Soil Water Balance Model for Water Budget and Irrigation Optimization

Application for Funding Opportunity Number R23AS00446 (CFDA #15.557)

WaterSMART-Applied Science Grants for Fiscal Year 2023

Applicant:

Utah Geological Survey
Utah Department of Natural Resources
1594 West North Temple , Suite 3110
Salt Lake City, Utah 84116
geology.utah.gov

Project Manager:

Paul Inkenbrandt
Utah Geological Survey
1594 West North Temple
Salt Lake City, Utah 84116
paulinkenbrandt@utah.gov
801-537-3361

Technical Proposal

Submission of a technical proposal (limited to 20 pages) is mandatory and must be received by the application deadline.

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Executive Summary

September 03, 2023, Utah Geological Survey, Salt Lake City, Salt Lake County, Utah

The Utah Geological Survey, with support from the Colorado River Authority of Utah and the Utah Division of Water Rights, will configure an existing soil-water-balance model to work with Google Earth Engine. We will validate the model using field based measurements from the Utah Geological Survey's Utah Flux Network, a network of eddy covariance stations, as well as with infiltration and soil moisture, capacity, and vertical hydraulic conductivity measurements. This project will allow for rapid and updatable estimates of groundwater infiltration, runoff, and evapotranspiration. Using the products of the soil-water-balance model, the Utah Geological Survey will produce scripts that allow for rapid estimates of water needs and water savings based on soil-water-balance conditions and changing land use. The model will be able to be integrated with data products like OpenET, to improve estimates of consumptive use and diversions. The resulting reconfigured model will greatly expedite the estimation of water budget components for a wide range of uses, as well as making soil-water-balance estimates accessible to a wider audience. This project will take two years to complete, and is not located on a Federal facility, but may have some modeled areas that overlap federal land.

Technical Project Description

Applicant Category

The Utah Geological Survey is a division of the Utah Department of Natural Resources, making it a **Category A** applicant located in the state of Utah.

Detailed Project Description

The UGS will conduct the following tasks to accomplish our goals:

1. Translate Utah Basin Model (UBM) code into Google Earth Engine (GEE) JavaScript and/or Python to run with GEE layers
2. Check calibration and fit of the translated model using ground-based measurements
3. Generate scripts and tools to make GEE output more usable for water managers and farmers

The Utah Geological Survey (UGS) has conducted several water budget studies throughout the State of Utah. These studies are used by the Utah Division of Water Rights to make water management decisions. Several of the the components of each water budget, including groundwater infiltration and soil moisture, come from soil-water-balance (SWB) models. SWB models use soil properties, land use, and meteorological inputs to calculate the primarily vertical movement of water through and above the soil. The models can also provide estimates of runoff and evapotranspiration, and may be the best way to estimate regional evapotranspiration in high-elevation complex mountainous terrains.

In previous studies, we used established models like SWAT (Bieger and others, 2017), the Utah Basin Model (Jordan and others, 2019), the Basin Characterization Model (Flint and Flint, 2007b), and the SWB v2 (Westenbroek and others, 2018) as the SWB models. These models require several gridded raster inputs of soil properties, land use, and monthly or daily meteorological data, including precipitation and temperature. If a model is run for multiple years, the number of rasters can quickly exceed 100 and the size of the data can be several hundred gigabytes, which can be onerous and time consuming to download and analyze. More than half of the time that we spend for SWB models is preparing and downloading raster data for use in our model.

We propose transcribing an existing SWB model to work natively with Google Earth Engine (GEE), allowing for rapid running of an SWB, and modular inputs of different climate datasets. GEE has a cloud-based repository of all of the necessary inputs for running a SWB. We will run this transcribed model on the Upper Colorado River Basin and the Great Salt Lake Basin and compare it to outputs from other models. We will further validate the model with field measurements collected from the two watersheds. This project will cover a large area, but most of the work will be done at the Utah Department of Natural Resources on Utah State Property. This project will take two years to complete.

Model Translation

The UGS will work to make two soil water balance models compatible with GEE, the Utah Basin Model and the SWB v2. In 2019, the UGS deployed the Utah Basin Model (UBM; https://github.com/utah-geological-survey/UBM) for use in the Ogden Valley study (Jordan and others, 2019). The UBM is a SWB model based on the U.S. Geological Survey Basin Characterization Model (Flint and others, 2004; Flint and Flint, 2007a; Flint and Flint, 2014). The UBM has working versions in both Python and Excel-based formats. The scripts in the UBM uses soil properties and antecedent soil moisture and allows for inputs of various types of monthly gridded meteorological data, including PRISM precipitation data (PRISM Climate Group, Oregon State University, 2019). Using our experience with these SWB models, we will transcribe a version of the UBM to be directly compatible with data from Google Earth Engine (GEE). We will also work to provide a compatible version of the USGS SWB v2 model with GEE. USGS SWB v2 has been applied to the Upper Colorado River Basin of Utah (Tillman, 2015) and is applicable to large areas. Its valuable to be able to run the model for different time periods. Using Python code provided by the author of the USGS SWB v2 model (https://github.com/smwesten-usgs/pyswb), we will create script wrappers and Jupyter Notebooks that will run SWB v2 models leveraging GEE for access to data. The advantage of GEE is that it has many gridded climate, soil, and land use datasets stored in its cloud-based archives, allowing for cloud based processing of these datasets without the need for downloading and manipulating large amounts of raster data. Rebecca Molinari and Paul Inkenbrandt will be in charge of converting the soil-water balance models into GEE compatible scripts.

SWB models use soil properties to determine how much water can be held by a specified volume of soil given precipitation, evapotranspiration, and temperature over time. At various soil water volume thresholds, such as field capacity and wilting point, the pathways of water change. For example, if a soil is “full” (i.e. beyond field capacity), then runoff and infiltration

will occur and the amount of actual evapotranspiration should be close to equivalent with the potential evapotranspiration.

To calculate a SWB model in GEE, we would use 1) time-stationary land data, including lithology information, soils data, and land use information (we acknowledge that land use changes over time), and 2) time-varying data, like precipitation rasters, evaporation rates, and temperature. The land data is used to constrain the amount of water that the soil and rock can infiltrate, and the time-varying data dictates the availability of water over time. The most applicable land use datasets in GEE area the OpenLandMap Soil Texture Class (USDA System), US Lithology, OpenLandMap Soil Water Content at 33kPa (Field Capacity), USDA NASS Cropland Data Layers, and USGS GAP CONUS 2011. Time-varying data can be discretized at monthly, daily, or hourly intervals. Some of the time-varying data we plan to use are Daymet, GRIDMET, GPM, PRISM, and OpenET.

We will run the model on the select watersheds to test it. We will compare the GEE adaptation to the original models to see how they compare. The validation areas are: 1) Milford Valley, 2) the Great Salt Lake Watershed, 3) Sanpete Valley, and 4) Castle Valley.

Model Validation

We will use field-based measurements to validate the model. Field validation for this project will be in four watershed areas in Utah, selected for their geographic distribution and representation of Utah geography and soil conditions. These areas are 1) Milford Valley, 2) the Great Salt Lake Watershed, 3) Sanpete Valley, and 4) Castle Valley. To perform field-based validation, we will use existing meteorological stations, new instruments to measure evapotranspiration, and portable soil hydraulic conductivity and infiltration meters to measure soil properties. Paul Inkenbrandt and Kathryn Ladig will oversee the collection of validation data.

Many meteorological stations are equipped with soil moisture sensors that output percent saturation. We will convert percent saturation to soil water volume using measurements of soil properties collected on site at our six eddy covariance stations. We plan on using a METER HYPROP and KSAT to validate the soil saturated and unsaturated hydraulic conductivity, generating a soil moisture characteristic curve that will allow for volumetric soil validation. These tools can translate soil moisture percentage measurements into soil water content measurements. Soil water volume, which is an output variable of SWB models, can be validated using this approach.

Another output of SWB models is surface water infiltration into the soil. This is an important component to validate, because it is typically the most valuable variable for groundwater budgets, as it constrains “safe yield”. To directly measure the infiltration, we will use an infiltrometer, which will measure the soil’s ability to absorb water and the rate of infiltration. We will compare these measurements to the estimates provided by our model.

We will use a temporary LICOR LI-710 installation to check the evapotranspiration at select locations in the validation watersheds. The LICOR LI-710 devices will be temporarily appended to existing meteorological stations in the validation watersheds. If a meteorological station is not available or in a location of interest, we will append the equipment to one of our

existing eddy covariance locations. We will append the LI-710 on the Utah State University Agrimet network or similarly instrumented station. Paul Inkenbrandt will add LI-710 to relevant weather stations.

Water Management Optimization

Finally, In order to maximize the utilization of SWB models in GEE, we will create scripts and tools that allow for groundwater calculations and rapid irrigation quantification. We will modify and publish open-sourced scripts that take output from our model and generate estimates of water needs based on available effective precipitation. These scripts would follow the irrigation scheduling checkbook method (Steele and others, 2010; Scherer and Steele, 2019). We will communicate the water need calculations with farmers electronically, ideally using an automated method, but at the very least using email and spreadsheets. Kathryn Ladig and Rebecca Molinari will work on these scripts.

Goals

The goals of this project are: to expedite water budget calculations, easily calculate effective precipitation, validate our SWB models for Utah, and make it easier to calculate the water needs and and water savings from changes in farm management practices. We seek to improve water management and water availability for ecological value, such as instream flow by allowing for rapid calculation of groundwater budgets that provide governing numbers for groundwater management plans, and putting soil water balance models in GEE for easy integration into GEE-based platforms like OpenET.

Expedite Water Budget Calculations

To expedite water budget calculations, we will translate the Utah Basin Model (UBM) code and the USGS SWB v2 model into GEE JavaScript and/or Python to run with GEE layers. Currently, running these models requires downloading all of the required raster layers into a geodatabase on a local machine. Making these models compatible with GEE allows us to leverage the cloud storage of GEE without having to download raster data. “GEE compatible” includes functionality in the Javascript interface native to GEE or leveraging the Python API that GEE provides that works with GEE.

Calculate Effective Precipitation

OpenET provides an effective means of estimating evapotranspiration using remote sensing technology. Water managers and growers need to understand effective precipitation to best manage irrigation scheduling and water use. In order to calculate effective precipitation, antecedent soil moisture and precipitation must be known. The best way to estimate antecedent soil moisture is a well calibrated soil-water-balance model. OpenET is a GEE-based platform, so creating a GEE-compatible SWB model will allow for more direct estimation of effective precipitation.

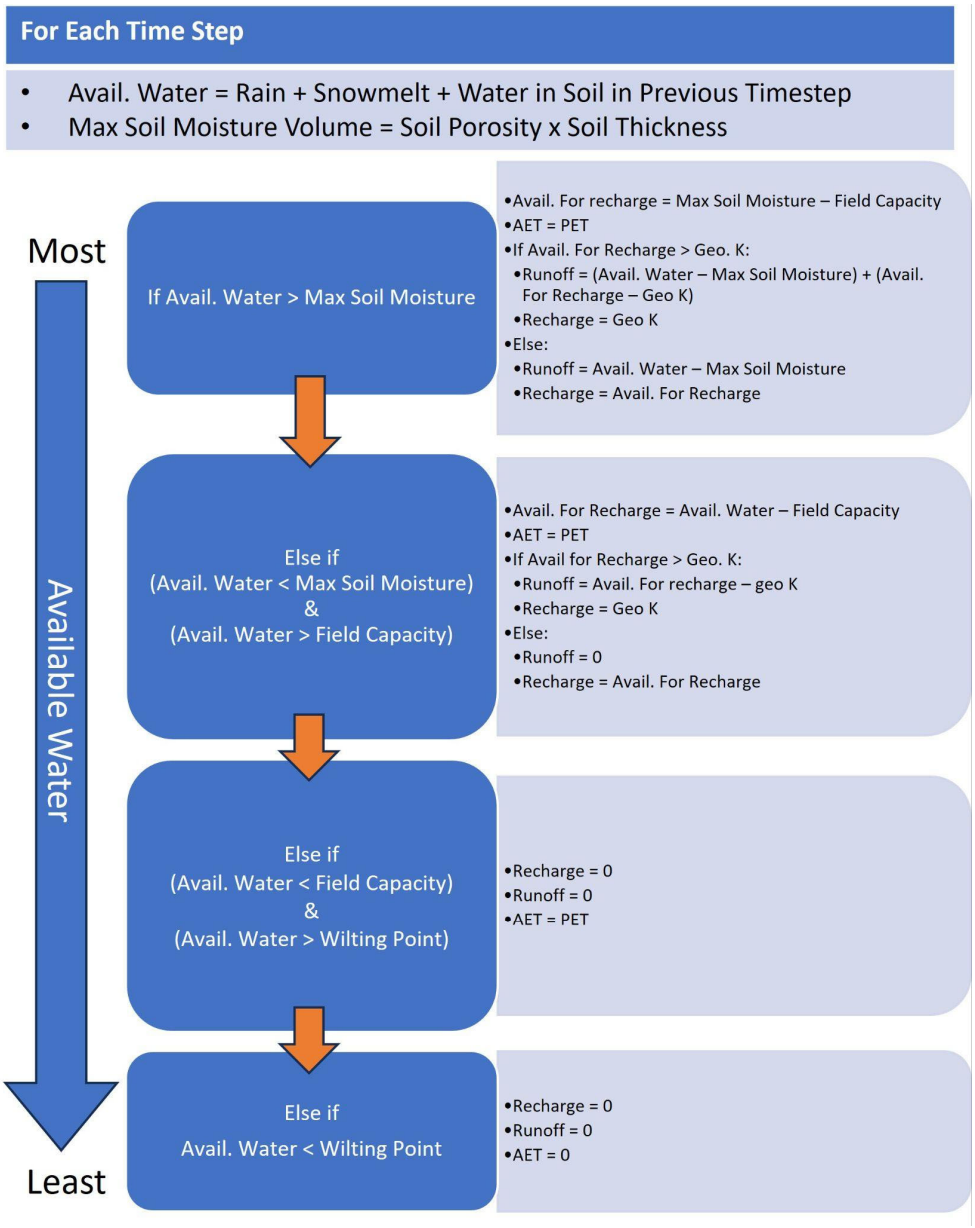

Figure 1. *General workflow and water routing for the Utah Basin Model.*

Validate Model Calibration

Once the models are translated to a GEE-compatible format, we intend to validate estimates from the SWB models. We will purchase the necessary tools to validate the model. These tools are necessary to measure the soil properties and soil-water content that SWB models calculate and rely on, as well as tools that measure evapotranspiration and precipitation. We will pick subwatersheds of Utah to validate the GEE-compatible models.

Project Location

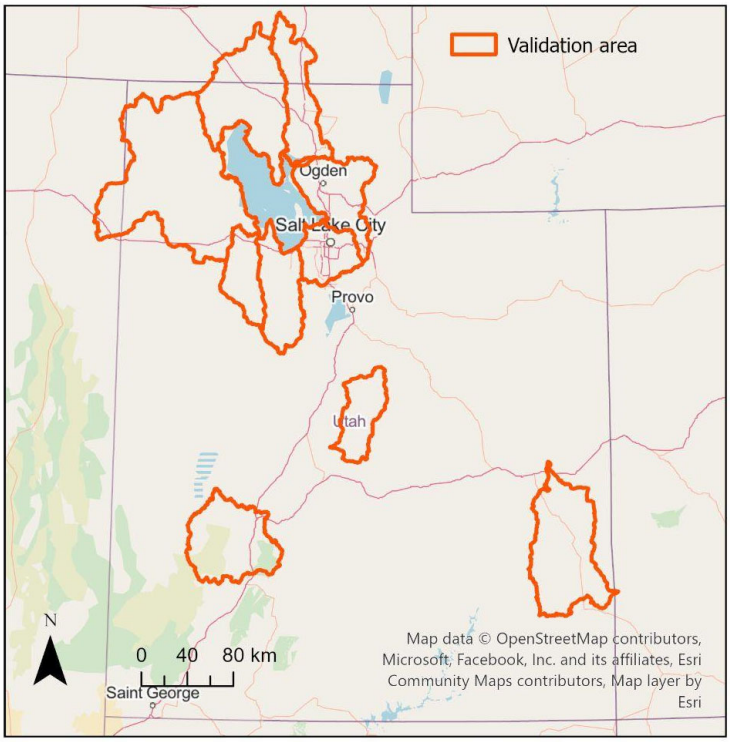

Figure 2. *Areas of study.*

The resulting reconfigured model will be applicable to any geographic region with available input data; however, we have selected areas (figure 2) to ensure the model is representative of the variables it is estimating. Immediate application and field verification for this project will focus efforts in four watershed areas in Utah, selected for their geographic distribution and representation of Utah geography and soil conditions. These areas are 1) Milford Valley, 2) Sanpete Valley, 3) Great Salt Lake Watershed, and 3) Castle Valley. See attached shapefiles for exact areas.

Evaluation Criterion

E.1.1. Evaluation Criterion A—Water Management Challenge(s) (30 points)

Water Management Challenges

Water Budgets and Groundwater Management Plans

Water budgets are tools used by water managers to understand the paths and quantities of water moving through a watershed. The Utah Division of Water Rights and the Utah Geological Survey use water budgets to understand how much water is available for use in a watershed. Because the availability of water is dictated by multiple factors, especially time-varying

parameters like precipitation, temperature, and evapotranspiration, water budgets should have the ability to be regularly and rapidly updated (Healy and others, 2007). Because of variations in climate variables and the many different measured components, water budgets can take 1-5 years to complete.

The State of Utah and the Utah Department of Natural Resources was recently implicated in a lawsuit accusing the State for a perceived delay in reaction to the decline in water levels of the Great Salt Lake (Singh, 2023), despite ongoing efforts to preserve the lake (Utah Department of Natural Resources, 2023, https://greatsaltlake.utah.gov/actions-resources/). Quick calculation of water budgets could help quell the perception of delays in reaction to water crises, and expedite the availability of information to water managers. On a slightly longer time scale, our SWB model will contribute directly to the ongoing Great Salt Lake Basin Integrated Plan (https://water.utah.gov/gsl-basin-integrated-plan/) by providing a key component to the Great Salt Lake water budget, which is identified by the Plan as a key data gap and is required by the authorizing legislation (le.utah.gov/~2022/bills/static/HB0429.html). Statewide, our work will provide direct input to several key policy issues in Utah's Coordinated Action Plan for Water, including Great Salt Lake; Colorado River; Interconnectedness of the Water System; Wetlands, Waters of the U.S., and Permitting; Instream Flows And Riparian Aquatic Ecosystems; and Groundwater aquifers (gopb.utah.gov/waterplan/). Each of these policy issues require accurate, flexible and timely estimates of water quantity that our improved SWB will provide.

Utah has several areas with significant decline in groundwater levels and observed land subsidence related to groundwater depletion (Rojanasakul and others, 2023). Groundwater management plans are enacted by the Utah Division of Water Rights to govern groundwater use in these parts of Utah. Many basins in Utah have been flagged as having significant groundwater level decline. Utah Statute 73-5-15 3(c)(i) states that the State Engineer shall use the best available scientific method to determine safe yield. Safe yield is determined by groundwater recharge in a watershed, which is commonly determined from SWB models (Healy, 2010). The State Engineer can adopt a groundwater management plan to protect the physical and chemical integrity of the aquifer and deploy the principles of prior appropriation to limit the volume of groundwater withdrawn from an aquifer.

OpenET and Effective precipitation

OpenET has means for estimating evapotranspiration, but currently does not have a means to rapidly calculate effective precipitation. Effective precipitation is a means of accounting for consumptive use, by subtracting evapotranspiration from precipitation and available antecedent soil water. OpenET provides estimates of evapotranspiration and precipitation in gridded formats through their website, API, and GEE layers. A SWB model allows for calculating the missing component of antecedent soil water, which in turn allows for direct estimates of consumptive use of irrigated areas. OpenET is based on a GEE platform. Creating a SWB model compatible with the same platform would allow for a direct interface between OpenET data and output from the SWB model.

Irrigation scheduling

Growers in Utah don't currently have a way to leverage OpenET for easy calculation of their seasonal water needs. A SWB model that works with open ET could provide output that

could be augmented and delivered to growers. SWB models and ET estimates can be used to optimize irrigation scheduling. By post processing outputs from our GEE model, we can provide estimates of irrigation needs to farmers.

Concerns or Outcomes if this Water Management Challenge is Not Addressed

- Aquifer depletion and permanent loss of storage
- Ongoing drought
- Subsidence
- Inefficient use of state resources to manage water

Delaying water management decisions, especially Groundwater Management Plans, can result in permanent loss of aquifer storage capacity and land subsidence.

Subsidence has caused severe infrastructure damage in the area of Enoch, Utah, costing over $27 million. More than 300 subdivision lots are now too damaged to develop. The federal government and the State of Nevada spent over $7.5 million to move residents out of and demolish the Windsor Park subdivision in North Las Vegas due to subsidence-created earth fissures from groundwater withdrawal (Utah Geological Survey, 2023).

Drought throughout the western United States has impacted surface reservoirs, aquifers, and lakes, causing record lows and increasing tensions between western states. Last spring, Lake Powell was the lowest it has been since it began filling in the 1960s. In November 2022, the water level of Great Salt Lake reached its lowest recorded elevation since measurement began in 1847. In addition, Utah's population is growing rapidly, from 2,233,169 in 2000 to 3,380,800 in 2022 (census.gov accessed 10/4/2023). The 2019 Utah Hazard Mitigation Plan highlights that this rapid growth, combined with limited water availability, will lead to increased vulnerability.

While the impact of the drought on surface reservoirs is observed easily, the drop in groundwater levels in groundwater reservoirs (aquifers) can only be observed by the collection and presentation of data. Based on the data we have seen so far, many parts of the state have seen significant groundwater level declines over the past 40 years. The State of Utah has stepped up with millions of dollars in additional funding to study and enhance the availability of water, in an effort to mitigate this historic drought.

Drought is described in detail in section 6.1 of Utah's 2019 Hazard Mitigation Plan. Droughts can be the cause of groundwater level declines and intensify the reliance on groundwater when surface water is depleted. The mitigation plan indicates that reduced water availability during drought years reduces aquifer recharge and lowers the water table, causing increased pumping and depleted aquifers.

Page 195 of the Utah 2019 Hazard Mitigation Plan speaks directly to subsidence hazard. Aquifer compaction and land subsidence are caused by groundwater mining and declining groundwater levels. The Mitigation Plan suggested three mitigation strategies to deal with subsidence hazard: (1) increasing water resources by importing water from other basins, (2) increasing groundwater recharge to the basin-fill aquifer through conjunctive management of ground- and surface-water resources, (3) dispersing high discharge wells to reduce localized land subsidence, and (4) reducing overall groundwater withdrawals in a basin.

How this project will address water management issues identified above

This project will help water supply reliability (a) and the ability to administer water rights (f) throughout the state of Utah by improving. Groundwater extraction in Utah totaled 1.17 million acre-feet in 2021, 0.74 and 0.3 million acre feet of which was used for agriculture and public water supply, respectively (U.S. Geological Survey, 2021). Currently, more than 20 of Utah's groundwater areas are in some stage of groundwater management plans with the Utah Division of Water Rights (Utah Division of Water Rights, 2019), with only 13 of those plans being finalized. The Utah Division of Water Rights uses the "best available science" to dictate the amount of groundwater that can be safely withdrawn from an aquifer system, and often turns to the UGS for help in providing that information. We can expedite our studies if we have the ability to quickly determine the most important parts of water budgets. Beryl Enterprise and Cedar City Valley have specified reductions in groundwater pumping of between 3000 and 5000 acre feet per year (Utah Division of Water Rights, 2019). For every year that these plans are delayed in finalization, up to 5000 acre-feet stands to be lost from that system. Additionally, aquifer compaction will result in permanent storage loss from that system. Rapid and accurate assessment of water budgets is key to preserving the groundwater resources of the state, and allowing for water supplies to be more reliable

This project will also help with sensitive species (g), watershed health (h), and natural features (i). Imbalanced groundwater budgets were instrumental in causing depletion of groundwater discharge points like springs, groundwater supplied streams, and other groundwater dependent ecosystems. Groundwater depletion was identified in Current Creek of Juab Valley during the quantification of the valley's water budget. Sensitive species, like the Least Chub and the Columbia spotted frog can no longer be found in the ecosystems of this area, whose decline correlates with reduction in flow of Currant Creek. A streamlined SWB would allow for rapid assessment of groundwater budgets, allowing for intervention prior to the loss of sensitive species. Clear Lake Spring is being impacted directly by agricultural pumping (Mower, 1967), and not flowing beyond its original spring pool for the first time in its measurement history this year. We are working currently to develop a groundwater budget to guide a new groundwater management plan for the area that provides recharge to Clear Lake Spring. Clear Lake Spring has a delayed response time to changes in recharge and well pumping conditions (Mower, 1967). Rapid assessment of changing water budget conditions would be possible with an easily deployable SWB model.

E.1.2. Evaluation Criterion B—Project Benefits (30 points)

How the project was identified

The main stakeholders interested in efficient soil-water balance models are the Utah Division of Water Rights, the Colorado River Authority of Utah, and rural water users. Each stakeholder is interested in the project for different reasons, all of which benefit Utah water users and water managers.

The Utah Division of Water Rights works with the Utah Geological Survey to quantify groundwater budgets for various aquifers throughout the state. These budgets are used for many purposes, including the development of Groundwater Management Plans, which are legal agreements with communities to measure and limit groundwater withdrawals. While necessary,

quantification of groundwater budgets is costly and time consuming, requiring the compilation and assimilation of many different datasets, as well as field measurements. Also, groundwater budgets are variable over time and depend on climate and crop demands.

One of the most valuable components of groundwater budgets for a Groundwater Management Plan is the estimate of groundwater recharge. Utah, by statute uses the concept of "safe yield" to manage aquifers, essentially meaning that discharge from the aquifer must balance recharge. The most efficient way to calculate groundwater recharge is a soil-water balance model like the SWB. Expediting the calculation of soil water balance model would expedite the process of implementing groundwater management plans, which will expedite the savings of groundwater and decrease the permanent loss of groundwater storage in aquifer systems.

Groundwater and surface water are intimately related in many of Utah's aquifer systems. Many of our basin studies have shown that reductions in groundwater availability also reduce natural surface water flows, eliminating important habitat for conservation species. For example, in Juab Valley, wetlands surrounding Currant Creek supplied valuable habitat to the Least Chub and the Columbia Spotted Frog. Flow from Currant Creek is controlled by groundwater, and has shown significant declines with proportional declines in groundwater level, reducing the availability of habitat and eliminating the populations of these sensitive species. Clear Lake Spring, another habitat for Least Chub, is seeing declines in flow due to decrease in groundwater availability. In our most recently completed groundwater basin study in Emery and Johns Valleys, just north of Bryce Canyon National Park, an area undergoing intense growth and water resource problems, we documented close connections between surface water and groundwater and used an SWB model to calculate the water budget, demonstrating the usefulness of this technique to groundwater basin evaluations and the benefits of improving and streamlining SWB calculations.

In response to the drought that led to the decline of surface water and groundwater reservoirs in Utah, the Utah State Government has enacted pilot projects to decrease the use of water and increase the availability of water in natural habitats. Examples of these projects include the System Conservation Pilot Program (SCPP) and the Agricultural Optimization Program. To properly quantify water savings from these programs, the amount of effective precipitation must be known. The Colorado River Authority of Utah and OpenET are interested especially in quantifying the effective precipitation. OpenET currently provides an estimate of consumptive use (evapotranspiration) on their interface, but it gives the consumptive use of precipitation, irrigation water, and available antecedent soil water. To properly quantify the consumption of diverted irrigation water (and the savings from not using it), precipitation and antecedent soil water must be quantified. The most efficient and effective way to quantify antecedent soil water is a soil-water-balance model. Quantified water savings can be put towards natural water systems like the Great Salt Lake and tributaries to the Colorado River.

Lastly, we are interested in being able to provide growers with water data to enable them to save water. While building the Utah Flux Network, we have interacted with several farmers who wish to use our data for water savings and efficient irrigation.

We have received support for adjacent projects from Trout Unlimited, the Friends of the Great Salt Lake, the Moab Area Watershed Council, and The Nature Conservancy. Their

support will continue for this project, as it contributes to their goals of quantifying water savings and water use efficiency in Utah.

How and when this information will be applied

The tool will be implemented immediately by the Utah Geological Survey in quantifying the water budgets of Castle Valley, Sanpete Valley, and Milford Valley, Utah. The water budgets will be immediately implemented by the Utah Division of Water Rights for water management decisions. The code will be immediately consumable by OpenET due to the leverage of the GEE platform and code. They will be able to use the data to refine their ET calculations and to assist in completing their contractual obligations to the Colorado River Authority of Utah. Farmers/Producers/Growers will be able to implement the values we provide them to make informed decisions about irrigation and other management practices. Data will either be available through a web interface or delivered by mail depending on the farmer's preference.

Extent of Benefits

Scientists and water managers seeking rapid estimates of soil water budget components, including the Utah Division of Water Rights and the Colorado River Authority of Utah, will use this tool. The tool will increase the rate at which water managers can make decisions, allowing for the conservation of water resources and the prevention of groundwater-related natural disasters. This project would expedite water management decisions, and allow for more accurate assessment of water budgets, effective precipitation, and soil water conditions. The project could be applied any place where the applicable GEE layers are available.

- Utah Division of Water Rights - water management plans
- Colorado River Authority of Utah - assessment of water resources and monitoring of those resources; calculating decreased consumptive use for compact
- OpenET - ET

Additional benefits

We are conducting a number of water budget studies in Utah, including in parts of Utah that are similar to the validation areas. This research will support those studies by refining key hydrologic variables. Posting our model and analysis codes to Github and GEE will make them available to researchers conducting similar studies, providing support for their own analyses. This will also afford the opportunity for the hydrologic community to improve and unify data analysis methods. The USGS is working on a number of hydrogeologic models in Utah, including one for the Great Salt Lake. Our data, specifically infiltration and soil properties from our validation, will help them calibrate their models.

The UGS is involved in several Watershed Restoration Initiative projects (https://wri.utah.gov/wri/) throughout the state. Our projects focus on monitoring the effects of beaver dam analogue installations and pinyon juniper removal. A SWB would be an important tool in separating the hydrologic effects due to climatic fluctuations from those resulting from watershed restoration. These studies involve monitoring soil moisture at multiple locations throughout each study area. The UGS is also monitoring soil moisture at our eddy covariance tower sites. This proposal would further contribute to our soil moisture monitoring network. We

are working to supply all soil moisture data from the state to the National Coordinated Soil Moisture Monitoring Network.

E.1.3. Evaluation Criterion C—Project Implementation (20 points)

Support for Approach

Google Earth Engine (GEE) is the standard tool for calculating OpenET data (Melton and others, 2021). eeMetric and SSEBop are two models in OpenET data that are supported by the Upper Colorado River Commission and the Colorado River Authority of Utah (O'Connor, 2016). Soil Water Balance models are recognized as a standard way to calculate recharge, and this practice has been applied to entire states, like Maine (Nielsen and Westenbroek, 2019). SWB v2 has been applied to the Upper Colorado River Basin in a previous BOR-funded project (Tillman, 2015). Infiltrometers are a standard approach to understanding soil properties (Reynolds and Elrick, 1991), as is lab-based measurement of soil properties (Whitman and Breitmeyer, 2019; Zhang and others, 2019). Evapotranspiration measurement is also a good way to validate models, and can provide constraint for soil-water-balance models (Jordan and others, 2019).

Work Plan

Task		Milestone	Personnel	Description	Start	End
Convert Existing Model	1	**Examine Existing Models**	Paul Inkenbrandt Rebecca Molinari	Look at the existing open-sourced SWB models, including the UBM and SWB v2 to see what modifications are necessary to translate the code into a GEE compatible format	1/1/25	3/30/25
	2	**Translate GEE code**	Paul Inkenbrandt Rebecca Molinari	Translate code from the existing languages into formats and versions that work with Google Earth Engine	1/1/25	3/30/25
	3	**Test GEE code**	Paul Inkenbrandt Kathryn Ladig Rebecca Molinari	Compile existing scripts and methods; Test Google Earth Engine code and see how it compares with the output from the original codes.	1/1/25	9/30/25
	4	**Run Model**	Paul Inkenbrandt Kathryn Ladig	Run the optimized GEE SWB model	4/1/25	9/30/25
Model Validation	5	**Validation Site Selection**	Paul Inkenbrandt Kate Baustian Kiersten Winwood	Site selection will be based on existing field locations, meteorological station locations, and access.	10/1/24	10/15/24
	6	**NEPA**	Paul Inkenbrandt	Work with US BOR staff to get categorical exceptions (B3.1 and B3.8) for soil characteristic measurements at validation sites.	10/15/24	12/31/24
	7	**Model Validation Analysis**	Paul Inkenbrandt Kathryn Ladig Kate Baustian	Select and conduct field measurements of infiltration and saturated and unsaturated hydraulic conductivity, as well as equipping meteorological equipment with ET measurement devices.	10/1/25	8/1/26
Information dissemination	8	**Soil Water Planning tools for Growers**	Kathryn Ladig Rebecca Molinari Kiersten Winwood	Develop tools to allow users to leverage soil-water-balance data generated by validated model	4/1/25	8/1/26

Task		Milestone	Personnel	Description	Start	End
	9	**Presentations and communication**	Hugh Hurlow Paul Inkenbrandt Kathryn Ladig	Present and share progress and to assist in review of final deliverables; Documenting workflow and data management and make data interpretable to public	12/1/25	9/30/26

			Yr 1				Yr 2			
		Calendar Year	2024	2025	2025	2025	2025	2026	2026	2026
		Quarter	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep
Task	**MS**	**Description**								
1	1	Examine Existing Models								
	2	Translate GEE code								
	3	Test GEE code								
	4	Run Model								
2	5	Validation Site Selection								
	6	NEPA and NHPA								
	7	Model Validation								
3	8	Soil Water Planning tools for Growers								
	9	Presentations and communication								

		Task				
Personnel	**Yr**	**1**	**2**	**3**	**Total hrs**	**% time**
Paul Inkenbrandt	1	330	70		400	19%
	2		230	20	250	12%
Hugh Hurlow	1				0	0%
	2			150	150	7%
Kathryn Ladig	1	250			250	12%
	2		200	100	300	14%
Rebecca Molinari	1	250			250	12%
	2			250	250	12%
Kiersten Winwood	1		100		100	5%
	2			100	100	5%

		Task				
Personnel	**Yr**	**1**	**2**	**3**	**Total hrs**	**% time**
Kate Baustian	1				0	0%
	2		200		200	10%
		1	**2**	**3**	**Annual Rate**	
Paul Inkenbrandt	1	$15,404.40	$3,267.60	$0.00	$18,672.00	
	2	$0.00	$11,272.30	$980.20	$12,252.50	
Hugh Hurlow	1	$0.00	$0.00	$0.00	$0.00	
	2	$0.00	$0.00	$9,982.50	$9,982.50	
Kathryn Ladig	1	$9,940.00	$0.00	$0.00	$9,940.00	
	2	$0.00	$8,350.00	$4,175.00	$12,525.00	
Rebecca Molinari	1	$7,360.00	$0.00	$0.00	$7,360.00	
	2	$0.00	$0.00	$7,727.50	$7,727.50	
Kiersten Winwood	1	$0.00	$3,010.00	$0.00	$3,010.00	
	2	$0.00	$0.00	$3,161.00	$3,161.00	
Kate Baustian	1	$0.00	$0.00	$0.00	$0.00	
	2	$0.00	$6,616.00	$0.00	$6,616.00	
Personnel		**$32,704.40**	**$32,515.90**	**$26,026.20**	$91,246.50	
Fringe		**$25,042.50**	**$21,623.90**	**$20,079.60**	$66,746.00	
Equipment			$36,553.37		$36,553.37	
Travel			$5,593.00	$5,039.00	$10,632.00	
Task Subtotal		$57,746.90	$96,286.17	$51,144.80	$205,178	
32.21%		$18,600.28	$31,013.78	$16,473.74	$66,087.79	
Task Total		**$76,347.18**	**$127,299.95**	**$67,618.54**	$271,266	

Project deliverables

- SWB script compatible with GEE posted on github with documentation
- Report summarizing SWB model validation using field measurements and estimates of effective precipitation
- Scripts that post-process SWB output for expedited estimates of water needs and water savings

Project Partners

- CRAU and OpenET will work with the UGS to integrate the SWB with existing OpenET products on GEE. CRAU has an ongoing agreement with the UGS, so we will regularly meet, and they will advise on our progress and approach.
- The Utah Division of Water Rights will use deliverables from this project for groundwater management plans. The Utah Division of Water Rights is a sister agency of the UGS and regularly oversees our water budget projects so they will advise and oversee our approach.

Staff Credentials

This team has accomplished projects of similar scope and complexity to the proposed project and does not require additional training upon entering into a financial agreement.

- **Paul Inkenbrandt** - UGS Senior Geologist - Paul Inkenbrandt has worked at the UGS for 14 years. He has overseen the assembly and deployment of six eddy covariance towers. Paul Inkenbrandt was the co-creator of the UBM. He is responsible for time series analyses and data management of a large groundwater level database for Utah. He is trained in R and Python and holds certifications in Python scripting. He has developed numerous Python scripts for time-series analysis and climate data compilation. Paul will act as the principal investigator on this project. Paul Inkenbrandt, Senior Geologist has been involved in Juab, Round Valley, Ogden Valley, Bryce Canyon, and Pahvant water budget studies.
- **Hugh Hurlow** - UGS Groundwater and Wetlands Program Manager - Hugh Hurlow will assist in project management and ensure that equipment purchases and project tasks are completed in a timely manner. He will review relevant deliverables of the project.
- **Kathryn Ladig** - UGS Project Geologist - Kathryn Ladig, has significant experience managing weather stations in harsh environments for the National Park Service and United States Geological Survey. She has installed, maintained, and calibrated remote data loggers associated with weather, water quality, and air quality monitoring. She has used Microsoft products, R, and ArcGIS for data management and correction. Kathryn Ladig has experience running soil water balance models, including the SWB v2 and SWAT models for the Matheson Wetland Preserve and Bryce Canyon field areas. Kathryn will oversee data collection, model running, and data processing.
- **Rebecca Monlinari** - UGS GIS Analyst - Rebecca Lee has a master's in Environmental Science and has experience analyzing and processing large statewide spatiotemporal datasets including climate, evapotranspiration, surface water extent, and NDVI. Rebecca Monlinari is adept at implementing Google Earth Engines scripts and has undergone formal training in using GEE. She has successfully written scripts that conduct water area change maps of Utah, as well as scripts that perform zonal statistics on hydrologic layers pertinent to the state of Utah. She is also familiar with the Python and R scripting languages, and has competently applied scripts in both languages to hydrology problems
- **Kiersten Winwood** - UGS GIS Analyst - She earned a B.S. degree in watershed and Earth systems, with a minor in Geographic Information Sciences, from Utah State University in 2019. She joined the UGS in the spring of 2023 after working for the Utah Division of Water Rights. Originally from Utah, Kiersten is passionate about implementing GIS tools in research and conservation efforts surrounding our water resources in the state. In her free time she enjoys cooking, reading, spending time with her family, and hiking in the nearby mountains.

Paul Inkenbrandt and Kathryn Ladig also run the Utah Flux Network, a network of eddy covariance stations in Utah. This network collaborates with the CRAU and OpenET to produce and verify evapotranspiration and other components of the hydrogeologic budget.

E.1.4. Evaluation Criterion D—Dissemination of Results (10 Points)

The results from this project will be shared with other water managers in four different ways:

1. We will communicate our methods and share links to our scripts through presentations at conferences, specifically the American Geophysical Union meeting, the Utah Water

Users Workshop, and an online Ameriflux meeting. These conferences cater to the intended user base. The Utah Water Users Workshop is attended by all of the water managers of the State, and is a good venue for disseminating information.
2. We will publish our approach and validation in a report published by the Utah Geological Survey. The Utah Geological Survey publications are made available free of charge on the web (geology.utah.gov) and include attachments of script and GIS files.
3. We will make others aware of our work through direct communication with the stakeholders, including the Utah Division of Water Rights, the Colorado River Authority of Utah, the Utah Division of Water Resources.
4. We will post the resulting scripts, models, and code on GitHub, open to public access.
5. Via a Reclamation-sponsored webinar

E.1.5. Evaluation Criterion E—Presidential and Department of the Interior Priorities

Climate Change: E.O. 14008

With the exception of a few years, drought conditions have prevailed in Utah since 1987 (2019 Utah Hazards Mitigation Plan). Results from this project will help local and state water managers understand how water is moving through key, water-limited valleys in the state. This knowledge will inform decisions about water conservation and development that will create more drought resilient communities and influence the health and economy of these key regions through increased knowledge of water budget components, the connection between surface and groundwater resources (infiltration, runoff, ET), and water needs. It will decrease the amount of time to calculate these data and will make these data more available to underserved communities. It will create open source scripts that can be used to affordably analyze remotely-sensed data products in perpetuity. These scripts could be adapted by disadvantaged communities throughout the United States, serving drought stricken areas across the country in need of analytical methods to affordably generate the data necessary for informed response.

In 2018, forest fires in Utah caused an estimated $13.4 million in damage (2019 Utah Hazards Mitigation Plan). While the largest forest fires in arid regions usually stem from periods of wetter-than-average soil moisture that yield biomass growth, ignition usually occurs after a period of below-normal soil moisture (O and others, 2020). This research will increase the number of soil moisture monitoring stations across Utah and provide data to local and international researchers to better understand the relationship between soil moisture and forest fires, increasing the ability to predict and mitigate catastrophic burns.

Low soil moisture results in lower crop yield, which can also reduce livestock numbers. It is estimated that the 2002 drought cost the agricultural sector $150 million (Utah Division of Water Resources, 2007). This project supports efficient irrigation, which will help sustain normal soil moisture, high crop yields, and healthy livestock herds.

H.B. 33, signed into law on March 21, 2022, allows instream flow to be considered beneficial use (https://le.utah.gov/~2022/bills/static/HB0033.html). With a temporary change application, Landowners are now able to fallow their fields, allowing water to continue as instream flow for beneficial use, without having to forfeit their water rights for not putting the water to “beneficial use”.

Agencies interested in shepherding the water to the Great Salt Lake and other watersheds are able to lease water rights. The land owners are compensated based on the consumptive use saved by fallowing fields or altering management practices. The proposed project will provide a means of efficiently calculating the amount of water that can be transferred to instream flow.

Disadvantaged or Underserved Communities: E.O. 14008 and E.O. 13985

The study areas for this project include communities identified as disadvantaged by the Climate and Economic Justice Screening Tool due to one or more burden thresholds and the associated socioeconomic threshold. The Castle Valley study area falls within tract number 49019000300, and portions of the Sanpete Valley study area within tract number 49039972200. This project will serve these communities with valuable, timely information about their water resources, allowing them to make informed decisions that will limit drought impacts to culinary and irrigation water supplies (Utah Division of Water Resources, 2007). Most of these tracts are above the 90th percentile for expected population loss due to fatalities and injuries resulting from natural hazards each year (Utah Division of Emergency Management, 2019). This project will provide data to local water managers that could be used to expedite the enactment of plans to limit natural hazards associated with drought and water overuse, such as land subsidence.

Data Management Practices

D.2.2.6 Data Management Practices

The UGS uses ArcGIS Pro and ArcGIS Desktop to analyze and generate data products. Any relevant GIS data will be made available in the industry standard format of geodatabases. Data products will be accessible through Google Earth Engine and/or open script repositories. All toolboxes and datasets will include metadata with a title, summary, descriptions, keywords, and usage limitations. All relevant scripts will be stored in an open Github repository (https://github.com/utah-geological-survey), with documentation and citation.

D.2.2.9 Environmental and Cultural Resources Compliance

- Will the proposed project impact the surrounding environment (e.g., soil [dust], air, water [quality and quantity], animal habitat)? We will take soil samples for analysis of the soil properties.Soil will be tested in place and not be removed from the sites. We will work with the US BOR and the state to ensure we are in compliance with the appropriate regulations. We will work to get clearance and exemptions prior to soil disturbance. We plan to get a categorical exclusion for these activities
- Are you aware of any species listed or proposed to be listed as a Federal threatened or endangered species, or designated critical habitat in the project area? No endangered species will be affected by these activities.
- Are there wetlands or other surface waters inside the project boundaries that potentially fall under CWA jurisdiction as “Waters of the United States”? This project will not affect waters of the United States
- When was the water delivery system constructed?Not applicable

- Will the proposed project result in any modification of or effects to, individual features of an irrigation system (e.g., headgates, canals, or flumes)? This will not result in modification of irrigation systems

D.2.2.10 Required Permits or Approvals

Applicants must state in the application whether any permits or approvals are required and explain the plan for obtaining such permits or approvals. Note that improvements to Federal facilities that are implemented through any project awarded funding through this NOFO must comply with additional requirements. The Federal government will continue to hold title to the Federal facility and any improvement that is integral to the existing operations of that facility. Please see P.L. 111-11, §9504(a)(3)(B). Reclamation may also require additional reviews and approvals prior to award to ensure that any necessary easements, land use authorizations, or special permits can be approved consistent with the requirements of 43 CFR §429, and with the requirement that the development will not impact or impair project operations or efficiency.

D.2.2.11 Overlap or Duplication of Effort Statement

The proposal submitted for consideration under this program is not in any way duplicative of any proposal or project.

D.2.2.12 Conflict of Interest Disclosure Statement

No actual or potential conflict of interest exists at the time of submission.

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State of Utah
SPENCER J. COX
Governor

DEIDRE M. HENDERSON
Lieutenant Governor

Department of Natural Resources

BRIAN C. STEED
Executive Director

Utah Geological Survey
R. WILLIAM KEACH, II
State Geologist/Division Director

Oct. 10, 2023

Bureau of Reclamation
Financial Assistance Support Section
Attn: Applied Science NOFO
P.O. Box 25007, MS 84-27810
Denver, CO 80225

Subject: Official Resolution, Department of Interior, Bureau of Reclamation Notice of Funding Opportunity R23AS00446, WaterSMART: Applied Science Grant.

The Utah Geological Survey (UGS) is pleased to offer this Official Resolution for the Department of Interior, Bureau of Reclamation Notice of Funding Opportunity, R23AS00446, WaterSMART: Applied Science Grant. The UGS has titled this project, "Soil Water Balance Model for Water Budget and Irrigation Optimization".

The total estimated cost of the anticipated UGS's effort, if the award is fully funded, would be $271,266 of which UGS would provide cost share in the amount of $135,633. The amount of requested federal funding would be: $135,633. This project will provide ground-truthed validation data for soil-water-balance models and make the models more compatible with Google Earth Engine. The UGS will work with Reclamation to meet deadlines established in the 2-year scope of work.

The mission of the proposed project is consistent with UGS's knowledge and mission. The UGS Board has reviewed and approved the application being submitted. We look forward to working with the Bureau of Reclamation on establishing a grant or cooperative agreement. If you have any further questions or concerns, please contact the UGS project lead, Paul Inkenbrandt at (801) 537-3361 or paulinkenbrandt@utah.gov.

Sincerely,

Michael Hylland
UGS Deputy Director

State of Utah

SPENCER J. COX
Governor

DEIDRE M. HENDERSON
Lieutenant Governor

Colorado River Authority of Utah

Gene Shawcroft, P.E.
Chair

Amy I. Haas
Executive Director

October 13, 2023

Bureau of Reclamation
Attn: Mr. Matthew Reichert
Denver Federal Center Mail Room
Bldg. 56, Rm. 1940 Dock S-66th Avenue and Kipling Street
Denver, CO 80225

RE: Official Resolution, Department of Interior, Bureau of Reclamation Notice of Funding Opportunity R23AS00446, WaterSMART: Applied Science Grant.

Dear WaterSMART Grant Proposal Review Committee,

The Colorado River Authority of Utah (Authority) supports the Utah Geological Survey (UGS) 2024 WaterSMART Applied Science grant proposal. Ongoing drought and climate change have strained the Colorado River system in Utah and neighboring Colorado River Basin States, requiring science that improves our understanding of the hydrologic systems in the basin, and can be applied to drought mitigation initiatives.

If funded, the deliverables produced by the proposed UGS study would benefit the Authority's mission, Five-Year Management Plan, and associated projects by advancing our understanding of soil water that is available and consumptively used in the Colorado River Basin in Utah. Advanced soil water balance modeling would complement, and not duplicate, the following Authority efforts as follows:

1) Informing estimates of effective precipitation that are being actively explored by OpenET under a funding agreement with the Authority.
2) Expanding the application of the Authority-funded Utah Flux Network Eddy Covariance Towers to soil water balance along with water depletion measurement and ground-truthing of OpenET data products.
3) Furthering general, fundamental climate, and hydrology research to better understand water supply and demand in the Colorado River Basin in Utah.
4) Exploring options for estimation of changes to field scale water balance for agricultural resiliency project implementation, including fallowing, deficit irrigation, and crop changes.
5) Informing development of the Utah Colorado River Accounting and Forecasting Model and Decision Support Tool (UCRAF-DST).

Given the synergies listed above, the Authority supports the UGS proposal as it will improve both the fundamental understanding of soil water balance and applications of soil water modeling for water management.

Sincerely,

Amy I. Haas

Amy I. Haas
Executive Director
Colorado River Authority of Utah

OPENET
FILLING THE BIGGEST DATA GAP IN WATER MANAGEMENT

304 S. Jones Blvd STE 1332
Las Vegas, NV 89107

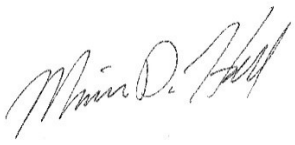
October 17, 2023

Bureau of Reclamation
Financial Assistance Support Section
Attn: Applied Science NOFO
P.O. Box 25007, MS 84-27810
Denver, CO 80225

Subject: Official Resolution, Department of Interior, Bureau of Reclamation Notice of Funding Opportunity R23AS00446, WaterSMART: Applied Science Grant.

We support the Utah Geological Survey in their efforts to create a soil-water-balance model that is compatible with Google Earth Engine and will assist these efforts by offering guidance on leveraging Google Earth Engine and our understanding of effective precipitation in relation to antecedent soil moisture. This project would promote water management in Utah and improve cross compatibility between data products from OpenET and the results of soil-water balance models.

Sincerely,



Maurice D. Hall, PhD, PE
Interim Director, OpenET Inc.

State of Utah

SPENCER J. COX
Governor

DEIDRE M. HENDERSON
Lieutenant Governor

Department of Natural Resources

JOEL FERRY
Executive Director

Division of Water Resources

CANDICE A. HASENYAGER
Division Director

October 16, 2023

Bureau of Reclamation
Attn: Mr. Matthew Reichert
Denver Federal Center Mail Room
Bldg. 56, Rm. 1940 Dock S-66th Avenue and Kipling Street
Denver, CO 80225

RE: WaterSMART Applied Science Grant Application (R23AS00446)

Dear U.S. Bureau of Reclamation WaterSMART Grant Proposal Review Committee,

The Utah Division of Water Resources supports the Utah Geological Survey (UGS) WaterSMART Applied Science grant application. The proposed project promotes our mission to plan, conserve, develop, and protect Utah's water resources. Accurate and rapid estimates of the soil-water conditions of Utah is essential for effective management of water. Validation and ground-truthing of water budget approaches is an important step in managing Utah's waters.

Sincerely,

Candice A. Hasenyager, P.E.
Director

1594 West North Temple, Suite 310, PO Box 146201, Salt Lake City, UT 84114-6201
telephone (801) 538-7230 · TTY (801) 538-7458 · *www.water.utah.gov*

SPENCER J. COX
Governor
DEIDRE M. HENDERSON
Lieutenant Governor

State of Utah
DEPARTMENT OF NATURAL RESOURCES
JOEL FERRY
Executive Director
Division of Water Rights
TERESA WILHELMSEN
State Engineer/Division Director

October 16, 2023

Bureau of Reclamation
Financial Assistance Support Section
Attn: Applied Science NOFO
P.O. Box 25007, MS 84-27810
Denver, CO 80225

Subject: Official Resolution, Department of Interior, Bureau of Reclamation Notice of Funding Opportunity R23AS00446, WaterSMART: Applied Science Grant.

To Whom It May Concern:

This is a letter of support and financial commitment for the Utah Geological Survey WaterSMART Applied Science (R23AS00446) 2023 grant application. The Utah Division of Water Rights supports the UGS proposal, and the deliverables of this proposal would directly benefit water rights administration in Utah. This project will help expedite the calculation of water budgets, useful for groundwater management plans and other water management decisions.

Sincerely,

James Reese, P.E.
Assistant State Engineer – Technical Services
Utah Division of Water Rights

1594 West North Temple, Suite 220, PO Box 146300, Salt Lake City, UT 84114-6300
telephone (801) 538-7240 • facsimile (801) 538-7467 • TTY (801) 538-7458 • *www.waterrights.utah.gov*