National Aeronautics and Space Administration

NASA Western Water Applications Office

Annual Report

2018

NASA Jet Propulsion Laboratory

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Western Water Applications Office – 2018 In Review

1. Major Achievements

The Western Water Applications Office (WWAO) is a NASA program based at the Jet Propulsion Laboratory in Pasadena, California. WWAO's mission is to develop game-changing water applications that help solve the most important and pressing water issues faced in the western U.S. today. To do this, WWAO delivers NASA's capabilities – remote-sensing data, expertise and tools – directly to water decision makers who can make use of them across a host of western states and water basins. 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. More details are at wwao.jpl.nasa.gov .

CY 2018 was a productive year in which WWAO expanded and matured its activities in various ways.

Innovative Water Projects. In 2018, five water projects continued in implementation phase and a new project was launched towards the latter part of the year. These 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. The six projects are listed below and summarized in more detail in the Appendix.

- *Drought Monitoring in the Navajo Nation*

  Goal: Use satellite data to improve the Navajo Nation Department of Water Resources Drought Report, which is presented to emergency managers and used to allocate drought-relief dollars throughout each chapter in the Navajo Nation.
- *High-Resolution Soil Products for Multiple Stakeholders*

  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.
- *Operational Evapotranspiration for the State of New Mexico*

  Goal: Develop operational evapotranspiration data for New Mexico so it can better monitor drought conditions, process water-rights applications, and refine its water budget modeling.
- *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.
- *NASA's Airborne Snow Observatory (ASO) and Automated Water Supply Model*

  Goal: Harness data from NASA's ASO to improve runoff forecasts in California's Sierra Nevada and Colorado's Rocky Mountain ranges. Such forecasts help reservoir managers meet often conflicting needs for drought planning, ecological flows, groundwater recharge and flood prevention.
- *Snowpack Representation in the Colorado River Basin Forecast Center Model (CBRFC)*

  Goal: Use data from NASA's ASO to improve streamflow forecast skill by refining how snowpack is represented in the CBRFC's snow model.

Project water partners have been enthusiastic to harness NASA's capabilities. According to Molly Magnuson, of the New Mexico Office of the State Engineer, WWAO's New Mexico water project "*will improve water*

management decisions throughout New Mexico." Carlee McClellan, Senior Hydrologist of the Navajo Nation Water Management Branch, presented WWAO's Navajo Nation project at the Native Waters on Arid Lands Summit in Reno, Nevada, which covers climate change, water resources, traditional knowledge, livestock and ranching and conservation practices. McClellan said that the Navajo Nation Drought Severity Tool being developed by WWAO "*will … aid the Navajo Nation in its drought decision-making processes for many, many years to come.*"

In 2018, WWAO's Higher-Resolution Soil Moisture Project delivered a prototype close to operational implementation. An interagency agreement between NASA's Goddard Space Flight Center and its project partner – the U.S. Department of Agriculture's (USDA's) National Agricultural Statistics Service (NASS) – was established to enable the use of high-resolution soil moisture in the NASS system. Zhengwei Yang of the NASS R&D Division reflected that *"the project could be a game changer when both top soil moisture and root-zone soil moisture data are available, since it enables near-field-level soil moisture assessment.*"

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. Meanwhile, for the Crop Management project, NASA's Satellite Irrigation Management Support (SIMS) system and a SIMS application programming interface (API) were implemented on Google Earth Engine, while integration and near-real-time processing of data from the Sentinel-2A Earth observation mission were completed.

Prioritizing Western Water Needs. As part of its push to identify the most important water issues in the western U.S., in April 2018 WWAO held a Colorado River Basin Needs Assessment Workshop at Caltech in Pasadena, California. This followed on from the characterization study of the Colorado River Basin that WWAO commissioned in 2017, and from a rapid assessment of water needs conducted in 2016.

WWAO's Colorado River Basin Needs Workshop was attended by a select group of water managers interested in working with NASA. Attendees included 15 non-NASA stakeholders from five states in the Colorado River Basin; they represented irrigation districts, agriculture, state and municipal water-resource departments, regional wholesale water suppliers, non-governmental organizations, and academia. Paul Brierley, one of the attendees and Executive Director of the Yuma Center of Excellence for Desert Agriculture in Arizona, commented that *"NASA was eager to hear what capabilities we could put to use. I'm excited for them to develop capabilities based on the needs of Ag [agricultural] producers!"* Peter Gill, River Basin Planning Project Manager of Wyoming's Water Development Office, felt that *"the workshop informed our agency's move toward better informed, science-based decision making."*

At the end of the two-day meeting, eight key water themes impacting the Colorado River Basin were identified along with around 80 water needs. Within those eight categories, 13 needs were identified as high-priority and expanded upon in detail. The outcome: a set of three high-priority water needs for those working within the Colorado River Basin, which were summarized in a WWAO report in 2018. These themes are: 1) water-supply forecasting; 2) evapotranspiration over land and water; 3) and the prediction and impacts of extreme events. They are driving the formulation of the next round of WWAO's water projects to be funded in FY19.

As an additional outcome of the workshop, WWAO was invited to participate in the Colorado River Climate and Hydrology Working Group, an interagency collaboration encompassing private, academic, interagency and state representatives from all the Colorado Basin states. That working group has identified 44 priority needs related to streamflow forecast modeling in the basin; three of those water needs were added to the shortlist of Colorado River Basin needs identified by WWAO as warranting further exploration.

Reach and Impact. WWAO's goal is to develop game-changing water applications. To do this, it requires detailed insight from water managers and decision makers on what they need to make more informed water-management decisions. To gain that insight, WWAO builds strategic partnerships at federal, state and local levels. This is done through joint studies and projects, topical workshops, formal agreements, participation in interagency working groups, and other collaborations. Highlights of WWAO's partnership activities in 2018 include:

- *Water Studies.* Working with the Western States Water Council, WWAO conducted an in-depth study on the use of cloud computing technology and information systems by western-state water-resource agencies, publishing a report in late 2018.
- *Strategic Working Groups.* In 2018, WWAO participated in a number of interagency working groups that are crafting water priorities in the west. These include the National Oceanic and Atmospheric Administration's (NOAA's) National Integrated Drought Information System (NIDIS) Observations and Monitoring Working Group, and the NIDIS Southwest Drought Early Warning System Working Group, both of which focus on drought monitoring; the West Wide Climate Risk Assessment Working Group; the Southwest Oklahoma Action Plan effort; and the Colorado River Climate and Hydrology Working Group. In July, WWAO (through its Program Scientist, Forrest Melton) was invited by the California Department of Water Resources to serve on the Technical Working Group for the California AB1755 Open Water Information Architecture (OWIA). OWIA is being designed to comply with AB1755 and to improve access to water data in California. In late 2018, WWAO was invited to join the Hydrology and Forecast Technical Advisory Subcommittee for Flood Managed Aquifer Recharge, which is run by the state of California. WWAO is submitting information on NASA's tools and data, and this engagement is an ongoing effort that may bear fruit in terms of new water-project concepts further down the line.
- *Topical Workshops and Conferences*. In collaboration with the Western States Water Council, WWAO hosted a Water Information Management System Workshop at NASA's Jet Propulsion Laboratory in January. A key outcome was the above-mentioned technical report on the use of cloud computing technology in the water domain. In June 2018, WWAO's Crop Management project gave a presentation to around 100 growers at the Salinas Valley AgTech Summit on its capability. During the NASA ASO Annual Meeting in September, WWAO and NASA's ASO conducted an AWSM user workshop with over 20 users, while in October, approximately 25 growers were trained to use the SIMS / CropManage app. Also in October 2018, WWAO was invited to talk at the Texas Water Conservation Association Fall meeting about how satellite data can be used to improve water management. The audience included river authorities, floodwater drainage and irrigation districts, municipalities, utilities and those interested in groundwater. At the American Water Resources Association meeting in November, WWAO co-hosted a session on Water Quality. And in December 2018, WWAO co-hosted a Winter Outlook on Water Workshop with the California Department of Water Resources, the Water Education Foundation and the Center for Western Weather and Water

Extremes. As 2018 came to a close, WWAO convened sessions at the Fall American Geophysical Union Meeting on Science to Action and Food Security (the latter in partnership with the NASA Harvest program), which proved fruitful.

- *Other Collaborations*. In 2018, WWAO held discussions with the Metropolitan Water District of Southern California to establish a Memorandum of Understanding supporting multiple water-management efforts. 2018 also saw the Western States Water Council / WestFAST continue to be a key partner. WWAO explored possible areas of collaboration (such as impact assessment and project coordination) with NASA's SERVIR venture and the Short-Term Prediction Research and Transition Center at NASA's Marshall Space Flight Center. As a result, Dan Irwin, SERVIR Director, and Ashutosh Limaye, SERVIR Project Scientist, are now part of the WWAO working group. And in September 2018, WWAO met with the USDA's Natural Resources Conservation Service (NRCS) in Oregon to discuss remote-sensing for hydrology and climatology, modeling and water forecasting tools, and the NRCS' products and services. Possibilities for collaboration are being explored.

WWAO Impact Assessment. In 2018, WWAO completed the process of formalizing its impact assessment strategy. Impact assessment helps projects maximize their potential benefits to society. WWAO has adopted a "theory of change" methodology that will be integrated into all WWAO water projects launched in FY19 and beyond. First, the potential benefits of each project to the decision-making community are identified and articulated at the initial stage of project formulation. Next, project deliverables are designed so that they directly connect to those identified long-term, desired impacts.

WWAO will use its impact assessment process not only to increase the program's long-term impact, but also to determine whether or not to transition individual projects to stakeholders for operational use. Impact assessment will also help to increase awareness of the value of WWAO's work, and may strengthen and boost support for NASA's broader Applied Science research.

NASA Water Capabilities Catalog. While identifying water-manager needs is one key thrust of WWAO's work, identifying and disseminating NASA capabilities that can meet those needs is another crucially important effort – as has been emphasized by water partners. In 2018, WWAO launched a new effort to catalog NASA's technical capabilities in water science and technology. Its Capabilities Catalog will offer a collection of useful NASA water-capability summaries to water managers, decision-makers, and the NASA community. A template was developed based on input from WWAO's Water Partner Engagement Team and work started on a series of two-page briefs outlining key water projects funded by WWAO and NASA's Applied Science Program. In 2019, the catalog will become available online and in-print for distribution to water partners and at events.

Western Water Alliance. 2018 saw WWAO initiate efforts to create a Western Water Alliance. The Alliance is a group of public organizations and private sector companies involved in western-water management and infrastructure that can partner with WWAO to 1) forge innovative collaborations and 2) help transition WWAO's water projects out of NASA to sustainable, long-term states. In 2018, a strategic charter and communications plan were drawn up. Around 800 organizations were vetted to assess potential areas of synergy with WWAO, and a shortlist was identified. In 2019, organizations will be engaged in dialog leading to recruitment to the Alliance so that collaborations may begin.

2. Looking Ahead

WWAO will strengthen its efforts on a number of fronts in the coming year.

New Water Projects. In 2019, WWAO will focus on devising water projects by explicitly starting from water-partner needs rather than from a hybrid of needs and NASA capabilities. This strategy will ensure that WWAO's water projects reflect the consensus needs of the water decision-making community and that those needs drive the process from the outset. To this end, in late 2018, WWAO sent out a Solicitation of Interest to the NASA technical community to request project ideas that could potentially satisfy the Colorado River Basin needs identified. In 2019, WWAO will fund two or three projects that satisfy these criteria. Water partners will be an integral part of the process from project conception on. Impact assessment and project transition efforts will also be built into project development from day one.

Water Needs Catalog. One of WWAO's key goals is to develop a Water Needs Catalog comprised of Use Cases that can drive the formulation of WWAO projects. Such a catalog will inform the NASA Applied Sciences community of water-resource needs and also provide applications guidance to future NASA missions. A Western Water Needs Catalog will be constructed in two ways: 1) through focused engagement with high-priority water partners; and 2) by building additional relationships with partners and overall public awareness of WWAO.

In 2018, a Water Needs Assessment was performed for the Colorado River Basin. In 2019 the process will be extended to the Columbia River Basin. First, a study will be conducted to characterize the Columbia River Basin in terms of physical characteristics and the socioeconomic and water-management factors at play, and to identify key stakeholders in the basin. In mid-2019, WWAO will host a Columbia River Basin Needs Assessment Workshop with key water partners / decision makers to identify the most important needs in the Columbia Basin. Finally, further needs analysis will be performed by the WWAO team in late 2019 to identify the top-priority needs for the region on which WWAO could potentially focus. These water needs will drive WWAO's FY20 round of water projects.

Water Partnerships. A top 2019 priority for WWAO is to continue building and maintaining relationships with western-water partners. Focused engagement with the right decision makers enables WWAO to understand what water-resource gaps exist, which gaps can be filled, and, critically, the context surrounding how water decisions are made. In 2019, WWAO will continue to collaborate with the Western States Water Council / WestFAST, the USDA, NOAA, the U.S. Army Corp of Engineers, the Colorado River Hydrology & Climate Working Group, the U.S. Bureau of Reclamation, the California Department of Water Resources, the California State Water Resources Control Board, and the Metropolitan Water District of Southern California. WWAO will also explore new partnerships in the Pacific Northwest (with the NRCS), in the Columbia River Basin and in states such as Texas and Utah.

Water Operations Study. WWAO will conduct at least one study in 2019 to dig deeper into the decision-making context – specifically operations and workflow – of a selected western water decision-making agency. Work has already begun to assess the operational models and workflows being employed by CBRFC and the U.S. Bureau of Reclamation.

WWAO Applications Transition Workshop. By invitation from the Western States Water Council, WWAO will co-host a workshop on how to transfer the technology it develops in its projects from NASA to operational and / or sustaining partners. This will happen around the middle of 2019. Tech transfer will become a more important thrust as WWAO's projects mature.

Visiting Committee. In 2019, WWAO will establish a committee of experts who can help NASA identify key water challenges and partnerships as well as strategic opportunities and gaps. The committee will consist of people from academia, water agencies (local, state and federal), non-governmental organizations, foundations and possibly commercial entities with a range of expertise (snow, groundwater, irrigation and urban water management, flood response, water quality, water policy and meteorology / forecasting). Committee members will ideally serve as advocates for WWAO's mission to the broader water management community, and may help review project proposals and plans as needed.

Appendix – WWAO 2018 Water Project Summaries

Project: Operational Evapotranspiration for the State of New Mexico
Project Lead(s): Joshua Fisher, NASA Jet Propulsion Laboratory
Description: New Mexico is among the most arid states in the U.S. and consistently suffers from drought conditions that make agriculture, ranching, grazing, fire response, and other water-related activities difficult to manage. This project is working to deliver to the New Mexico Office of the State Engineer remote-sensing-based information that it can use to assess agricultural water use and drought conditions across the state, and improve water planning particularly during droughts.
End Users / Decision Makers: New Mexico Office of the State Engineer, U.S. Bureau of Reclamation, New Mexico State Forestry, New Mexico Department of Agriculture, New Mexico Fish and Game, U.S. Geological Survey.
Data Sources, Models, Technology: Evapotranspiration, potential evapotranspiration, evaporative stress index, normalized difference vegetation index, albedo, land surface temperature, MODIS.

Project: Satellite-Based Irrigation for Better Crop Management
Project Lead(s): Alberto Guzman, NASA Ames Research Center Cooperative Agreement for Research in Earth Science and Technology
Description: The goal of this project to help growers and water managers in the western U.S. make more informed and efficient decisions about the amount of water and fertilizer to apply to crops. By combining two existing online tools (NASA's Satellite Irrigation Management system and CropManage), satellite, weather and soil data can be used to help growers tailor irrigation times and nutrient application to the specific needs of crops like lettuce, strawberries, broccoli and cabbage. NASA's Satellite Irrigation Management system provides detailed maps and trends of crop canopy conditions and irrigation demand, while CropManage is an app that helps growers and water managers make water and nitrogen-fertilizer decisions at the field level. Results from the project suggest that water use can be significantly reduced with no loss of crop yield or quality. The combined system is also expected to lower the cost of planning, water budgeting and reporting for compliance with California's Sustainable Groundwater Management Act.
End users / decision makers: Commercial growers / shippers, agricultural water managers including farmers primarily on the California Central Coast, crop consultants, irrigation districts, groundwater sustainability agencies, state agencies. Initial focus is on California with potential expansion to stakeholders in the greater western U.S.
Data sources, models, technology: Landsat, MODIS, Sentinel-2, Satellite Irrigation Management system, CropManage app, remote-sensing-based vegetation indices, green fractional-crop cover, basal crop coefficients.

Project: Satellite-Based Drought Reports for the Navajo Nation
Project Lead(s): Amber McCullum, NASA Ames Research Center
Description: The Navajo Nation is the largest federally-recognized Native American tribe in the U.S. in terms of land area, covering over 70,000 km^2 and occupying parts of northeastern Arizona, southeastern Utah, Southern Colorado, and northwestern New Mexico. With a population of over 200,000, the Navajo Nation is prone to frequent and pervasive droughts, and suffers from poor water-supply reliability. Over 40% of homes do not have direct access to potable water and must rely on water haulers. The goal of this project is to help improve the Navajo Nation Department of Water Resources Drought Report, which is presented

to emergency managers and used to allocate drought-relief dollars throughout the community. Drought-relief funds, which are around $25 million, are currently disseminated throughout the Navajo Nation evenly among all agencies. A more informed Drought Report would help funds to be allocated in proportion to drought severity and needs.
End Users / Decision makers: Navajo Nation Department of Water Resources, Navajo Nation Department of Emergency Management.
Data Sources, Models, Technology: Navajo Nation rain-gauge data, multi-satellite precipitation product from TRMM and GPM, integrated multi-satellite retrievals for GPM, Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) (a quasi-global rainfall dataset), Drought Severity Evaluation Tool.

Project: High-Resolution Soil Moisture Data for Monitoring Crop Conditions
Project Lead(s): Rajat Bindlish, NASA Goddard Space Flight Center
Description: Operational agencies like the U.S. Department of Agriculture's National Agriculture Statistics Service (NASS) provide agricultural forecasts and assessments that rely on best estimates of soil moisture. Currently these are created using ground input from farmers or field offices, which is an expensive approach that offers only sparse observations across different counties. For better forecasts, they need estimates that track changes in soil moisture with fine resolution over both space and time. This WWAO-funded project is working to explore the feasibility of using soil-moisture data from satellites to improve measures of soil moisture at both ground-level and in the root-zone for NASS, and to satisfy its operational data needs. The information will be helpful for the NASS Crop Weather report, crop grower associations and other agricultural groups.
End Users / Decision Makers: U.S. Department of Agriculture's National Agriculture Statistics Service (NASS) (Pacific and Northern Plains Regions), crop grower associations such as the Almond Board, agricultural extension groups and university contacts.
Data Sources, Models, Technology: SMAP, SMOS, SMAP-Sentinel product.

Project: Operational Analysis and Modeling with NASA's Airborne Snow Observatory
Project Lead(s): Tom Painter, NASA Jet Propulsion Laboratory / UCLA
Description: The Airborne Snow Observatory (ASO) is a NASA airborne mission that provides water managers with the first ever estimates of basin-wide snow water equivalent, snow depth, and snow albedo. ASO began in 2012 as a cooperative effort between the California Department of Water Resources and NASA Terrestrial Hydrology, with flights over the Sierra Nevada and Colorado Rocky Mountains starting in 2013 and continuing to the present day. The objective of this project is to incorporate ASO data into precipitation runoff models in order to improve predictions of runoff through the Sierra Nevada. Decision makers will potentially use the information to inform decisions about water allocation and reservoir operation, including hydroelectric generation and flood management.
End Users / Decision Makers: California Department of Water Resources, U.S. Department of Agriculture Agricultural Research Service, San Francisco Public Utilities Commission, irrigation districts.
Data Sources, Models, Technology: ASO measurements of snow depth, snow water equivalent and albedo.

Project: Improving Snowpack Representation in the Colorado Basin River Forecast Center's Snow Model Using NASA's Airborne Snow Observatory Data
Project Lead(s): Kat Bormann, NASA Jet Propulsion Laboratory

Description: The Colorado Basin River Forecast Center (CBRFC) relies on a lumped snow model (SNOW-17) and point observations to estimate snow water equivalent (SWE), that is, how much water is contained as snow, and to guide streamflow forecasts. Streamflow in the Colorado River Basin is driven predominately by snowmelt and the magnitude and spatial distribution of the snowpack in the CBRFC's model is currently poorly constrained with sparse observations. NASA's Airborne Snow Observatory (ASO) provides spatially-complete measurements of snow depth and SWE estimates at basin-scale resolution. These measurements will allow the CBRFC to markedly improve their understanding of the snowpack and in turn improve daily to seasonal streamflow forecasts. This project leverages existing ASO data collected within the Colorado River Basin and compares it to historic snow realizations from the CBRFC's snow model. The work explores how to use this refined understanding to improve snow representation in the SNOW-17 model and, in turn, skill in forecasting runoff.

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