA that can forecast snow water equivalent (SWE).
- In June 2019, ASO passed a milestone for transitioning its SWE forecasting service to the private sector. Using data collected by a commercial lidar airborne services provider, several SWE forecasts were delivered to the Colorado Water Conservation Board, offering a crucial demonstration of the feasibility of ASO SWE forecasts. The flights were operated by Quantum Spatial Inc. and data processing was funded in part by WWAO.



Computer rendering of ASO flight data collected in June 2019 showing snowfields above Dillon Reservoir in Summit County, Colorado. Credit: NASA ASO.

- Denver Water Tap published a story highlighting this milestone, explaining that the use of ASO data has helped Denver Water take its first major step forward in snow information gathering since the 1980s. *"The analysis of the flight data indicated there was nearly 19 inches worth of SWE still on the ground in the basin between 12,000 and 13,000 feet on June 24. That was more than double the 9.5 inches of SWE the computer modeling indicated might be in place at that elevation that day."*

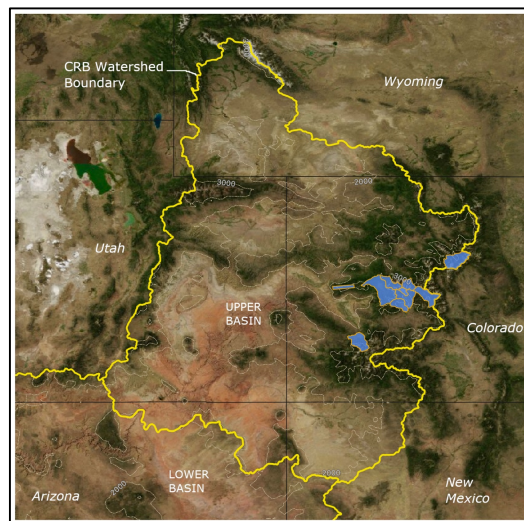
vi) Using NASA's Airborne Snow Observatory to Improve Runoff Forecasts Provided by the U.S. River Forecast Centers

Goal: Derive tangible pathways for the quantitative use of NASA's ASO SWE products to improve runoff forecasting using existing operational tools at the Colorado Basin River Forecast Center (CBRFC) and California Nevada River Forecast Center.

Lead: Kat Bormann, NASA Jet Propulsion Laboratory

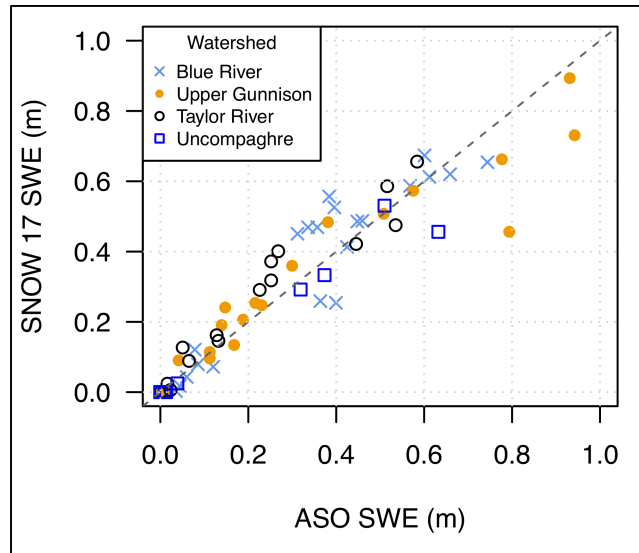
Partners: NOAA Colorado Basin River Forecast Center, Southern Nevada Water Authority, University of Colorado Boulder.

Motivation: Streamflow across the western U.S. is predominantly snowmelt-driven. As such, SWE representation in models is a major source of uncertainty in current runoff forecasts. Sparse point-measurement networks have been recently supplemented with spatially-complete snow depth measurements and SWE estimates from NASA's ASO. ASO data represent the state-of-the-art for instantaneous SWE mapping in mountainous regions and are specifically designed to improve runoff estimates. However, there are logistical barriers to inserting these new ASO data into operational streamflow forecasts that are provided by the River Forecast Centers of the National Weather Service (such as the Colorado Basin River Forecast Center (CBRFC)). This project directly compares zonally-averaged SWE from ASO with areal estimates of SWE from the River Forecast Centers' Snow Accumulation and Ablation Model (SNOW-17 model).



Achievements & Highlights:

- This project began in earnest in 2019 and will come to a close in 2020. Data from around 30 ASO snow surveys conducted between 2013 and 2019 are being used for the analysis. 75% of the ASO data being employed have been processed, with 25% still to be processed.
- Initial results suggest that the zonal SWE values from SNOW-17 are highly correlated with those from ASO.
- SNOW-17 performance in Colorado varies greatly with month, with smaller errors at near-peak SWE (April) and larger errors during late season (May). SNOW-17 performance in California varies greatly by sub-basin.



Comparison of zonal SWE obtained from ASO data and the SNOW-17 model in Colorado.

- The CBRFC has begun hindcasting work to evaluate if runoff forecasts improve when SWE data are updated in near-real-time.
- A report will be completed in 2020 summarizing the findings and recommending next steps and tangible actions for using ASO data to improve water operations.

New Water Projects



Credit: Carlee McClellan, Navajo Nation Department of Water Resources / Kim Locke, NASA Harvest.

At the heart of WWAO's Project Formulation process, we continue to ask four questions:

- What is the current way of solving the issue?
- What does the partner specifically need?
- How can NASA data contribute to improving the issue?
- How will a tool be used after the project has ended?

In 2019, WWAO formulated two new Water Projects. To ensure solutions that reflected the consensus needs of the water decision-making community, WWAO's starting point was the Water Needs that had been identified at its Colorado River Basin Needs Assessment Workshop. WWAO then:

- **Prioritized the Water Needs and identified three top needs.** These were Streamflow, Consumptive Use and Drought Monitoring.
- **Surveyed NASA capabilities related to the top needs.** NASA Water Capabilities were matched to the top needs using 1) WWAO's Capabilities Catalog and 2) by identifying researchers who were able to devise new projects with partners and were interested in doing so. Emphasis was placed on the *impacts* that a new capability will have on decision making and the ability to *transition* the NASA research to sustained use by the stakeholders.
- **Formed project teams.** External project partners were identified and teamed up with NASA researchers.
- **Asked the project teams to develop project concepts.** Two concepts were sent out to WWAO's Capability and Stakeholder Engagement Working Groups for review. Both concepts passed their review criteria and moved to a formulation phase, which was fully-funded for up to 12 weeks, in which project ideas were fully fleshed out.
- **Selected projects to move to implementation phase.** Project awards for these two new efforts are expected in the spring of 2020. Attention will be paid to whether projects can be addressed in the short-term, medium-term or long-term.

4. RESEARCH TO OPERATIONS



Black Canyon of The Gunnison National Park, Colorado. Credit: National Park Service.

NASA has a wealth of information - Earth observations, tools and scientific expertise – that can help state, local and federal water agencies respond to complex water problems. But while water managers recognize the value of NASA’s capabilities for decision support, it has historically been challenging to use the data operationally. Bridging the “great divide” between Research and Operations, sometimes also termed technology transfer or applications transition, is a key area of focus for WWAO because it can dramatically affect the long-term impact and sustainability of its solutions to water problems.

Applications Transition Panel

WWAO chaired a panel on Applications Transition at the NASA Water Resources Team Meeting in Portland, Oregon, in July. The panel members – Charon Birkett (University of Maryland), Blake Schaeffer (U.S. Environmental Protection Agency (EPA)), and Jennifer Jacobs (University of New Hampshire) – shared advice on how to effectively move (water) science from Research to operations. They discussed what they have learned about transitioning applications / technology to sustained use by a non-NASA partner or end-user.

Technology Transfer Workshop



In August 2019, the Western States Water Council (WSWC) and WWAo hosted a joint workshop on Technology Transfer in Irvine, California. The goals were to understand how different agencies approach the technology transfer and Research to Operations (R2O) process, to identify best practices, and to discuss existing barriers to the successful infusion of a new capability into operational water management systems at state and federal levels.

The workshop was opened by Rep. Grace Napolitano who spoke about the critical value of water data and the importance of collaboration between state and federal agencies to advance the use of water data in water management, planning and policy. About 70 people attended in-person and remotely. They included P.I.s and project teams supported by NASA (CyAN, Western ET, ESI, ASO, Sierra Snow, Fallowed Area Mapping) and representatives from federal (USGS, NOAA, USBR, EPA) and state (CA DWR, WY State Engineer's Office, Oregon Water Resource Department, Nebraska Department of Natural Resources) agencies.

The workshop drove home the point that technology transfer is really challenging, and that it is never too early to think about project transition. Examples of truly successful R2O do exist, but these success stories can take a decade of concerted effort between different stakeholders to achieve.

A key best practice that emerged from the workshop discussions was the importance of broadening (and sustaining) communications in projects with a NASA Applications Readiness Level (ARL) of around 5 to 7.

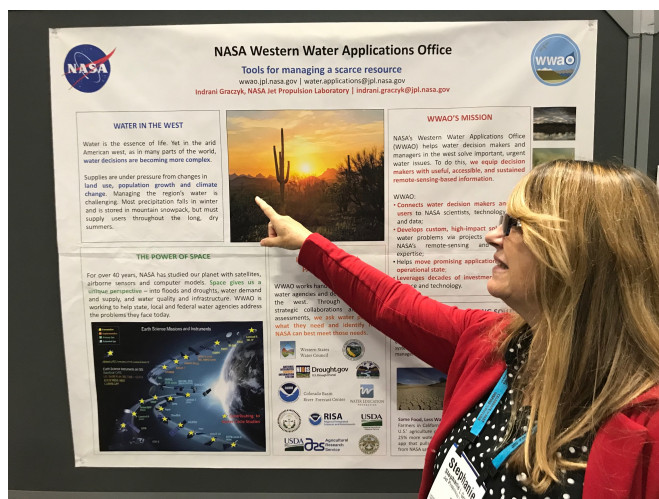
Such communications should involve representation from senior management and IT staff at the operational / partner agency. This would allow adequate lead time for budget and IT planning processes to ensure that the financial and technical resources required for technology transfer could be secured.

The gathering was a first step to developing a broader community and discussion around R2O in (western) water management. Many of the best practices and key takeaways represent starting places for action at WWAO, WSWC and the other participants' institutions. These takeaways and next steps are summarized in a workshop report, available at <https://wwao.jpl.nasa.gov/articles/20200114/WWAO-WSWC-Workshop-Report-2019-final.pdf>. Effective implementation of these lessons learned will require significant time, resources and planning. For this reason, WWAO proposes to host regular meetings (for instance, an annual workshop) on the topic.

Science to Action Forum

In December 2019, WWAO hosted a technical session on “Enabling science- and data-driven water decisions” at the American Geophysical Union (AGU) Fall meeting in San Francisco, California. Around 30 presenters from diverse backgrounds and institutes talked about best practices for moving from research to evidence-based decision making and action, mainly in 5-minute lightning-style talks, making it one of the largest sessions in the Science to Action track. One seasoned AGU organizer described the forum as “one of the best sessions I have attended”, and attendees appreciated listening to a range of topics in succinct style.

The speakers were made up of water scientists, water managers, decision makers and practitioners who are not traditionally part of the AGU. Their home institutions included the U.S. Bureau of Reclamation, CA DWR, the Navajo Nation, the Southern Nevada Water Authority, ECMWF, NASA, and the USGS. Session participants hailed from the U.S., U.K., Uganda, China and Thailand.



WWAO Program Strategist Stephanie Granger presents a WWAO overview at the Science to Action poster session.

5. LOOKING AHEAD

In 2020, WWAO will grow from strength to strength, deepening its reach and impact in the water and applied science arenas.

Water Needs

In early 2020, WWAO's Columbia River Basin Needs Assessment report will be released to the community. The Use Cases identified therein will be prioritized by WWAO's Stakeholder Engagement Working Group for the purposes of driving needs-based Water Projects in 2020.

Needs Assessments will be carried out for the Rio Grande and Missouri River Basins. As in previous years, each of these assessments will 1) commission a stakeholder survey, 2) hold a Needs Assessment workshop and 3) culminate in a technical report with fleshed-out Use Cases that can be used to inspire future NASA Water Projects.

By the end of 2020, WWAO will have surveyed six of the ten major river basins in the continental U.S. west of the 100th meridian – the California, Upper Colorado, Lower Colorado, Columbia, Missouri and Rio Grande River Basins. A Needs Database will be built to store the Needs and Use Cases derived from all Needs Assessments done to date. This database will be available outside and inside NASA and will help inform WWAO project development, NASA mission work, partnership building, and other strategies.

Engagement and discussions will continue with a diverse range of partners and stakeholders across the western U.S. at the local, regional, state and national level. The WWAO team will explore information needs and data gaps where NASA capabilities could be of use, synergies and partnership opportunities.

Water Projects

WWAO will continue to fund its portfolio of continuing Water Projects – the High-Resolution Soil Moisture Product, the Navajo Nation Drought Tool, ET Mapping in New Mexico, and Satellite-Based Irrigation for Better Crop Management.

The project focused on using NASA's ASO to improve runoff forecasts provided by the U.S. River Forecast Centers will come to an end in the first half of 2020 once data processing and hindcasting is complete. A detailed report of findings and recommendations for next steps will be delivered to the WWAO team and NASA Applied Science Program.

Early on in 2020, the formulation review of WWAO's two FY19 Water Projects will be completed. These projects, which are based on Water Needs identified in the Upper and Lower Colorado River Basins, will then shift from formulation to implementation phase. Details of these projects will be shared at that time.

In parallel, WWAO's Project Formulation process will continue to be refined. Projects will continue to be needs-driven. WWAO's Stakeholder Engagement and Capability Working Groups will work together to match NASA capabilities to needs identified in the Columbia River Basin and beyond.

WWAO Water Alliance

In 2020, WWAO will complete its first Industry-Based Water Needs Assessment and begin to define collaborations and / or pilot projects with the private sector. In Q1, WWAO's Private Sector Water Survey

will be conducted, and the results compiled into a report that the WWAO team will digest and analyze. Depending on the potential synergies identified, WWAO will either host a single Industry Water Needs Assessment Workshop later on the year with multiple Alliance partners in attendance, or it will hold a variety of one-on-one meetings to uncover specific areas of collaboration with NASA.

Research to Operations

WWAO will continue to lead the way in exploring how to effectively build NASA science applications that can ultimately be transitioned to an operational state.

In 2019, WWAO began establishing an interagency network of experts that can facilitate effective R2O in water management. In April 2020, WWAO will continue this work by co-hosting with the Western States Water Council (WSWC) a second R2O workshop in Irvine, California. The workshop will bring together NASA scientists and partners from federal and state agencies that have experience with technology transfer. The workshop will:

- strengthen interagency partnerships and increase support for R2O within state and federal entities;
- establish pathways that overcome barriers to technology transfer;
- define / refine best practices for streamlining R2O;
- establish the WSWC's Western Federal Agency Support Team (WestFAST) as a bridge to help transition applicable NASA-supported research to operational federal programs;
- help the research community understand the connections needed to successfully transition projects to operational federal agencies.

Also in 2020, WWAO will publish a peer-reviewed paper on its R2O findings – best practices, challenges faced, lessons learned and examples of successful case studies – with co-authors from the WSWC and U.S. Environmental Protection Agency, with the aim of reaching a broad, interdisciplinary community. WWAO's work will also help make up a special issue of the Journal of American Water Resources Association (JAWRA), which will publish a collection of NASA remote-sensing achievements in the field of water and discuss successful examples of R2O.

Market Survey on Evapotranspiration

In 2020, WWAO plans to conduct a survey to quantify the size of the ET market with the aim of helping the office assess viable operational pathways for ET-based information. The work will start by identifying a segment of ET data users to canvas, either within agriculture and water use or in water reporting and monitoring agencies. A contractor will then be selected to conduct the market survey, exploring the ways in which ET information is currently being used.

Other Efforts

In 2020, WWAO plans to develop a framework for engaging with NASA missions. On the capabilities front, and to aid the matching of NASA Capabilities to Water Needs during project formulation, WWAO will expand its Capabilities Catalog and continue to share WWAO and other NASA water capabilities with its various partners.

Following on from its work in 2019 to define a formal Impact Assessment process for its projects, in 2020 WWAO will partner with Resources for the Future and the VALUABLES Consortium to quantify the impact of its New Mexico ET project. With the support of the New Mexico Office of the State Engineer, the team will

conduct a rigorous, quantitative study of the socioeconomic impact of using satellite-based Earth information on five water rights transfer cases in the state.

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