Supplementing Estimates of Evapotranspiration: The Utah Flux Network

Application for Funding Opportunity Number R21AS00289 (CFDA #15.557)

WaterSMART-Applied Science Grants for Fiscal Year 2021

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

Wellington, UT eddy covariance station.

Table of Contents

Executive summary

April 3, 2021; Utah Geological Survey, Salt Lake City, Salt Lake County, Utah

Utah Geological Survey (UGS), with support from the Utah Division of Water Rights, the Utah Division of Water Resources, and the Central Utah Water Conservancy District, will establish a network of high-quality eddy covariance flux stations in Utah, including new and existing stations, to provide ground-based evapotranspiration estimates. Data will be uploaded to the AmeriFlux site and will be used to calibrate actual evapotranspiration and sequent depletion models for evapotranspiration, which generate gridded evapotranspiration rates from remotely sensed data. Evapotranspiration measurements and the resulting model grids will have many important applications: (1) measurement of consumptive water use by crops to facilitate water conservation efforts and depletion-based water rights management; (2) measurement of consumptive use to aid efficient management of water resources related to the Colorado and Bear River Compacts; (3) enable water banking strategies for more efficient irrigation practices and preservation of instream flow; and (4) supporting watershed management by quantifying a major part of watershed water budgets. We will establish two new stations, provide data to and receive data from the AmeriFlux network, and build a web-based application to access the data collected by the UGS. When this project is completed, the UGS will operate a total of four stations, and Utah will have a total of eight active stations. This project will result in a web-based application that provides water managers and the general public with direct access to eddy covariance data, as well as interpretations and statistics of the measurements. Eddy covariance stations are a proven standard to measure evapotranspiration and carbon flux. Assuming that it is of high measurement quality, data from eddy covariance stations provides checks for models based on remotely-sensed data. The Utah Geological Survey is a division of the Utah Department of Natural Resources, making it a **Category A** applicant. This project will satisfy a need of the Utah Division of Water Rights and the Utah Division of Water Resources to better characterize the water budget components of consumptive use in the state. This project will take two years to complete, starting on October 1, 2021 and finishing on September 30, 2023. This project will not be located on a Federal facility.

Technical project description

Remote Sensing Estimates

Evapotranspiration (ET) is the combination of evaporation and transpiration (water used by plants). ET is the biggest portion of Utah's water budget, and its current estimates have the least constraint and largest error of the water budget components. Better constraint of ET estimates improves models, water banking quantification, and consumptive use estimates. Eddy covariance (flux) stations can measure evapotranspiration directly. We propose to collect and compile direct measurements of ET to compare with estimates from remote sensing techniques. Remote sensing is when satellites and aircraft collect information about an area as they pass, measuring the reflected and emitted radiation using special sensors. OpenET (https://openetdata.org) will be the standard for remotely-sensed ET estimates. OpenET is the result of a large-scale collaborative effort with NASA, DRI, EDF, and Google Earth Engine to provide an ensemble/amalgamation of tested ET estimates from remote sensing. These estimates include the results of the following models: ALEXI/DisALEXI (Anderson and others, 2007),

METRIC (Allen and others, 2007), PT-JPL (Fisher and others, 2008), SEBAL (Bastiaanssen and others, 1998), SIMS (Melton and others, 2012; Pereira and others, 2020), and SSEBOP (Senay and Kagone, 2019). However, none of these methods have been vetted for Utah, and calibration varies with geography. The limitation of remote sensing is that it only provides data when satellites pass overhead on days when there are few clouds. Calibrating remotely-sensed ET values using ground-based measurements will greatly improve their accuracy and utility and will promote user confidence in the validated data.

Remote sensing estimates of ET provide a spatially continuous estimate of consumptive use by plants. ET can be estimated using remote sensing based on three different approaches: (1) crop coefficients, (2) soil-water balance, and (3) energy balance. Soil-water balance models use rasters of precipitation, soil properties, potential ET, and temperature to estimate runoff, groundwater recharge, and actual ET by balancing the amount of water a one dimensional soil column can hold. Examples include the USGS Basin Characterization Model (Flint and others, 2004; Flint and Flint, 2012; Flint and Flint, 2014) and the TerraClimate model (Abatzoglou and others, 2018). Crop coefficient techniques use remotely-sensed vegetation indices to generate an adjustment factor for a reference ET to estimate actual ET. Rafn and others (2008) and French and others (2012) are two examples of how this method is applied and verified with eddy covariance data. Models in OpenET depend primarily on estimates from the energy balance approach of remote sensing, which uses satellite thermal sensors to estimate ET. Examples of the energy balance approach include METRIC (Allen, 2006; Allen and others, 2007) and SSEBop (Senay and Kagone, 2019)**,** both of which are included in OpenET.

Eddy Covariance Stations

We propose to establish an eddy covariance network in Utah that we will use to validate remotely-sensed data. We will compile data from 6 existing stations and construct 2 new stations to provide additional ground-based measurement. Calendar year 2021 is Ameriflux's "Year of Water Fluxes," during which the network will amplify its support to its contributors with additional technical assistance and guidance for studies related to the hydrologic cycle and fluxes.

AmeriFlux (https://ameriflux.lbl.gov/) is a network of independently operated eddy covariance stations throughout the Americas. AmeriFlux has stringent quality control to ensure that network contributions are high quality. In addition, AmeriFlux has requirements for the stations that contribute to their network, including that they measure heat flux, water vapor flux, and carbon (carbon dioxide and/or methane) flux. The AmeriFlux network contributes to the international FluxNET. Data compiled in the FluxNET and AmeriFlux networks are used to validate climate models, including those used in OpenET.

Existing Flux Station Data

Eight flux stations have operated in Utah, with seven stations still in operation. Three of the seven currently operating stations contribute to the AmeriFlux network, as did the discontinued station. Two stations, US-xNQ and US-xMB contribute data to the National Ecological Observatory Network (NEON; https://www.neonscience.org), Phenocam, and Ameriflux. One station is a temporary installation on Cedar Mesa (US-CdM), measuring fluxes

within a pinyon-juniper community. The discontinued station, US-Cop, was south of Moab, Utah. The two long-term stations not in AmeriFlux are overseen by James Prairie (USBR) and operated by Dr. Larry Hipps (Utah State University). We will directly download and compile available post-processed (hourly and half-hourly) data from the AmeriFlux website for stations operated by other agencies in Utah. Those data and the data we collect, will be compiled into one postgresql database. If it can be released, Larry Hipps (USU) will provide data from the stations he oversees. Ideally, the resulting output data will have a reported frequency of 0.5 hr to 1 hr (note that raw data have a measurement frequency of 10-20Hz). We will combine this compiled data with post-processed data that we collect from the stations we install.

In collaboration with the Central Utah Water Conservancy District (CUWCD) and Trout Unlimited (TU), the UGS is establishing two new eddy covariance stations in the Upper Colorado River Basin. We have established a land use agreement and installed one station near Wellington, Utah (US-UTW). The second station will be installed near Duchesne, Utah. Both stations will be installed in agricultural settings, immediately adjacent to fields of alfalfa or a comparable crop. For the proposed project, we will include data collected from these stations. Costs of data collection and data management from those stations will be covered by other grants and will not be included in this proposal.

New Flux Stations

The UGS currently owns two weather stations equipped with the basic power, tower, and data logger requirements for eddy covariance sensors. These stations are made by Campbell Scientific, a Utah-based and internationally renowned company that specializes in eddy covariance stations. Campbell Scientific software requires carbon dioxide and soil-heat-flux measurements for effective processing using its cloud-based software and integration into its cloud based data storage (EasyFlux). The UGS is currently purchasing peripheral equipment to upgrade the existing stations to measure soil heat flux.

We propose to upgrade the existing UGS stations so that they can: (1) measure water and carbon fluxes and (2) work in a network with other eddy covariance stations. Carbon (carbon dioxide or methane) measurement is a requirement for inclusion in the AmeriFlux network. Also, automated flux calculations are easier with the datalogger software that we use if carbon dioxide is measured. Once the stations are upgraded, we will deploy one in the Matheson Wetlands Preserve near Moab, Utah, or a comparable wetland setting in Utah, to measure evapotranspiration of phreatophytes, and one in the Nephi, Utah area. Once the stations are established, we will register them in the Ameriflux network. We will visit and maintain the stations monthly, assure data quality, complete post-processing, and upload the data to the AmeriFlux network. The AmeriFlux network is used to help groundtruth the OpenET network. Adoption of Utah flux stations into the Ameriflux network will improve the spatial validation and accuracy of the models in OpenET.

With the deployment of new stations, we also need a means of calibrating the stations in the field. The standard for calibration of an eddy covariance infrared gas analyzer is a zero-gas and constant gas. In the case of ET, the constant gas is air with a precisely generated water vapor concentration. This is achieved using a field-ready water vapor generator.

Data Processing

Data processing and quality assurance from flux stations can be time consuming and requires a multi-step process customized to each station. We will establish a workflow for the new stations to ensure a steady flow of data to the Ameriflux network. We will collect one year of data from the new stations for this project, processing as we collect the data.

The EasyFlux and EddyPro software packages provide a good starting point for eddy covariance data processing, but additional processing with established methods is required in many cases. This processing includes numerous processing steps, including frequency analysis (FFT) and despiking (Aubinet and others, 2012). We will pull together existing processing scripts (Zhou and others, 2016; Perez‐Priego and others, 2018; Nelson and others, 2018) into a Python or R-based package and make that available on GitHub (https://github.com/) when complete, so other scientists can make use of the processing workflow.

Remote Sensing Calibration

Once a network of stations and data flow have been established, we will use the data we have compiled and collected to validate and check the remotely-sensed methods. OpenET is scheduled for release in 2021. Working with the creators of OpenET, we will compare our measurements with their model aggregates. We will also compare our measurements with the METRIC and SSEBop techniques, two approaches which are used in OpenET. METRIC data are available through the EEFLUX web interface (https://eeflux-level1.appspot.com/) and SSEBop data can be calculated using a GitHub library created by Charles Morton, a major contributor to OpenET (https://github.com/spizwhiz/openet-ssebop-beta). We will aggregate station data to monthly values and compare them to the corresponding pixel values from the remotely-sensed data. We will make a comparison between remote sensing data and station data using techniques applied in previous reports (Wang and others, 2015; URS, 2016; Jung and others, 2020). Methods of comparison will include linear regression between outputs and root mean squared error for differences between flux station and remotely-sensed cumulative ET. We will compare data from the stations against remotely-sensed data using well established methods of statistical comparison. The end result of the analysis will include adjustment coefficients that can be applied to raster data to better fit the measured evapotranspiration.

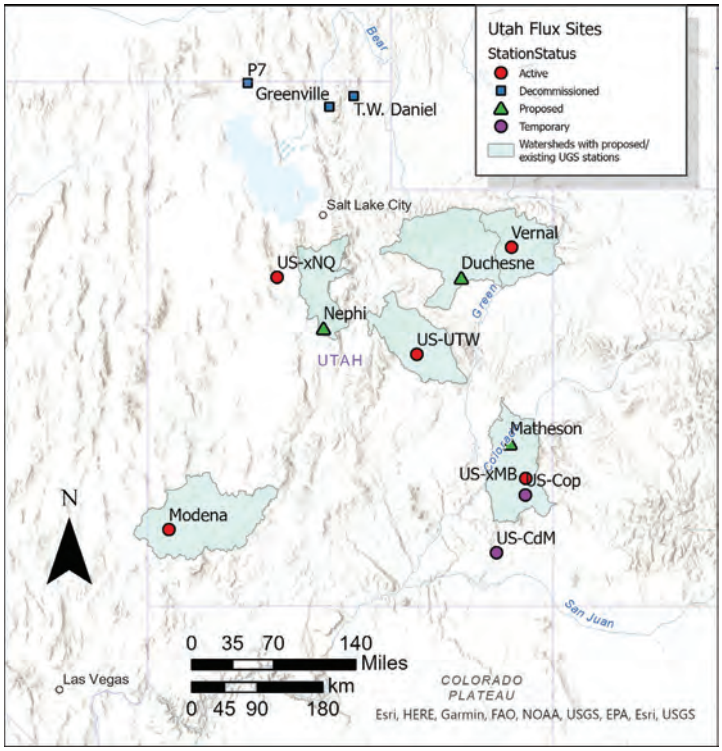
Web Application

We will share available data once they have been collected, compiled, and processed. We will upload the data we collect to the AmeriFlux network. In addition, our data will be available through a map-based interface that we create, where a user can click on a point and a popup will display a photo of the station, metadata of the station, vegetation near the station, and a link to the station data. The link to the station data would most likely be to the AmeriFlux download point, but it could also be to Campbell Scientific's cloud-based EasyFlux system (https://www.campbellsci.com/easyflux-webs).

Project location

Results of this project will be applicable to the entire western United States due to improvements to ET models. Based on individual station location, results of this project will

encompass several watersheds in the State of Utah, with a focus on the Upper Colorado River Basin. Individual stations will be located in Price, Moab, Duchesne, Tooele, Vernal, and Enterprise.



Data management practices

The UGS uses ArcGIS Pro and ArcGIS Desktop to analyze and generate data products. Data products will be delivered to the Utah Division of Water Rights in the form of raster datasets and will be contained in geodatabases. All toolboxes and datasets will include metadata with a title, summary, descriptions, keywords, and usage limitations. All time series data will meet data requirements of the AmeriFlux network.

Evaluation criteria

E.1.1. Evaluation Criterion A — Benefits to Water Supply Reliability (40 points)

Water Management Issues

Because water is scarce in Utah and the western United States, effective management of this resource requires reliable information describing and quantifying water availability, diversions, returns, and consumptive use (ET). State law and interstate compacts have established a framework for the distribution of naturally occurring water and these laws and agreements depend on the ability to measure or quantify water flows. While flows in streams and through diversions have long been measured, quantification of the consumption of irrigation use has been a particular challenge.

Consumptive use is the portion of a water diversion that is consumed and does not return to any surface stream or groundwater aquifer. For irrigation uses, consumptive use consists of evaporation and plant transpiration of the water that was diverted. This evapotranspiration principally occurs from the surface of the irrigated land, though some portion may occur during water conveyance or after runoff or seepage of excess irrigation. Evapotranspiration of precipitation water is not considered consumptive use.

Allocations under the Upper Colorado River Compact are based on consumptive use, which is estimated and reported annually by each Upper Basin state. Utah has a significant

interest in the accuracy of these estimates. Utah has historically estimated its Upper Basin consumptive use by surveying irrigated acreage and applying a calibrated Blaney-Criddle crop coefficient method. This method requires that crop type is assigned to each area manually. Depending on the measured vegetation, remote sensing methods can improve estimates of ET by up to 25% and typically have accuracy values of more than 90% (Chen and others, 2016; Paula and others, 2019; McColl, 2020).

In recent years, various methods of estimating evapotranspiration using remote sensing have been developed. Utilization of these methods has required substantial expertise and resources and has not been applied widely in Utah. The OpenET project has developed means to automate several of these methods using freely available satellite imagery and plans to begin making the results freely available online. Specifically, OpenET is anticipated to publish results obtained using ALEXI/DisALEXI, METRIC, PT-JPL, SEBAL, SIMS, and SSEBOP. The development of methods to estimate and disseminate evapotranspiration estimates at moderately high spatial resolution and time frequency has the potential to improve the state's ability to quantify consumptive use. However, the state needs to be able to assess the accuracy and reliability of this new data. There is a need for ground measurement of evapotranspiration so the automated remote sensing methods can be evaluated and perhaps improved.

Some measurements of actual evapotranspiration have been and are being made in other states. There is a need for measurements in Utah because the accuracy of satellite-based evapotranspiration methods can vary regionally. The satellite-based methods depend on there being a sufficient frequency of cloud-free satellite images; but midday cloudiness is somewhat common during early summer months in some regions of Utah. Further, alfalfa – the most common crop cultivated in the state – requires a relatively high frequency of usable images to capture the variation in evapotranspiration resulting from frequent cuttings. Many of the methods utilize relations and correction factors that have been developed for certain regions and crops, but ground-based measurements in Utah have not been available for calibrating models. Because of this, a satellite-based evapotranspiration method may work well in some areas, but perform unreliably in Utah until we extend the network of ground-based sensors locally.

Addressing Water Management Issues

Water Supply Reliability: One of four fundamental water management measures in any water management program is adequate water measurement and accounting (U.S. Bureau of Reclamation, 2000). Time-series measurements of crop consumptive use have the potential to improve the timing of irrigation water applications. Improved timing of irrigation water management can increase production and decrease water use. If consumptive use data is available to farmers in near-real-time, then farmers can adjust their irrigation practices in response to data.

Uncertainties in model input data can create uncertainties in the results produced. The chosen method used to estimate ET significantly affects the results of the Utah Water Budget model used by the Utah Division of Water Resources (Miller, C.W., 2017). Other entities and states with an interest in estimating ET and crop water requirements are evaluating standards currently, but there is not a consensus. OpenET may help build that consensus. The Utah Water

Budget, Great Salt Lake Integrated, river basin, and reservoir models could be improved with better estimates of ET.

Water Marketing Activities: Measurement of consumptive use is essential to successful water marketing activities. Current water banking trials in Utah would have the consumptive (ET) portion of a water right transferred into a water bank. In order to bank the consumptive portion of a water right, it must be quantifiable. In their review of case studies of water banking in the western United States, Ebeling and others (2019) noted that water use is typically poorly quantified, causing gaps in reporting between water users and regulators, leading to costly and time consuming transfer process and disincentives to water users who would otherwise engage in the market.

Conservation and Efficiency: The U.S. Bureau of Reclamation Moving Forward project emphasized that maintaining and expanding monitoring networks (U.S. Bureau of Reclamation, 2015) and improving remote sensing data is a strategy to conserve agricultural water and increase productivity.

Drought Management Activities: Currently, more than 90% of Utah is in extreme (D3) or exceptional (D4) drought, where more than half of the state is in exceptional drought (D4) (National Drought Mitigation Center, 2021). Reduction of consumptive use through demand management (namely water banking) is one of three drought management strategies outlined by former Colorado River District General Manager Eric Kuhn in his presentation to the Colorado Water Congress (Kuhn, 2016).

Water Rights Administration: Consumptive use is a critical consideration for water right change applications. Changes that would increase consumptive use are not allowed because of the impact this would have on other water users. Because it has been impractical to measure actual consumptive use accurately, the beneficial use of irrigation rights has been quantified historically using the long-term average potential evapotranspiration of alfalfa for the acreage irrigated. This administrative practice does not allow farmers to irrigate more acres of a less water-demanding crop or to irrigate different parcels of land with the same water right during different periods of the year. Crop-based measurements of consumptive use could provide necessary flexibility in water-right administration.

Utah currently has a policy of "use it or lose it" with water rights, where water rights not put to beneficial use can be forfeited under certain circumstances. Opponents of this management strategy suggest that this policy leads to inefficient use of water. Proponents of natural habitat conservation, like The Nature Conservancy and Trout Unlimited, are supporting projects that allow water marketing (Stavney, 2021). California introduced policy changes to the "use it or lose it" policy by giving farmers with unused allocations the ability to sell, lease, or transfer conserved water. This approach provides both incentives for farmers to conserve, as well as providing access for others to unused water. Technological advances in agriculture, including irrigation practices and crop genetics have increased water efficiency. However, the "use it or lose it" policy can generate negative incentive toward conservation. In Utah, beneficial use includes domestic drinking water, agricultural use, aquatic life, and recreation, but excludes conservation (Bateman, 2014).

Endangered Species Requirements: Successful water marketing strategies can help promote instream flow, which in turn can maintain habitat for a wide range of wildlife and conservation species. Having the ability to measure changes in ET allows for quantification of water saved by changes in water management, which, in some cases, results in the preservation of instream flow. The UGS oversees Utah State Wetland delineation and hydrologic monitoring. Measuring wetland evapotranspiration can help us monitor wetland plant response to changes in climate, restoration projects, and changes in water use around the wetlands. For example, the UGS made considerable efforts quantifying the flow of springs in the central part of Snake Valley. These springs support unique populations of Least Chub and Columbia spotted frog, both of which are classified as Species of Greatest Conservation by the Utah Division of Wildlife Resources. Frequently, all of the water that leaves the wetland system is through evaporation. Improved quality of ET estimates from these habitats can help us better understand changes in the flow of the springs over time (Inkenbrandt, 2020).

Watershed Health: Maintaining watershed health requires an informed water budget. The volume of irrigation water lost to evapotranspiration, as opposed to the quantity that returns back to water bodies, is important for hydrologic studies. The diversion and use of water for irrigation significantly impacts water systems in many Utah basins and the quantification of consumptive use is critical for hydrologic and hydrogeological studies. Past studies have relied on generalized approximations, assuming for example that some percentage of applied irrigation is consumed and the remainder returns to the groundwater system.

Quantification of Benefit

Because water measurement is a key step in initiating water markets and other similar water conservation practices, this project would be instrumental in saving water and quantifying those savings. The Bureau of Reclamation estimated that approximately one million acre-feet of water could be conserved by 2060 with the application of agricultural water conservation practices in the Colorado River Basin (U.S. Bureau of Reclamation, 2015). The largest potential water savings at the lowest cost of implementation are in agriculture and outdoor residential use (Edwards and others, 2017).

Total irrigated crop sales for Utah in 2018 were $486 million, but the true value of the crops was likely 40% higher ($680 million), as they were fed to livestock, which make up a larger portion of the agricultural economic income (Hilton and Gentillon, 2018). Crop irrigation withdrawal in 2015 (the most recently available estimate) was about 3 million acre-feet (U.S. Geological Survey, 2021). Assuming the average cost of agricultural irrigation water is 10¢ per 1000 gallons in Utah (~$30/ac-ft) (Wiebe and Gollehon, 2006), 3 million acre-feet of water would cost about $109 million. It is important to note that the *value* of water is likely higher, as it provides ecosystem services and recreation opportunities that are difficult to quantify. Agricultural consumptive use makes up about 88% of the consumptive use in Utah (Wiebe and Gollehon, 2006). The consumptive use for agriculture was about 2.3 million acre-feet, which equates to a value of about $75 million (U.S. Geological Survey, 2021). Assuming that at least a 0.1% improvement in irrigation consumptive use efficiency can be established as a result of our additional measurements and improved accuracy in estimation of consumptive use, then the state has the potential to save about $75 thousand per year in agricultural water costs.

In fact, more water is evaporated from streams and ponds and used in transpiration than is withdrawn for public supplies.

Projects the Proposal Complements

This project will complement efforts by the Upper Colorado River Commision (UCRC) and James Prairie of the USBR to assess agricultural consumptive use in the upper Colorado River basin (URS, 2013; URS, 2016). [redacted] of Utah State University, working under contract with Prairie, has measured ET in Vernal, Utah since June 2017 using strict scientific standards. James and the UCRC have agreed that additional data would supplement and add value to their current research.

Models used by the OpenET program require ground-truthing data for validation and calibration. This project would complement validation of those models, especially if UGS ET measurements are fed into the AmeriFlux network. Once in the AmeriFlux network, our data could complement many studies and models, as it will be readily available to the general public and easily referenced. Enhanced estimates of ET have shown to significantly improve model results (Herman and others, 2018).

The State is actively pursuing the development of water marketing activities through its Utah Statewide Water Marketing Development Strategy (Utah). This effort was supported by a 2019 $400,000 WaterSMART award. Water marketing depends on high quality evapotranspiration accounting, which this project will supply.

E.1.2. Evaluation Criterion B — Need for Project and Applicability of Project Results (20 points)

Meeting Existing Needs

Recent drought and renegotiations of Colorado River water have necessitated accurate accounting of ET. Utah needs an agreed-upon metric with which to measure ET and there should be some consensus among all stakeholders who rely on Colorado River water, including tribal entities, basin states, and Mexico. OpenET would likely help build consensus, but we need to ensure that ET is well represented throughout the Colorado River basin by having a spatially-distributed network of ground-truthing ET stations.

ET measurement can help address many of Utah's water needs. The Recommended State Water Strategy (Water Strategy Advisory Team, 2017) for Utah calls for improved water conservation and efficiency in Utah through implementation of several approaches, including approaches that can be accomplished by measuring consumptive use directly. Specifically, they recommended that (1.2iii) water budgeting approaches and depletion amounts (1.2iv) should be refined; both would be substantially improved with ET measurements. In many basin-scale water budgets, ET is often the most poorly constrained component. In Utah, agriculture accounts for 82% of water diverted from natural sources and 15.1% of the economy. The Water Strategy Advisory Team (2017) called for an effective means of optimizing water resources by supporting water use measurement (3.7). They also recommended programs that promote water markets and demand management, where farmers are incentivized financially to decrease or temporarily

suspend their use of water. Measuring the changes in ET induced by these programs is essential to quantifying their effectiveness. The Water Strategy Advisory Team (2017) also recommended increased funding for climate science monitoring and research in assessing climate change impacts, including changes in evapotranspiration. Finally, they recommended that the State explore technology's effect on agricultural water usage, including using near-real time monitoring to inform irrigation practices (11.3).

Immediate Applicability

Measurements of the flux stations will be readable immediately after QA/QC and applicable to understanding consumptive use at the flux stations. Evaluation of remote sensing approaches to measuring ET will also be available and interpretable immediately after the work is completed. The web interface will also contain links to the data and will provide information about weather conditions and consumptive use as soon as the data are available.

Transferability

Our data will be available for everyone to view and use as they see fit once they are posted to the internet. While the flux stations that we are monitoring will be extremely localized, the data they produce are potentially applicable to a wide geographic area, especially if they are used in the calibration and validation of remote sensing techniques like those applied in the OpenET interface. Dependable ET products like those that will be offered by OpenET can be applied by all of the western states, with varying degrees of certainty of the accuracy of the data. Data measured by these stations can be used by the greater community of climate scientists, as the stations also provide measurements of carbon dioxide, which is a valuable parameter for calibration of climate models.

Beneficiaries

OpenET will benefit from this project because it is potentially (assuming high-quality data) providing additional ground-truthing points. Utah Division of Water Rights and the Upper Colorado River Commision will benefit from additional ET data. Water Marketing projects need measurements of consumptive use for appropriate water allocation and reimbursement.

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

Approach

1. **Upgrade the current UGS stations to meet Ameriflux Network requirements** - Purchase and install two IRGASONs onto the existing UGS Campbell Scientific stations.
2. **Deploy upgraded stations** - Once the new equipment arrives, we will deploy the stations. The UGS is currently in negotiations with landholders in Nephi and Moab. One of the non-upgraded UGS stations is already deployed in Nephi, on land owned by the Church of Jesus Christ of Latter Day Saints. The other station will be deployed in Matheson Wetlands Preserve (north of Moab, UT), owned by the Utah Division of Wildlife Resources who co-manages the property with The Nature Conservancy (see

letters of support). If landowners are not amenable to station deployment at these locations, we will coordinate with The Nature Conservancy and Central Utah Water Conservancy District to find alternative deployment locations.

3. **Register stations into Ameriflux Network** - We will register the new stations with the Ameriflux network using metadata collected during installation.
4. **Record high-quality measurements -** The UGS will visit each station monthly to ensure that they are recording high-quality measurements. Visits will include sensor cleaning and calibration. We will use a zero-air generator to calibrate the IRGASONs.
5. **Develop workflow with established methods to process, correct, and compile data** - Using predefined methods from the literature (Lee and others, 2005; Aubinet and others, 2012) and scripts available on GitHub (Zhou and others, 2016; Perez‐Priego and others, 2018; Skaggs and others, 2018; Wutzler and others, 2018; Nelson and others, 2018), Paul Inkenbrandt, Rebecca Lee, Clayton Lewis (Utah Division of Water Resources) and Kathryn Ladig will devise a series of data QA/QC steps to help flag and correct erroneous time series data. This includes spike detection and removal, spectral analysis, and anemometer vector transformations. Once the workflow is established, we will compile existing available data (raw and processed) from eddy covariance stations in Utah. With the existing data, we will reprocess when possible in an attempt to improve data quality. , UGS Data Manager, will provide oversight with database schemas and assist in the data compilation efforts.
6. **Compare station data with remote sensing estimates** - , Rebecca Lee (UGS), Clayton Lewis (Utah Division of Water Resource) and Nathan Payne (UGS), will collaborate with developers at OpenET, including Forrest Melton and Justin Huntington, to establish metrics of comparison between the UGS data and OpenET data. Nathan Payne, UGS GIS analyst, will be responsible for comparing the ground-based measurements against METRIC and SEEBOP, generating calibration factors for the datasets.

   will also check the ground-based measurements against a raster-based evapotranspiration model that he developed to gage the accuracy of his model and the station data.

7. **Create an application showing location of stations and linking station data** - Nathan Payne will create a front-end web application that displays a map of the stations in the Utah Flux Network (UFLUX). Each station will have a popup that describes the station metadata and links to the finalized time-series data.
8. **Disseminate information to the public -** will work with Hugh Hurlow and Kathryn Ladig, to generate a published report of our methods and findings, and provide documentation for the front-end application, allowing for public interpretation of the ET data.

Work Plan and Project Schedule

Following the steps outlined above, we will set up and register new stations, develop a processing workflow, compile data, compare our data with remotely-sensed data, create an interactive web map, and generate an explanation of our data. This project will take two years to

complete. From the upgraded and deployed stations that we establish, we will collect at least one year's worth of data. See the project timeline for the proposed order of operations.

Table 1. *List of tasks and personnel needed to complete the project. See table 3 for hours.*

Task	Personnel	Description
1. Upgrade current stations	Paul Inkenbrandt Kathryn Ladig	Purchasing equipment; Station design logistics and communicating with manufacturer
2. Deploy upgraded stations	Paul Inkenbrandt Kathryn Ladig	Station placement negotiations; Receiving and inspecting parts and field preparation; Travel and station assembly in field
3. Register sites	Paul Inkenbrandt	Populate metadata of both sites and communicate with AmeriFlux Team; Establish data stream
4. Processing workflow	Paul Inkenbrandt Kathryn Ladig Rebecca Lee Clayton Lewis Martha Jensen	Compile existing scripts and methods; Add new python scripts; Communication and training; Validating and reviewing scripts in R and Python; Develop a schema to house results of processing;
5. Data collection	Paul Inkenbrandt Kathryn Ladig	Visiting field sites, downloading data, and maintaining stations on a monthly basis.
6. Comparison with remotely-sensed methods	Paul Inkenbrandt Rebecca Lee Nathan Payne Clayton Lewis	Communicate with OpenET developers; Research comparison practices; Conduct analytical comparison; Document and report comparison methods; Compare samples of his gridded approach against the ground-truthed measurements
7. Front-end development	Nathan Payne	Develop a map-based interface to allow users to access ET data collected by UGS
8. Information dissemination	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

Table 2. *Timeline needed to complete the project.*

	Federal Fiscal Year	FY22	FY22	FY22	FY22	FY23	FY23	FY23	FY23
	Calendar Year	2021	2022	2022	2022	2022	2023	2023	2023
	Quarter	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep
Step	**Description**								
1	Upgrade Stations								
2	Deploy Stations								
3	Register Stations								
4	Record Measurements								
5	Develop Processing Workflow								
6	Compare to Remote Sensing								
7	Front-end Development								
8	Present and Interpret Results								

Table 3. *Summary of hours needed for each member of the project.*

Task	Paul	Kathryn	Hugh	Rebecca	Martha	Nathan	Clayton*
Title	Senior Geologist	Geologist	Program Manager	GIS Analyst	Data Manager	GIS Analyst	Engineer III
1	20	20					
2	130	130					
3	30						
4	300	120		120	80		80
5	220	220					
6	40			200		200	80
7						200	
8	120	120	120				
Total	860	610	120	320	80	400	160

* Clayton is with the Utah Division of Water Resources; All other personnel are with the Utah Geological Survey

Products and Deliverables

This project will result in the following deliverables:

- Rasters of "calibrated" ET for the entire state derived from the best fit of our measurements to existing approaches METRIC and SEEBop; calibration parameters and process will be documented and provided in the raster metadata
- Two functional eddy covariance systems, capable of contributing to the AmeriFlux network.
- An analysis and comparison of estimates from OpenET to ground-based measurements.
- Data processing workflow scripts available on GitHub.
- A web application to provide data access to the public and water managers

Staff Identification

- **Paul Inkenbrandt** - UGS Senior Geologist - Paul Inkenbrandt has worked at the UGS for 11 years. He has overseen the assembly and deployment of three eddy covariance towers. 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.
- **Hugh Hurlow** - UGS Groundwater and Wetlands Program Manager - will assist in project management and ensure that equipment purchases, land owner

agreements, and project tasks are completed in a timely manner. He will review relevant deliverables of the project.

- **Kathryn Ladig** - UGS 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 will oversee data collection, station maintenance, and data processing at the stations.
- - UGS Senior GIS Analyst - Nathan Payne is an expert in remote sensing analysis, with a B.S. in GIS analysis.
- UGS Data Coordinator - Martha Jensen creates, manages, and maintains data and security on all UGS enterprise databases, as well as all of the UGS public-facing data repositories in our web applications. She has training in database management, R, Python, ESRI products and SQL. She will help with database schema development and data compilation.
- - 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. She is skilled in Google Earth Engine, R, and ArcGIS Pro.
- **Clayton Lewis** - Utah Division of Water Resources - Engineer III - Clayton Lewis has a Ph.D. in Civil Engineering and has been involved in evapotranspiration and water resources projects for local, state, national, and international entities for the past 12 years. He has managed a network of reference evapotranspiration weather stations, assisted in maintaining several eddy covariance towers, and has developed software in estimating potential and actual evapotranspiration from various methods and datasets including eddy covariance. Primarily, his experience has revolved around automating data collection and clean up, developing models and comparisons, and generating data and reports. He is a (permissive) open source advocate, and some of his favorite software are GDAL, SQLite, .NET, ZFS, and FreeBSD.

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

The UGS will conduct recorded presentations of the project, including sharing measurements and how to access them. We will make a link to our database available on the UGS website (geology.utah.gov). Data will also be disseminated on the AmeriFlux network. AmeriFlux conducts regular webinars that are made available on YouTube. If allowed, we will share our efforts in one of the webinars, to make others aware of our data, and to get input from the professional community. We will present our results to the Utah Division of Water Rights, and other agencies interested in the data. The UGS will participate in at least one Reclamation-sponsored webinar to disseminate deliverable(s) and discuss ways to apply deliverables to management questions.

Required Permits or Approvals

The stations we construct will be on private and managed land. This project will require land access agreements with the landowners. The UGS has already initiated land access agreements

with the various landholders. Part of the project will be to complete the agreements for station deployment. Station installation will not result in ground disturbance or permanent structures.

References

Abatzoglou, J.T., Dobrowski, S.Z., Parks, S.A., and Hegewisch, K.C., 2018, TerraClimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958–2015: Scientific Data, v. 5, no. 1, p. 170191., doi: 10.1038/sdata.2017.191.

Allen, R.G., 2006, Benefits From Tying Satellite-Based Energy Balance To Reference Evapotranspiration, *in* EARTH OBSERVATION FOR VEGETATION MONITORING AND WATER MANAGEMENT – AIP Conference Proceedings: Naples (Italy), AIP, p. 127–137., doi: 10.1063/1.2349336.

Allen, R.G., Tasumi, M., and Trezza, R., 2007, Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC)—Model: Journal of Irrigation and Drainage Engineering, v. 133, no. 4, p. 380–394.

Aubinet, M., Vesala, T., and Papale, D. (Eds.), 2012, Eddy Covariance: A Practical Guide to Measurement and Data Analysis: Dordrecht, Springer Netherlands, doi: 10.1007/978-94-007-2351-1.

Bateman, M., 2014, Flowing toward 2050—Utah's water outlook: Utah Foundation Research Report 723.

Chen, M., Senay, G.B., Singh, R.K., and Verdin, J.P., 2016, Uncertainty analysis of the Operational Simplified Surface Energy Balance (SSEBop) model at multiple flux tower sites: Journal of Hydrology, v. 536, p. 384–399., doi: 10.1016/j.jhydrol.2016.02.026.

Ebeling, E., Kearl, Z., Weaver, E., and Wentzel, N., 2019, Water banking and water marketing in select western states: Washington State Department of Ecology Unpublished consultants report, 110 p.

Edwards, E.C., Bosworth, R.C., Adams, P., Baji, V., Burrows, A., Gerdes, C., and Jones, M., 2017, Economic Insight from Utah's Water Efficiency Supply Curve: Water, v. 9, no. 3, p. 214., doi: 10.3390/w9030214.

Flint, L.E., and Flint, A.L., 2012, Downscaling future climate scenarios to fine scales for hydrologic and ecological modeling and analysis: Ecological Processes, v. 1, no. 1, p. 2., doi: 10.1186/2192-1709-1-2.

Flint, L.E., and Flint, A.L., 2014, California Basin Characterization Model: A Dataset of Historical and Future Hydrologic Response to Climate Change:, doi: 10.5066/F76T0JPB.

Flint, A.L., Flint, L.E., Hevesi, J.A., and Blainey, J.B., 2004, Fundamental concepts of recharge in the desert southwest: A regional modeling perspective, *in* Hogan, J.F., Phillips, F.M., and Scanlon, B.R., editors, Water Science and Application: Washington, D. C., American Geophysical Union, p. 159–184., doi: 10.1029/009WSA10.

French, A.N., Alfieri, J.G., Kustas, W.P., Prueger, J.H., Hipps, L.E., Chávez, J.L., Evett, S.R., Howell, T.A., Gowda, P.H., Hunsaker, D.J., and Thorp, K.R., 2012, Estimation of surface energy fluxes using surface renewal and flux variance techniques over an advective irrigated agricultural site: Advances in Water Resources, v. 50, p. 91–105., doi: 10.1016/j.advwatres.2012.07.007.

Herman, M.R., Nejadhashemi, A.P., Abouali, M., Hernandez-Suarez, J.S., Daneshvar, F., Zhang, Z., Anderson, M.C., Sadeghi, A.M., Hain, C.R., and Sharifi, A., 2018, Evaluating the role of evapotranspiration remote sensing data in improving hydrological modeling predictability: Journal of Hydrology, v. 556, p. 39–49., doi:

10.1016/j.jhydrol.2017.11.009.
Hilton, J., and Gentillon, J., 2018, Utah agricultural statistics and Utah Department of Agriculture and Food 2018 annual report: United States Department of Agriculture National Agricultural Statistics Service Mountain Region, Utah Field Office Annual Report, 62 p.
Inkenbrandt, P.C., 2020, Time series analyses of a Great Basin groundwater-fed wetland complex, Juab County, Utah: Utah Geological Survey Report of Investigation 282, 34 p.
Jung, M., Schwalm, C., Migliavacca, M., Walther, S., Camps-Valls, G., Koirala, S., Anthoni, P., Besnard, S., Bodesheim, P., Carvalhais, N., Chevallier, F., Gans, F., Goll, D.S., Haverd, V., and others, 2020, Scaling carbon fluxes from eddy covariance sites to globe: synthesis and evaluation of the FLUXCOM approach: Biogeosciences, v. 17, no. 5, p. 1343–1365., doi: https://doi.org/10.5194/bg-17-1343-2020.
Kuhn, E., 2016, The 2007 interim guidelines, contingency planning, the risk study, demand management & water banking—How do they all fit together? Colorado Water Congress Summer Conference and Membership Meeting, Steamboat Springs, Colorado.
Lee, X., Massman, W., and Law, B., 2005, Handbook of Micrometeorology A Guide for Surface Flux Measurement and Analysis: Atmospheric and Oceanographic Sciences Library, 29, Dordrecht, Springer Netherlands, Atmospheric and Oceanographic Sciences Library, 29, 263 p., doi: 10.1007/1-4020-2265-4.
McColl, K.A., 2020, Practical and Theoretical Benefits of an Alternative to the Penman-Monteith Evapotranspiration Equation: Water Resources Research, v. 56, no. 6, p. e2020WR027106., doi: https://doi.org/10.1029/2020WR027106.
Miller, C.W., 2017, Utah Division of Water Resources water budget program methods description: Online, https://westernstateswater.org/utah-division-of-water-resources-water-budget-program-methods-description/, accessed March 2021.
National Drought Mitigation Center, 2021, United States drought monitor: Online, https://droughtmonitor.unl.edu/CurrentMap/StateDroughtMonitor.aspx?UT, accessed March 2021.
Nelson, J.A., Carvalhais, N., Cuntz, M., Delpierre, N., Knauer, J., Ogée, J., Migliavacca, M., Reichstein, M., and Jung, M., 2018, Coupling Water and Carbon Fluxes to Constrain Estimates of Transpiration: The TEA Algorithm: Journal of Geophysical Research: Biogeosciences, v. 123, no. 12, p. 3617–3632., doi: 10.1029/2018JG004727.
Paula, A.C.P. de, Silva, C.L. da, Rodrigues, L.N., Scherer-Warren, M., Paula, A.C.P. de, Silva, C.L. da, Rodrigues, L.N., and Scherer-Warren, M., 2019, Performance of the SSEBop model in the estimation of the actual evapotranspiration of soybean and bean crops: Pesquisa Agropecuária Brasileira, v. 54., doi: 10.1590/s1678-3921.pab2019.v54.00739.
Perez‐Priego, O., Katul, G., Reichstein, M., El‐Madany, T.S., Ahrens, B., Carrara, A., Scanlon, T.M., and Migliavacca, M., 2018, Partitioning Eddy Covariance Water Flux Components Using Physiological and Micrometeorological Approaches: Journal of Geophysical Research: Biogeosciences, v. 123, no. 10, p. 3353–3370., doi: https://doi.org/10.1029/2018JG004637.
Rafn, E.B., Contor, B., and Ames, D.P., 2008, Evaluation of a Method for Estimating Irrigated Crop-Evapotranspiration Coefficients from Remotely Sensed Data in Idaho: Journal of Irrigation and Drainage Engineering, v. 134, no. 6, p. 722–729., doi: 10.1061/(ASCE)0733-9437(2008)134:6(722).

Senay, G., and Kagone, S., 2019, Daily SSEBop Evapotranspiration Data from 2000 to 2018:, doi: 10.5066/P9L2YMV.
Skaggs, T.H., Anderson, R.G., Alfieri, J.G., Scanlon, T.M., and Kustas, W.P., 2018, Fluxpart: Open source software for partitioning carbon dioxide and water vapor fluxes: Agricultural and Forest Meteorology, v. 253–254, p. 218–224., doi: 10.1016/j.agrformet.2018.02.019.
Stavney, J., 2021, Flexible water sharing reduces risk in dry times: Online, https://www.coloradoriverdistrict.org/water-banking/, accessed March 2021.
URS, 2013, Assessing agricultural consumptive use in the upper Colorado River basin - Phase 1: URS, 160 p.
URS, 2016, Assessing agricultural consumptive use including remote sensing of actual evapotranspiration in the upper Colorado River basin - Phase 2: URS.
U.S. Bureau of Reclamation, 2000, Achieving efficient water management—A guidebook for preparing agricultural water conservation plans: Boulder, Colorado, U.S. Bureau of Reclamation.
U.S. Bureau of Reclamation, 2015, Colorado River basin stakeholders moving forward to address challenges identified in the Colorado River basin water supply and demand study—Phase 1 report: U.S. Bureau of Reclamation Moving Forward, 452 p.
U.S. Geological Survey, 2021, Water use data for Utah: Online, https://waterdata.usgs.gov/ut/nwis/water_use, accessed March 2021.
Wang, S., Pan, M., Mu, Q., Shi, X., Mao, J., Brümmer, C., Jassal, R.S., Krishnan, P., Li, J., and Black, T.A., 2015, Comparing Evapotranspiration from Eddy Covariance Measurements, Water Budgets, Remote Sensing, and Land Surface Models over Canada: Journal of Hydrometeorology, v. 16, no. 4, p. 1540–1560., doi: 10.1175/JHM-D-14-0189.1.
Water Strategy Advisory Team, 2017, Recommended state water strategy.:
Wiebe, K., and Gollehon, N., 2006, Agricultural resources and environmental indicators, 2006: U.S. Department of Agriculture Economic Information Bulletin 16, 239 p.
Wutzler, T., Lucas-Moffat, A., Migliavacca, M., Knauer, J., Sickel, K., Šigut, L., Menzer, O., and Reichstein, M., 2018, Basic and extensible post-processing of eddy covariance flux data with REddyProc: Biogeosciences, v. 15, no. 16, p. 5015–5030., doi: 10.5194/bg-15-5015-2018.
Zhou, S., Yu, B., Zhang, Y., Huang, Y., and Wang, G., 2016, Partitioning evapotranspiration based on the concept of underlying water use efficiency: Water Resources Research, v. 52, no. 2, p. 1160–1175., doi: https://doi.org/10.1002/2015WR017766.

The Nature Conservancy
Moab Project Office
P.O. Box 1329
Moab, UT 84532

tel (435) 259-4629
cell (435) 260-9660

nature.org/utah

April 14, 2021

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

Dear Bureau of Reclamation Grant Proposal Review Committee,
The Nature Conservancy supports the Utah Geological Survey (UGS) WaterSMART application.
The Nature Conservancy is currently collaborating with the UGS to study the hydrology and wetland health of the Matheson Wetlands Preserve (north of Moab, UT). An eddy covariance station in this area would promote our goals for understanding and preserving the natural ecosystems in Utah. Also, the data provided by the Utah Flux Network will promote other projects important to TNC, including water marketing projects aimed to enhance natural habitats. As a contingency, if the UGS cannot find a suitable location in the Matheson Wetlands, we will coordinate with UGS to find the deployment locations in Utah for long-term eddy covariance stations.

Sincerely,

Linda Whitham

Linda Whitham
Central Canyonlands Program Manager
The Nature Conservancy

Cc: Dave Livermore, State Director Utah Chapter TNC

OPENET

April 19, 2021

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 R21AS00289, WaterSMART Applied Science Grant

To the WaterSMART Program:

On behalf of the OpenET project, I am writing to express support for the Utah Geological Survey (UGS) in their efforts to provide supplemental evapotranspiration (ET) data to the Ameriflux network. The OpenET project will assist these efforts by contributing data from all six OpenET models and the OpenET ensemble value to this study. The proposed data collection efforts by UGS will address an important data gap in the Ameriflux network, and we plan to work with UGS on a joint accuracy assessment of OpenET estimates for Utah to extend our ongoing OpenET model intercomparison and accuracy assessment. The proposed effort by UGS will be of significant value to OpenET, and will assist us in quantifying the accuracy of ET data from different satellite-driven ET models and providing the most accurate ET data possible for water resource management applications in Utah.

Sincerely,

Forrest Melton
Program Scientist, NASA WWAO
Associate Program Manager, Water Resources
NASA Applied Sciences Program
Mail Stop 232-21
Moffett Field, CA 94035

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

April 20, 2021

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 R21AS00289, 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, R21AS00289, WaterSMART: Applied Science Grant. The UGS has titled this project, "Supplementing Estimates of Evapotranspiration: The Utah Flux Network".

The total estimated cost of the anticipated UGS's effort, if the award is fully funded, would be $280,035.41 of which UGS would provide cost share in the amount of $103,730.20 and would receive in-kind funding from the Utah Division of Water Rights for $30,787.50 and the Utah Division of Water Resources for $11,000 (in personnel time). The amount of requested federal funding would be: $134,517.70. This project will provide ground-truthed calibration data for gridded evapotranspiration data and make it publicly accessible. 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,

R. William Keach II
UGS Director

CENTRAL UTAH WATER
CONSERVANCY DISTRICT

Al Mansell *Chair of the Board*
Shelley Brennan *Vice Chair of the Board*
Gene Shawcroft *General Manager / CEO*

April 12, 2021

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

Dear Bureau of Reclamation Grant Proposal Review Committee,

Central Utah Water Conservancy District (District) appreciates the opportunity to provide this letter in support of the Utah Geologic Survey's WaterSMART application for "The Utah Flux Network."

As the local sponsor of the Bonneville Unit of the Central Utah Project, the District relies on the Colorado River as its primary water supply. Using this supply, the District supplies water directly or indirectly to roughly 1.3 million Utah residents.

With continued climate change and population growth stressing the Colorado River Basin and the Great Basin, measurement and monitoring of depletions within these areas have become increasingly important to our understanding of how and where water is being used, and how and where water efficiency opportunities may be achieved.

The actual measurement of evapotranspiration for calibration of remote sensing methods is crucial for supporting and informing new technology development, and system management by water managers. Developing a statewide flux network by the Utah Geologic Survey, in partnership with the Utah Division of Water Rights, is an important step in the development of infrastructure necessary to improved measurement of actual evapotranspiration.

Central Utah Water Conservancy District urges the Committee to prioritize the Utah Geologic Survey Proposal for award. We believe that this work will provide valuable data for federal, state, and local policymakers and water users.

Sincerely,

Gene Shawcroft, P.E.
General Manager
Central Utah Water Conservancy District

Project budget Narrative

Funding plan and letters of funding commitment

The total project will cost $280,053.41 over a period of two years. The UGS will provide $103,730.20 (37.04%). The Utah Division of Water Rights will provide a monetary in-kind contribution of $30,787.50 and the Utah Division of Water Resources will provide a contribution of Clayton Lewis's personnel time equivalent to $11,000, totaling $41,787.50 (14.92%) in contributions from other divisions of the Utah Department of Natural Resources (DNR). The total contribution from Utah (DNR) is $145,517.70 (51.96%). Requested federal funding is $134,517.70. See attached documentation for letters of funding commitment.

Budget narrative

Salaries and Wages

Paul Inkenbrandt, Senior Geologist of the Utah Geological Survey, will be the project manager. He will oversee the project as well as conducting much of the technical work. Paul Inkenbrandt will work with Kathryn Ladig, Geologist at the UGS, to deploy the upgraded stations and maintain them. Hugh Hurlow, Groundwater and Wetlands Program Manager of the Utah Geological Survey, will also oversee the project progress. Nathan Payne, GIS Analyst at the Utah Geological Survey, will work with OpenET developers and Rebecca Lee to compare remote-sensing models to the ground-based data. See the Proposal Budget for details of hours, rates, and the yearly breakout. See the Technical Proposal for details on hours for each member of the team for this project.

Fringe Benefits

See budget sheet and attached fringe explanation form.

Travel

Travel will consist of two station deployments and monthly station visits. One station deployment will be on a farm in Nephi, Utah. For efficiency of setup, overnight stay will be required for setup at the Nephi farm, but it will not be required for the maintenance visits. The other station deployment will be to Moab, Utah. This area is farther from the Nephi area, and requires an overnight stay. Each station will require monthly maintenance visits to clean sensors

and download data. Some visits will only require one person, but many will require two people for safety and efficiency purposes. See budget sheet for a detailed breakout of travel.

Equipment

Two IRGASONs (Integrated CO2/H2O Open-Path Gas Analyzer & 3D Sonic Anemometer) will be required for this project. These devices are required for UGS to contribute station data to the AmeriFlux network. They will be purchased following state purchasing guidelines, and allow the UGS to upgrade existing equipment infrastructure. Each IRGASON has been quoted by the manufacturer (Campbell Scientific, Logan, UT) to cost $21,845. To maintain a level of calibration suitable for comparison to remotely sensed methods, the IRGASON needs a dew point generator ($13,185) that generates exact concentrations of water vapor. One dewpoint generator will work for all of the stations.

Materials and Supplies

Material costs have been included for the upgrade, deployment, and protection of the two eddy covariance stations used for this project. This includes fencing to protect from livestock (t-posts and fencing material). The other materials are for upgrading the stations.

The large amount of data produced by these stations requires mobile data transmission. We will order 2 standard mobile data plans through the manufacturer of the eddy covariance systems for 2 years, with each mobile data plan costing $940 per station per year. The total cost of the mobile data will be $3760. The stations are already equipped with the telecommunications equipment required for a mobile data connection.

Contractual

There are no contractual expenses.

Third-Party In-Kind Contributions

The Utah Division of Water Rights has committed to contribute $30,787.50 to help defer the costs of new equipment and supplies. Please see their attached letter of commitment and support. The Utah Division of Water Resources will provide $11,000 worth (160 hours) of personnel time from Clayton Lewis, an expert at the division in evapotranspiration. The UGS, the Division of Water Rights, and the Division of Water Resources are all in the Utah Department of Natural Resources.

Environmental and Regulatory Compliance Costs (as applicable to the project)

The proposed project does not include pilot activities. This project will deploy temporary meteorological stations on privately owned land. These actions are recognized as Categorical Exclusions under the code under the 43 CFR 46.210 exclusion E:

> *E. Operation, construction, installation, and removal – including restoration of sites to the pre-structure condition or equivalent of the surrounding environment – of hydrologic and water quality monitoring structures and equipment including but not limited to weirs, cableways, stream-gaging stations, groundwater wells, and meteorologic structures*

This project will not jeopardize the continued existence of any endangered or threatened species or destroy or adversely modify any designated critical habitat.

Other Expenses

There are no other expenses.

BUDGET ITEM DESCRIPTION	COMPUTATION		Quantity Type	TOTAL COST	Federal Share	State Share
	$/Unit	Quantity				
Salaries and Wages						
Paul Inkenbrandt	$61.68	860		$53,048.93		
Hugh Hurlow	$81.57	120		$9,788.40		
Kathryn Ladig	$42.56	610		$25,961.60		
Nathan Payne	$39.43	400		$15,772.00		
Rebecca Lee	$36.05	320		$11,536.00		
Martha Jensen	$48.17	80		$3,853.60		
Salaries & Fringe Benefits Total				**$119,960.53**	**$ 59,980.26**	**$ 59,980.26**
Equipment						
Integrated CO2/H2O Open-Path Gas Analyzer & 3D Sonic Anemometer	$21,845.00	2	Units	$43,690.00		
Dew point generator for equipment calibration	$13,185.00	1	Unit	$13,185.00		
Equipment Total				**$56,875.00**	**$ 28,437.50**	**$ 28,437.50**
Supplies and Materials						
Fencing	$62.00	3	rolls	$186.00		
T-posts	$5.20	15	posts	$78.00		
Wago Blocks	$109.00	4	blocks	$436.00		
Sensor Cross Arms	$120.00	2	arms	$240.00		
Mobile Data Plan for Remote Data Downloads	$940.00	4	plans/yr	$3,760.00		
Supplies and Materials Total				**$4,700.00**	**$ 2,350.00**	**$ 2,350.00**
Travel						
Nephi Station Deployment	$1,090.20	1		$1,090.20		
Nephi Station Maintenance	$145.10	22	11 visits each by 2 people	$3,192.20		
Matheson Station Deployment	$1,660.00	1		$1,660.00		
Matheson Station Maintenance	$395.00	20	10 visits each by 2 people	$7,900.00		
Travel Total				**$13,842.40**	**$ 6,921.20**	**$ 6,921.20**
Contractual/Construction						
Utah Division of Water Resources personnel time (Clayton Lewis)				**$11,000.00**	**$0.00**	**$11,000.00**
TOTAL DIRECT COSTS				**$206,377.93**		
Indirect Costs						
Federally approved annual fixed rate	37.70%	% (base = direct costs-contractual)		$73,657.48	$ 36,828.74	$ 36,828.74
TOTAL ESTIMATED PROJECT COSTS				**$280,035.41**	**$134,517.70**	**$145,517.70**

Third-Party In-Kind Contributions						
Water Rights Equipment Costs Contribution						$30,787.50
Utah Division of Water Resources personnel time (Clayton Lewis)						$11,000.00

SOURCE	AMOUNT	CONTRIBUTION		
Costs to be reimbursed with the requested Federal funding	$134,517.70	48.04%		
Costs to be paid by the applicant (UGS)	$103,730.20	37.04%		
Value of third-party contributions (Water Rights & Water Resources)	$41,787.50	14.92%	$145,517.70	51.96%
TOTAL PROJECT COST	$280,035.41	100.00%		

	Travel				Vehicle							
			hotel	$80.00				daily rate	mileage rate			
			per diem	$45.00				$35	$0.31			
Task	**days**	**hotel nights**	**hotel**	**per diem**	**drive time**	**vehicle days**	**vehicle milage**	**vehicle rental**	**vehicle mileage**	**vehicle total**	**Personnel**	**Totals**
	3	2	$160.00	$180.00	2.5	4	210	$140.00	$65.10	$205.10	Paul Inkenbrandt	
Nephi Station	3	2	$160.00	$180.00	2.5	4	210	$140.00	$65.10	$205.10	Kathryn Ladig	
Setup			**$320.00**	**$360.00**				**$280.00**	**$130.20**	**$410.20**		**$1,090.20**
	11	0	$0.00	$495.00	2.5	11	2310	$385.00	$716.10	$1,101.10	Paul Inkenbrandt	
Nephi Station	11	0	$0.00	$495.00	2.5	11	2310	$385.00	$716.10	$1,101.10	Kathryn Ladig	
Maintenance			**$0.00**	**$990.00**				**$770.00**	**$1,432.20**	**$2,202.20**		**$3,192.20**
	4	3	$240.00	$225.00	3.5	6	500	$210.00	$155.00	$365.00	Paul Inkenbrandt	
Matheson	4	3	$240.00	$225.00	3.5	6	500	$210.00	$155.00	$365.00	Kathryn Ladig	
Station Setup			**$480.00**	**$450.00**				**$420.00**	**$310.00**	**$730.00**		**$1,660.00**
Matheson	20	10	$800.00	$900.00	3.5	20	5000	$700.00	$1,550.00	$2,250.00	Paul Inkenbrandt	
Station	20	10	$800.00	$900.00	3.5	20	5000	$700.00	$1,550.00	$2,250.00	Kathryn Ladig	
Maintenance			**$1,600.00**	**$1,800.00**				**$1,400.00**	**$3,100.00**	**$4,500.00**		**$7,900.00**
			$2,400.00	**$3,600.00**				**$2,870.00**	**$4,972.40**	**$7,842.40**	**TOTAL**	**$13,842.40**

State of Utah

SPENCER J. COX
Governor

DEIDRE M. HENDERSON
Lieutenant Governor

Department of Natural Resources

BRIAN C. STEED
Executive Director

Division of Water Resources

TODD D. ADAMS
Division Director

April 19, 2021

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

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 measurement of evapotranspiration is essential for effective management of water. Remote-sensing approaches like OpenET will likely be adopted by western states as the standard for estimating consumptive use. Validation and ground-truthing of promising remote-sensing approaches is an important step in adopting estimates that all western states can agree on.

The proposed project is a collaborative effort between the UGS, the Utah Division of Water Rights, and the Utah Division of Water Resources. Clayton Lewis, an evapotranspiration expert in our group, will work with UGS hydrogeologists on this project to develop post-processing and validation workflows for eddy covariance station and remote sensing data. The Division of Water Resource would like to provide in kind services in the amount of $11,000 for Clay to work on this project. We hope you will fund this important project, as it promotes effective management of Utah's water resources.

Sincerely,

Todd D. Adams

Todd D. Adams, P.E.
Director

1594 West North Temple, Suite 310, PO Box 146201, Salt Lake City, UT 84114-6201
telephone (801) 538-7230 □ facsimile (801) 538-7279 □ TTY (801) 538-7458 □ *www.water.utah.gov*

SPENCER J. COX
Governor

DEIDRE M. HENDERSON
Lieutenant Governor

State of Utah
DEPARTMENT OF NATURAL RESOURCES

BRIAN C. STEED
Executive Director

Division of Water Rights
TERESA WILHELMSEN
State Engineer/Division Director

April 20, 2021

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 R21AS00289, 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 (R21AS00289) 2021 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. We will use the data collected by the proposed project to validate existing models of evapotranspiration.

To support this project, we commit an in-kind contribution of $30,787.50 to help match the costs of equipment and supplies. This funding will be available to the applicant when/if the USBR grant award becomes available to the UGS, which is likely the beginning of the federal fiscal year (10/1/2021).

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*

UPPER COLORADO
RIVER COMMISSION
355 South 400 East • Salt Lake City, UT 84111 • 801-531-1150 • www.ucrcommission.com

April 20, 2021

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

Dear WaterSMART Grant Proposal Review Committee,

The Upper Colorado River Commission (UCRC) supports the Utah Geological Survey (UGS) 2021 WaterSMART Applied Science grant application. If funded, deliverables produced by the UGS study would benefit the UCRC by improving our understanding of consumptive use in the Upper Basin of the Colorado River. Consistent, transparent and verifiable data promote our mission of interstate comity.

The UCRC has been studying and working to develop consumptive water use information for over ten years. We have published two reports on the subject. Our Phase 2 report, *Assessing Agricultural Consumptive Use Including Remote Sensing of Actual Evapotranspiration in the Upper Colorado River Basin,* highlighted the need for ground-truthing data to verify remote sensing estimates of evapotranspiration. We believe the work proposed by UGS, if funded, will help to fill an important data gap in the Upper Colorado River Basin.

Sincerely,

Amy I. Haas

Amy I. Haas
Executive Director

United States Department of the Interior

OFFICE OF THE SECRETARY
Washington, DC 20240

State and Local Governments
Indirect Cost Negotiation Agreement

EIN: 87-6000545

Date: 01/27/2021

Organization:

Utah Department of Natural Resources
Utah Geological Survey
1594 West North Temple, Suite 3110
Salt Lake City, UT 84116

Report Number: 2021-0065

Filing Ref.:
Last Negotiation Agreement
dated: 03/31/2020

The indirect cost rate contained herein is for use on grants, contracts, and other agreements with the Federal Government to which 2 CFR Part 200 applies subject to the limitations in Section II.A. of this agreement. The rate was negotiated by the U.S. Department of the Interior, Interior Business Center, and the subject organization in accordance with the authority contained in applicable regulations.

Section I: Rate

Start Date	End Date	Rate Type				
07/01/2021	06/30/2022	Fixed Carryforward	Indirect	37.70 %	(A) All	All Programs

(A) Base: Total direct costs, less capital expenditures and passthrough funds. Passthrough funds are normally defined as payments to participants, stipends to eligible recipients, or subawards, all of which normally require minimal administrative effort.

Treatment of fringe benefits: Fringe benefits applicable to direct salaries and wages are treated as direct costs; fringe benefits applicable to indirect salaries and wages are treated as indirect costs.

Section II: General

A. **Limitations:** Use of the rate(s) contained in this agreement is subject to any applicable statutory limitations. Acceptance of the rate(s) agreed to herein is predicated upon these conditions: (1) no costs other than those incurred by the subject organization were included in its indirect cost rate proposal, (2) all such costs are the legal obligations of the grantee/contractor, (3) similar types of costs have been accorded consistent treatment, and (4) the same costs that have been treated as indirect costs have not been claimed as direct costs (for example, supplies can be charged directly to a program or activity as long as these costs are not part of the supply costs included in the indirect cost pool for central administration).

B. **Audit:** All costs (direct and indirect, federal and non-federal) are subject to audit. Adjustments to amounts resulting from audit of the cost allocation plan or indirect cost rate proposal upon which the negotiation of this agreement was based will be compensated for in a subsequent negotiation.

C. **Changes:** The rate(s) contained in this agreement are based on the accounting system in effect at the time the proposal was submitted. Changes in the method of accounting for costs which affect the amount of reimbursement resulting from use of the rate(s) in this agreement may require the prior approval of the cognizant agency. Failure to obtain such approval may result in subsequent audit disallowance.

D. **Rate Type:**

1. Fixed Carryforward Rate: The fixed carryforward rate is based on an estimate of the costs that will be incurred during the period for which the rate applies. When the actual costs for such period have been determined, an adjustment will be made to the rate for a future period, if necessary, to compensate for the difference between the costs used to establish the fixed rate and the actual costs.

2. Provisional/Final Rate: Within six (6) months after year end, a final indirect cost rate proposal must be submitted based on actual costs. Billings and charges to contracts and grants must be adjusted if the final rate varies from the provisional rate. If the final rate is greater than the provisional rate and there are no funds available to cover the additional indirect costs, the organization may not recover all indirect costs. Conversely, if the final rate is less than the provisional rate, the organization will be required to pay back the difference to the funding agency.

3. Predetermined Rate: A predetermined rate is an indirect cost rate applicable to a specified current or future period, usually the organization's fiscal year. The rate is based on an estimate of the costs to be incurred during the period. A predetermined rate is not subject to adjustment.

E. **Rate Extension:** Only final and predetermined rates may be eligible for consideration of rate extensions. Requests for rate extensions of a current rate will be reviewed on a case-by-case basis. If an extension is granted, the non-Federal entity may not request a rate review until the extension period ends. In the last year of a rate extension period, the non-Federal entity must submit a new rate proposal for the next fiscal period.

F. **Agency Notification:** Copies of this document may be provided to other federal offices as a means of notifying them of the agreement contained herein.

G. **Record Keeping:** Organizations must maintain accounting records that demonstrate that each type of cost has been treated consistently either as a direct cost or an indirect cost. Records pertaining to the costs of program administration, such as salaries, travel, and related costs, should be kept on an annual basis.

H. **Reimbursement Ceilings:** Grantee/contractor program agreements providing for ceilings on indirect cost rates or reimbursement amounts are subject to the ceilings stipulated in the contract or grant agreements. If the ceiling rate is higher than the negotiated rate in Section I of this agreement, the negotiated rate will be used to determine the maximum allowable indirect cost.

I. **Use of Other Rates:** If any federal programs are reimbursing indirect costs to this grantee/contractor by a measure other than the approved rate(s) in this agreement, the grantee/contractor should credit such costs to the

affected programs, and the approved rate(s) should be used to identify the maximum amount of indirect cost allocable to these programs.

J. **Central Service Costs:** If the proposed central service cost allocation plan for the same period has not been approved by that time, the indirect cost proposal may be prepared including an amount for central services that is based on the latest federally-approved central service cost allocation plan. The difference between these central service amounts and the amounts ultimately approved will be compensated for by an adjustment in a subsequent period.

K. **Other:**

1. The purpose of an indirect cost rate is to facilitate the allocation and billing of indirect costs. Approval of the indirect cost rate does not mean that an organization can recover more than the actual costs of a particular program or activity.

2. Programs received or initiated by the organization subsequent to the negotiation of this agreement are subject to the approved indirect cost rate(s) if the programs receive administrative support from the indirect cost pool. It should be noted that this could result in an adjustment to a future rate.

3. Indirect cost proposals must be developed (and, when required, submitted) within six (6) months after the close of the governmental unit's fiscal year, unless an exception is approved by the cognizant agency for indirect costs

Section III: Acceptance

Listed below are the signatures of acceptance for this agreement:

By the State and Local Governments	By the Cognizant Federal Government Agency
Utah Department of Natural Resources - Utah Geological Survey	US Department of the Interior - USGS
DocuSigned by: Jodi T. Patterson 37D31811A5CD461...	DocuSigned by: Craig Wills B47DB1F4A5DB4BF...
Signature	Signature
Jodi T. Patterson Name:	Craig Wills Name:
Financial Manager II Title:	Division Chief Indirect Cost Services Division Interior Business Center Title:
2/1/2021 Date	2/1/2021 Date

Negotiated by: Omar Sheyyab
Telephone: (916) 930-3806

Next Proposal Due Date: 12/31/2021