Quantifying Sedimentation in Starvation Reservoir following the Dollar Ridge Wildfire Using Sonar and Drone Technologies

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Executive Summary

Quantifying Sedimentation in Starvation Reservoir following the Dollar Ridge Wildfire Using Sonar and Drone Technologies

Eligible Project Type

Using improved water and sediment measurement tools

Applicant Information

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Summary

Following the Dollar Ridge Fire in July 2018, operators of Starvation Dam witnessed large amounts of sediment flowing into the reservoir. More sediment and debris are anticipated to continue entering the reservoir over the next several years. To quantify the amount of deposition in the reservoir, Brigham Young University (BYU) proposed to study the sedimentation impacts of the fire using a combination of sonar and drone technologies. Sonar will be used to capture the underwater reservoir topography and drones to capture the topography above the water surface.

Project participants include BYU, Central Utah Water Conservancy District (CUWCD), the United States Geological Survey (USGS), Utah Division of Water Resources (DWRe), and United States Bureau of Reclamation (Reclamation). By surveying the reservoir, and using information obtained from previous surveys to develop an annual sedimentation rate, the sedimentation effects of the fire can be quantified and water storage accounted for. Efforts have been underway for approximately 11 months, with project completion date tentatively set for December 31, 2020.

Geographic Project Area Description

Starvation Dam is located on the Strawberry River approximately three miles northwest of Duchesne, Utah. Starvation Reservoir is filled directly by the Strawberry River and by diversion from the Duchesne River via the Knight Diversion Dam and Starvation Feeder Conduit. The reservoir originally provided 164,118 acre-feet of storage between the streambed and top of active conservation pool at water-surface elevation 5,712.0 feet and has a surface area of 2,989 acres at elevation 5712.0 feet. Starvation Reservoir lies in a semiarid region, receiving approximately 10 inches of precipitation at the reservoir, and 35 inches in the adjacent Uinta Mountains, annually.

Supervisor Approval

Written approval from the project manager's supervisor for the submittal of this proposal, and for the team to conduct the project if selected for funding was obtained and is attached as an appendix.

Statement of Work and Milestones

Statement of Work

Reclamation purchased a DT 101xi multi-beam sonar, DT 100 SIR box, Hemisphere V103 Smart Antenna, ruggedized laptop, and HYPACK software license. Reclamation will process the sonar data and, with BYU, merge the sonar and drone data in three different softwares to determine which platform provides the most efficient and accurate dataset. Reclamation will use HYPACK and ArcMap and BYU will use Metashape. The USGS provided 104-B grant funding of $25,000, on conditions of a minimal 2:1 match from BYU, CUWCD, and DWRe. BYU supplied a pontoon boat and sonar mount to conduct the survey, secured 104-B grants through the USGS, contributed $18,750 towards the grant, and are in the process of collecting and processing the topographic drone data. CUWCD provided access to reservoir and docking stations, $15,000 to BYU as a portion of matching funding towards the 104-B grant, provided boat operators and lookouts during the sonar survey, and collected daily reservoir water surface elevation readings. DWRe provided a combination of in-kind services and funding of $20,000, sending multiple people to help conduct the sonar survey and attend the HYPACK training workshop in December 2019.

After data has been processed, Reclamation and BYU will create contour maps and a report summarizing procedures and methodologies used, significant lessons learned, and improvements to implement in future surveys.

Project Location

Starvation Dam is located on the Strawberry River approximately three miles northwest of Duchesne, Utah. The reservoir originally provided 164,118 acre-feet of storage between the streambed and top of active conservation pool at water-surface elevation 5,712.0 feet and has a surface area of 2,989 acres. Starvation Reservoir lies in a semiarid region, receiving approximately 10 inches of precipitation at the reservoir, and 35 inches in the adjacent Uinta Mountains, annually. The Dollar Ridge Fire burned nearly 70,000 acres just upstream of Starvation, destroying or damaging approximately 80 homes and 400 trailers, sheds, and vehicles. Figure 1 shows the wildfire extents, its location along the Strawberry River and proximity to two major reservoirs, and relative vicinity in the state of Utah. The fire extents were provided by Robin Dunn from the Idaho Department of Lands.

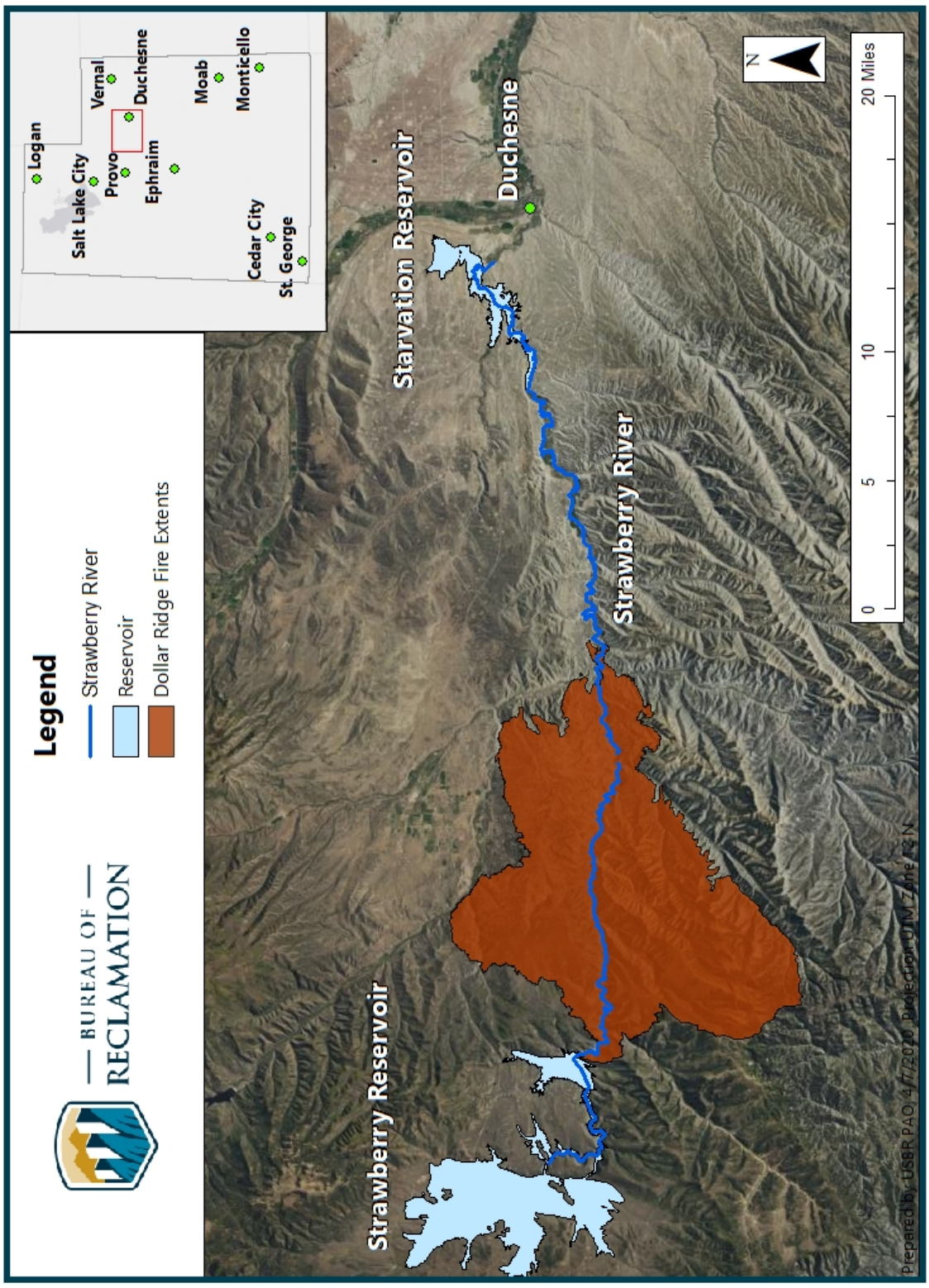

Figure 1: Starvation Reservoir Location Map

Data Management Practices

For conducting multi-beam surveys, a 50-percent overlap of the survey swaths should be maintained for quality control. This ensures sufficient coverage and capture of the reservoir bed. This also helps eliminate or confirm data outliers or artifacts by capturing each end of a swath (where the data is most subject to error) with the center of another pass (typically the most accurate data). The precise location of the sonar and GPS units relative to the boat's center of mass should be recorded, and patch tests should be conducted to account for pitch, roll, yaw, and latency offsets.

Sound velocity in the water column will also be recorded multiple times per survey. The number of sound velocity profiles (SVP) to be collected during each survey day is subject to a number of factors, including, but not limited to, temperature, wind, and precipitation changes throughout the day; proximity to tributaries, headwaters, and geographic surroundings (e.g., canyon walls, trees, flat land, etc.); and depth of water. It is good practice to record a new SVP every 1- to 2-hours. The CastAway CTD we use stores its GPS location and records temperature, salinity, and conductivity data to create an SVP for each 'cast'. Sound velocities will be interpolated each day using a combined effect of positioning and time collected, with more weight given to position than time. This data will be used to correct the sonar's readings.

Additional information for base station and rover setup will be logged as outlined in Reclamation's *Best Practices in Hydrographic Surveying (Version 1.0).*

Upon completion, hard and digital copies of reports, contour maps, and sonar and drone data will be distributed to project partners.

Project Team

The project team consists of multiple people from each project partner, including many students from BYU. David Tarboton, Director of the Utah Center for Water Resources Research, recommended Rollin Hotchkiss from BYU represent USGS.

Reclamation

Troy Ethington, tethington@usbr.gov, Upper Colorado Basin Regional Office, Resource Management Division. GIS Coordinator for the Upper Colorado Basin Region. Survey lead on past Bathymetric Studies for the Provo Area Office, including Starvation Reservoir. GIS consultant during research project.

Scott Elliott, selliott@usbr.gov, Provo Area Office, Chief of the Operations and Emergency Management Group. Manage all Operations and Emergency Management in the Provo Area Office. BS degree in Geological Engineering

Chris Garcia, cjgarcia@usbr.gov, Provo Area Office, Operations and Emergency Management. Principal project surveyor. Conducted surveys at Starvation Reservoir, Gunlock Reservoir, and Newcastle Reservoir in 2019. M.S. in Civil and Environmental Engineering with emphasis in reservoir sedimentation and GIS-based modeling. Worked with Kayla Ashworth, Josh Kresge, and Gary Henrie extensively on Starvation, Gunlock, and Newcastle.

BYU

Rollin Hotchkiss, rhh@byu.edu, Civil and Environmental Engineering Department, Brigham Young University. Directed research teams composed of Bureau of Reclamation, Utah Division of Water Resources, and Central Utah Water Conservancy District employees and BYU students performing drone and bathymetric surveys of Utah reservoirs. Extensive research experience dealing with reservoir sedimentation. Works with Gus Williams and several college students to help gather drone data.

DWRe

Carl Ege, carlege@utah.gov, Division of Water Resources, DWRe Sedimentation Group Lead. Participated in a sedimentation survey at Starvation Reservoir in 2019. B.S. in Geology and B.S. in Environmental Earth Science. Worked with fellow DWRe employees Leila Ahmadi, Ben Marett, Carmen McDonald, and Jacqueline Pacheco on Starvation.

CUWCD

Linda Ivie, lindai@cuwcd.com, Central Utah Water Conservancy District—Operations and Maintenance, Area Manager for the Duchesne Area. Responsibilities include Operating and Maintaining (O&M) Starvation, Currant Creek, and Strawberry Reservoirs along with all associate facilities, including large diameter pipelines, tunnels, and diversions. In her responsibilities in operating these reservoirs, she understands the impacts of wildfire on watershed areas and of increased sediment loads into reservoirs. She has been involved in both of the recent sediment surveys completed for Starvation Reservoir (2009 and 2019).

David (Dave) Lupold, davidl@cuwcd.com, Central Utah Water Conservancy District—Operations and Maintenance. Dave is an O&M Operator for the Duchesne Area, which includes the responsibility of Operating and Maintaining Starvation, Currant Creek, and Strawberry Reservoirs along with all associated facilities including large diameter pipelines, tunnels, and diversions. Dave has a lot of knowledge of Starvation Reservoir, having boated on it for several years. His involvement with the recent survey was as driver of the pontoon boat and assisting in setting up and storing the equipment daily.

Evaluation Criterion A—Project Benefits

What *types* of benefits will your project result in?

Reservoir operations. Accurate reservoir operations require accurate data—dam releases, reservoir elevations, reservoir storage, reservoir inflow, etc. Accurate reservoir operations modeling requires accurate historic reservoir operations data. Reservoir elevation-storage relationships are key to both reservoir operations and modeling. This study will result in the development of new reservoir capacity tables. Throughout the study, knowledge will be gained that may inform future Starvation Reservoir operations. It will likely provide insights on impacts of watershed wildfires on reservoir storage and sedimentation rates that can be applied to other Reclamation reservoirs throughout Utah and the western United States.

It is also important to note that Reclamation is moving towards requiring that reservoir allocations would have to be based on a reservoir survey not more than 20 years old. Throughout this study, Reclamation Provo Area Office personnel will gain familiarity and experience with the equipment

needed to meet this requirement at Starvation—and all 28 storage reservoirs within the Provo Area Office's inventory—with inhouse expertise.

Water deliveries. Following the fire, sediment has been observed entering Starvation Reservoir and exiting downstream through the outlet works. Sediment has deposited throughout the reservoir, including near the outlet works intake. This study aims to quantify and monitor sediment deposition for the entire reservoir, including areas near the outlet works intake. Sediment deposited near or covering the intake can impact release capacity and the ability to make water deliveries.

Hydropower production. While hydroelectricity is not produced at Starvation Reservoir, the hydrographic surveying methodology developed during this study will be implemented at hydropower producing reservoirs, including, but not limited to, Deer Creek, Jordanelle, Strawberry, Pineview, Causey, Echo, and Rockport Reservoirs. The study will also provide insights into the extents of sedimentation in Starvation that may provide insights into the possible extents that sedimentation after wildfires could occur at power-producing reservoirs.

Loss of reservoir capacity due to sedimentation can adversely impact hydropower production. De Miranda and Mauad (2014) modeled hydropower production in lieu of reservoir sedimentation in Três Irmãos Reservoir, Brazil. Data was obtained through a bathymetric study collected in 2008. It was observed that preserving storage capacity maintained higher levels of hydropower production against taking no action to mitigate the reservoir's depleting storage capacity. Schellenberg et al. (2017) noted that Inga I and II powerhouses in Congo had approximately 30% less power production due to sedimentation, and hydroelectric machinery, such as turbines and other mechanical equipment, were more likely to be damaged, resulting in decreased efficiency and a risk increase of mechanical breakdown and/or failure.

Recreation uses at Reclamation facilities. While recreation benefits are not the motivation for this study, the Starvation reservoir survey may serve to locate currently unidentified underwater hazards that should be marked to ensure safe recreation in the reservoir.

Management of fish and wildlife habitat. Management of fish and wildlife habitat is not the motivation for this study, however, the maps of the reservoir bathymetry that are produced by the study may show areas for focus or improvement of fish habitat.

Flood control management. The hydrology of the Uintah Basin is dominated by spring snowmelt runoff. Starvation Reservoir is subject to provisions of Section 7 of the 22 December 1944 Flood Control Act (58 Stat 890) and to special regulations for flood control—the Starvation Dam and Reservoir Water Control Manual—developed by the Sacramento District, U.S. Army Corps of Engineers. Based on runoff forecasts and time of year, a certain volume of the reservoir volume must be vacant for flood risk mitigation. Significant sediment deposition in the reservoir could impact safe flood risk management. Reservoir operators, using storage tables that are inaccurate due to sedimentation, may not keeping adequate vacant space in the reservoir to safely mitigate flood risks from snowmelt runoff. With the wildfire destroying vegetation in the Strawberry River basin, Starvation will see increases in runoff volumes and flow rates. This is confirmed by observing flow rates from a USGS stream gauge located along the Strawberry River 2-miles upstream from Starvation Reservoir (see Figure 2). The stream flowrate in August 2018 was 1,950 cfs. Now is an important time to ensure that the data being used for flood control (including storage tables) are accurate.

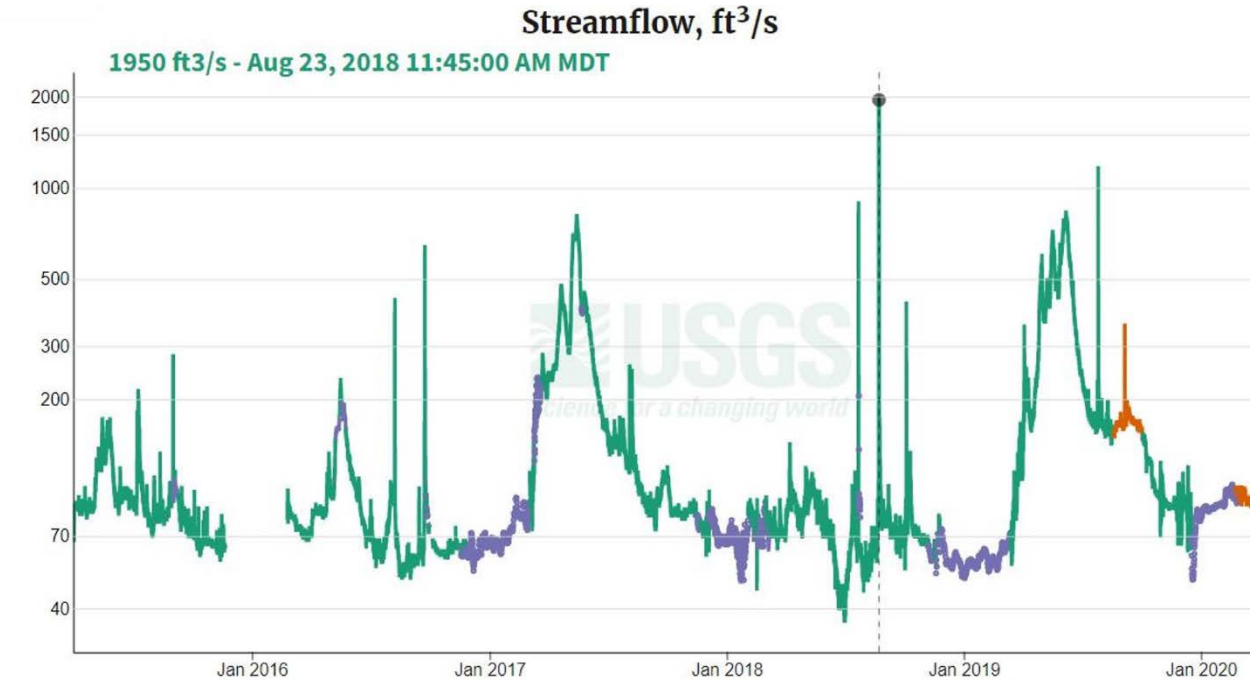

Figure 2: USGS Stream Gauge Data from Site ID No. 09288180

Reclamation-wide data management and use of GIS. Reservoir area and capacity data developed as part of this study will be incorporated into the Reclamation database of record (HDB in the Upper Colorado Basin Region) and from there to Reclamation publicly accessible data-sharing platforms (RISE, RWIS, etc.), ensuring that accurate reservoir operations (especially area, storage, and computed inflow) data are stored for future use and made available to the public.

To perform this and future reservoir surveys, a combination of software programs have been and will be used. GIS maps will be developed and used internally in the Provo Area Office.

Explain *how* your project will improve water management or other mission-based objectives.

This study will improve water management and mission-based objectives as described below. It will also improve the Provo Area Office's technical expertise and ability to collect survey-grade data and, if needed, quickly (in case of landslide, earthquake, or other emergency response).

Reservoir operations. Operators and decision-makers will have access to current and accurate reservoir area and capacity tables and database data to help inform safe operations. Reservoir bathymetry maps will provide operators and decision-makers information on sedimentation locations and rates and may help address sedimentation mitigation measures.

Water deliveries. Reservoir bathymetry maps will show sedimentation locations and rates and may provide insights into the sedimentation impacts on water deliveries.

Hydropower production. In the event of wildfire events near hydropower-producing facilities, the Provo Area Office could provide sedimentation information from this Starvation study to offer insights into potential sedimentation extents and hydropower impacts in other reservoirs.

Recreation uses at Reclamation facilities. Reservoir bathymetry maps generated in this study may indicate to recreation managers potential underwater hazards.

Management of fish and wildlife habitat. Reservoir bathymetry maps generated from the study may guide fish habitat improvements.

Flood control management. Accurate data is critical to accurate reservoir operations. Updated reservoir storage tables and data will provide decision makers accurate data to ensure adequate vacant capacity is available to mitigate flood risks.

Reclamation-wide data management and use of GIS. Incorporating reservoir area and capacity information into the reservoir operations database of record will provide decision-makers the most accurate reservoir operations data available. GIS bathymetry maps will provide quick visual reference to reservoir features and sedimentation locations and other areas of interest.

To *what extent* will your project result in a demonstrated benefit to improve water management or other mission-based objectives?

This project will help account for total and changing reservoir water storage capacity and reservoir sedimentation, assess mitigation efforts (if needed), determine areas prone to higher deposition rates, extend the useful lives of our reservoirs, and perpetuate benefits we enjoy today to future generations. The latter epitomizes intergenerational equity, the concept of meeting today's needs without compromising the ability of future generations to do so, too (Summers and Smith 2014; Annandale 2013).

Evaluation Criterion B—Project Relevancy: Need for Project and Project Fit with Program Priorities

Need and applicability of the project to address a specific management issue.

Project interest began when dam operators noticed large amounts of sediment entering into the reservoir. Jared Hansen, project manager at CUWCD, stated, "What really caused our interest in the survey at Starvation was the amount of sediment that we are getting in the runoff from the burn scar from the Dollar Ridge fire. We felt like there was new technology that would give us a better baseline so that we could go back down the road and see how much the fire had affected our storage" (personal correspondence, 26 March 2020). Carl Ege, DWRe sedimentation group lead, stated, "Prior to this project, the Division of Water Resources (DWRe) conducted an informal survey (via email/mail) reaching out to many reservoir owners and operators in the state of Utah. We learned that many of these folks are very interested in sedimentation and lost storage. Therefore, DWRe wanted a better understanding of defining the total amount of sediment deposition and total storage lost in a reservoir system through a sedimentation survey using UAVs and Sonar. Once this information is defined, we might be able to assist and provide guidance for reservoir owners/operators" (personal correspondence, 31 March 2020).

Regarding the project's urgency, each year between April and July the main runoff occurs. Being able to measure sediment pre- and post-runoff gives us the best indication of how much sediment is coming into the reservoir as a result of the Dollar Ridge Fire.

Will the results of your project be applicable elsewhere in Reclamation?

Yes, see below.

Describe how the results of the project could benefit other Reclamation offices and water managers within Reclamation's service area.

Denver's TSC has some experience in the field of performing bathymetric surveys to develop new area-capacity charts. Survey report and storage-capacity templates have already been completed by the TSC, and surveying guidelines and best practices are in the works. The methodology used on Starvation will be used on numerous Reclamation reservoir surveys for the Provo Area Office in the near future. Additionally, Tim Randle is considering putting together a Reclamation bathymetric team to meet annually and discuss successes, failures, lessons learned, and so on. Our work will contribute to the success of others, just as others' successes and failures will contribute to ours.

Will the project build on a completed Research and Development Office (R&D) project by applying or demonstrating the results of an R&D project in a new location or otherwise supporting the application of the project results?

Not that we're aware of.

Will the project increase technical capacity? Will your project apply a newer (i.e., new to your office or area) or improved tool, technology, or approach?

Years ago, our office used to perform single-beam hydrographic surveys. This practice stopped when the individuals who performed these surveys moved on. However, even single-beam surveys provide vague details and require immense interpretation. Depending on the reservoir surface area, grid size, and water depth, spacing between points can vary from 10-m to 100-m, with some closer and others further apart. The 2009 Starvation survey used 10-m spacing along grid lines, and linearly interpolated data in-between grid lines and data points (see Figure 3). This practice is not a reliable source of information for determining accurately reservoir changes over time but is better than no data. This project will apply a new technology and approach to our office, with the inclusion of a multi-beam sonar, sound velocity profiler, GPS antenna, and more.

The idea of combining sonar and drone technologies for complete reservoir bathymetry capture is also novel. Though the two sources are, of themselves, well established and prestigious, little work has yet to be done to combine their efforts. "The combination of dissimilar data types to develop a more complete bathymetric map … means that sonar surveys do not have to be completed during high-pool conditions, though performing sonar surveys at high-pool and drone surveys at lower pool is preferable. Even at high-pool, maps are not complete as reservoirs are rarely at spill condition" (BYU 2019).

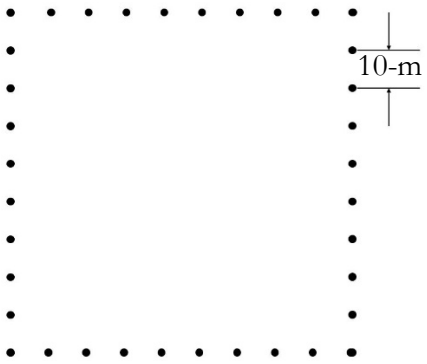

Figure 3: Survey grid spacing with single-beam

Will your project contribute to modernization or increased consistency across Reclamation's service area?

As stated previously, Reclamation will soon require reservoir storage-capacity charts be based on surveys no more than 20-years old. This project will propel our office forward towards meeting this guideline.

Will your project also increase the technical capacity of operating partners and stakeholders?

Many individuals from DWRe, CUWCD, and BYU have assisted in completing the survey. BYU has employed several students and two professors to assist with this project, CUWCD operates the dam and

reservoir, and DWRe was interested in learning sonar technology with the possibility of one day owning their own system. Carl Ege commented that DWRe will be able to educate some of their staff "in the process of conducting a survey through data collection and becoming familiar with data processing and interpretation techniques" (Carl Ege, personal communication, 31 March 2020).

Will your project complement other, similar efforts, rather than duplicate or complicate those efforts?

Multi-beam bathymetry work is already being performed by Kent Collins from TSC and Allen Giger from Grand Junction. Our efforts will bring greater competency and increased technical capacity to our office, enabling us to meet goals for developing sediment monitoring plans, and help us account for water storage capacity and sedimentation. Currently, we have a multi-beam sonar that performs below desirable standards. Specifications about the sonar might be true in 'ideal' conditions but have not proved themselves in field performances. In the 2019 Starvation survey, data point differences were observed as much as (+/-)1m from the median value. Across Starvation's 2,989-acre surface, that amounts to 9,800 acre-ft of storage and sedimentation either over or under accounted for, roughly 6- to 10% of the total storage capacity of the reservoir. The error worsens and propagates as beam-points get further away from nadir. Using nadir-only beams would reduce the error from 1m to less than 0.4m.

Are there other ways that your project will increase technical capacity within Reclamation and/or among our operating partners and stakeholders?

The practice of using sonar and drone technologies to measure storage capacity is a novel step for our office and for the world of data collection, in general. The unique combination of technologies will provide us with high-accuracy data that can be collected regardless of current reservoir water levels and brings together otherwise separate bodies. Drones, in our office, our flown by our survey team, while bathymetry data is collected through our dam safety team. After this project is completed, the two teams will likely be joined in efforts to establish base stations and perform bathymetric surveys to transform sonar depths to elevation readings.

Will the project result in the *application* of a tool, method, or information to a specific management issue?

This project began to address observed sediments entering Starvation following the Dollar Ridge Fire. There are guidelines for conducting surveys and updating storage-capacity tables, but the information is general and not always site specific. Finding out how to best use the tools and equipment our office has is a learning process. We anticipated developing our surveying

methodology throughout the course of this project and beyond; however, wherever possible, we implement standardized practices in our survey to shorten the learning curve.

When will the tool, method, or information be applied?

We anticipate to have this project completed by December 31, 2020. The sonar data has been collected and processed, about 90% of the reservoir perimeter has been flown with drones and most of that data has been processed. The remaining area will be flown Summer 2020, and the reservoir will be resurveyed Summer 2020. The next steps include combining the drone data with the sonar data.

Evaluation Criterion C—Project Implementation Plan and Likelihood of Success

Describe the objectives of the project and methodology and approach that will be undertaken.

The project's objectives are to quantify water storage capacity and the amount of sediment that entered into Starvation Reservoir following the Dollar Ridge Fire and develop a consistent, efficient surveying methodology to employ in future studies.

With the understanding that our methodology would likely change and improve over the course of this and future surveys, this is the methodology we began with, what we changed and incorporated, and where we believe we'll move to in the future:

Beginning

- Survey the reservoir bed using DT 101 multi-beam sonar, GPS data from Hemisphere V103 Smart Antenna, and water elevations gathered from the dam water elevation gauge. Sound velocity profiles (SVP) from Deer Creek were used to account for sound velocity changes over depth. Temperature and sound velocity data from the sonar's interface were used to select an approximate SVP from Deer Creek.
- Reservoir maps obtained from and georeferenced in ArcMap, then input into HYPACK software to guide boat paths during the survey.
- Use drones to fly Starvation Reservoir perimeter. Use photogrammetry and MetaShape to digitize the perimeter to account for above-water surface storage capacity+.
    - Lay ground truths every ¼-, ½-, and 1-mile to determine required distances between ground truth locations. This will help determine how far apart is 'far enough' without compromising data quality.
- Combine the two datasets to provide a complete picture of the reservoir bed and sides.
- Produce and provide reservoir contour maps, update storage-capacity tables, and repeat the survey until sedimentation rates return to normal to appropriately assess the wildfire sedimentation effects.

Changes Made

- Start and stop tracks at the ends and beginnings of tracklines.

    - Each trackline is assigned a color. The color repeats itself if there are enough tracklines, but typically side-by-side tracks are guaranteed to be different colors. This helps during the data processing to confirm the presence or absence of data artifacts.
- Use CastAway CTD to record sound velocity profile throughout the water column.
    - The DT 101 multi-beam sonar we have records sound velocity and temperature at its interface. However, as velocity changes with depth, the sonar imaging process does not know how to account for these changes without providing this information and assumes a constant profile for the entire water column. We've since acquired a CastAway CTD that records GPS location, temperature, salinity, and conductivity to produce sound velocity for the column. We record SVPs in the deepest parts of the reservoir, one in the morning and one in the afternoon, then apply these to the data. Based on when and where the data was recorded, HYPACK can interpolate using these two variables to adjust SVPs over the course and location of the day.

Future Changes

- Use the CastAway more frequently and record in various locations. We found that recording two profiles a day to be insufficient. There are a number of factors that influence temperature and sound velocity, such as proximity to tributaries, surrounding elevated or depressed terrain, stagnant or moving water, and water depth, to name a few. A survey we did at Newcastle Reservoir near Cedar City, UT illustrates this point. We took two profiles in approximate locations: one at 10:45 AM and another at 2:30 PM. During data processing, it was observed that warmer profiles were needed for the upstream, shallower waters, and the data had to be manipulated to account for these changes. Manipulating sound velocity profiles is common and the tool to do this is built into the HYPACK software. However, using actual rather than forged data will likely produce better and more consistent results, so we will record profiles more frequently and in various locations in the next survey.
- Electric downrigger: A downrigger is typically a fishing tool used to lower and raise a steel cable into the water to a desired depth. In our setup, we will use a downrigger to control the speed at which we lower the CastAway (desired to be around 1-m/sec). Using the sonar to get depth estimates, we will know when to expect the downrigger to hit the bottom. Leaving the CastAway on the reservoir bed for too long introduces errors into the sound velocity profiling, so it is best to reel in the device once it hits the reservoir bed.
- Talking with surveying experts, we've discovered that our sonar and GPS system are sub-par. It was a sad realization but a fact, nonetheless. We hope to purchase a new sonar and GPS system in the coming years. After speaking with Kent Collins and Tim Randle at TSC, and other surveyors from HYPACK and the U.S. Army Corps of Engineers (Corps), we were provided with four options to consider. Of course, there are more than four options available, but the Corps' surveying manual suggests to speak with local offices that are conducting similar work to best appraise systems and setups we might adopt. Additionally, we acquired an Applanix POS MV Wavemaster from the Corps, the industry standard when it comes to Inertial Navigation Systems (INS). We'll need to add to it some Trimble GPS units to obtain

Real-Time Kinematic (RTK) tide corrections during the surveying process. RTK uses a base station with known elevation, latitude, and longitude to communicate live details to the sonar to correct elevation changes induced by water fluctuations (tides), reservoir inflows and outflows, and slopes across the reservoir.

- We will build and install a new sonar mount with a tilt bracket. This tilt option allows the sonar to rotate about 15- to 25° toward inclined surfaces, reducing the amount of time spent traversing shallow waters by capturing multiple passes in one swoop. The new mount will also include a secure holding facility for the mount to rotate into, a shear pin to act as the breaking point in the event of hitting an obstruction, a protective case to hold the sonar, and 'bumpers' on the front and ends of the case to further reduce shock impacts from hitting obstructions.
- Upon acquiring RTK GPS capabilities, a $5,000 purchase for a small LiDAR system to be installed on the boat can be used to capture above-water reservoir storage. This will shorten the process of flying drones, processing data, and merging the two datasets, as well as cut back on costs of employing people to fly the drones and process their data. We anticipate, however, instances where the LiDAR will be unable to completely capture shorelines or other topography, such as elongated, shallow water shorelines (this LiDAR has a limited ranged) or in areas heavily infested with aquatic vegetation. However, in these instances, a remotely operated survey boat may be able to obtain data where a normal boat could not. These boats are significantly smaller and have a shallow draft, usually a few inches. Although they are small, these boats are still capable of holding and employing the sonar and possibly the LiDAR.

Project Work Plan, Schedule, and Budget

Work Plan

We (Reclamation and the project stakeholders) established a memorandum of understanding (MOU) near the onset of the project. However, some things changed overtime due to delays in equipment arrival and the start of school (for BYU). The former delayed the project start until almost the beginning of Fall semester for BYU, placing its students in a predicament to perform the work we agreed on. Thus, the following work plan will include both the original agreement and the amendments we made along the way. The main deviation in original to amended work plans involves Reclamation bearing a larger portion of the workload with responsibilities shifting from BYU to Reclamation.

Original work plan

- Reclamation will:
  - Purchase and provide equipment for the sonar including a multi-path sonar array, ruggedized laptop, and software to receive the sonar output.
  - Provide employees to manage and secure equipment.
  - Obtain USBR approvals for UAV flights.
- BYU will:
  - Provide participants with project results in the form of a report and data.
  - Ensure data security.
  - Complete surveys on Starvation Reservoir and other sites as approved by project participants.

    - Supply unmanned aerial vehicle (UAV) and photogrammetric equipment.
    - Apply for and secure 104-B grant through the USGS.
    - Provide UAV pilots with current Federal Aviation Administration (FAA) licenses.
    - Obtain FAA clearances for UAV flights.
- USGS will:
    - Provide 104-B grant funding of $25,000.
- CUWCD will:
    - Provide access to project locations.
    - Provide $15,000 to BYU as a portion of matching funding for the 104-B grant.
- DWR will:
    - Provide a combination of employee time and funding of $20,000.

Amendments to the original work plan

- Reclamation will provide surveying training with one of HYPACK's technical support representatives.
- Reclamation will complete surveys on Starvation Reservoir and other sites as approved by the project participants.
- Reclamation and BYU will ensure data security.
- Reclamation and BYU will provide project participants with project results in the form of reports and data.

Project Schedule

Table 1 indicates the project's completed and scheduled tasks. Shading in the table indicates approximate working months for each task. It is estimated to complete this project by December 31, 2020, fiscal year (FY) 2021.

Table 1: Task Timeline. Shading Indicates Work and Completion Dates.

Tasks	FY 2019			FY 2020												FY 2021		
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Multi-beam Sonar Surveys																		
Learn how to setup survey project																		
Test communication between devices																		
Test equipment on Utah Lake																		
Train others on boat safety rules and operation																		
Patch test and device offsets																		
Test equipment on Starvation																		
Survey Starvation																		

Tasks	FY 2019			FY 2020													FY 2021		
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Survey Gunlock Reservoir																		
Survey Newcastle Reservoir																		
Collect Shoreline Topography Using Drones																		
Purchase approved drones																		
Setup ground truths																		
Fly drones around Starvation																		
Fly drones around Gunlock																		
Fly drones around Newcastle																		
Data Processing																		
HYPACK software training																		
Starvation sonar data																		
Starvation drone data																		
Gunlock sonar data																		
Gunlock drone data																		
Newcastle sonar data																		
Newcastle drone data																		
Merge Datasets																		
Newcastle in Metashape																		
Newcastle in HYPACK																		
Newcastle in ArcMap																		
Compare merged data																		
*Starvation in _____																		
*Gunlock in _____																		
Final Products and Reports																		
Contour maps, survey reports, and storage-capacity tables																		
Recap, Review, Collaborate, Improve																		
BYU, CUWCD, DNR, and USGS receive hard and digital data copies																		
Establish next projects																		
Review methodology and improvements to be made																		

* TBD after analyzing processed data from Newcastle

Budget

Detailed project budget information is provided in the 'Budget' section below. Expenditures are appropriately distributed across the project duration and align with the project schedule.

Final Products and Peer Review Process

The TSC has survey templates for reporting on practices used during the survey and updating storage-capacity tables. Storage-capacity tables will be used to update reservoir capacity allocation (RCA) sheets. The sonar and drone datasets, and their respective metadata, will be included. Contour maps delineating the reservoir topography will be generated for Starvation at 10-ft intervals.

The reports and surveys will be sent to Kent Collins for peer review. After revisions are made, if necessary, the reports and data will be distributed to project partners.

Evaluation Criterion D—Project Partners and Dissemination of Results

Does this project include partner involvement? If so, please respond to the following sub-criteria. If not, please explain why there are no partners.

- Have the appropriate internal and external partners committed to participate in this project? Have they submitted letters of support?
    - Yes. As outlined in the 'Project Team' section above, Reclamation, Brigham Young University, the Utah Division of Water Resources, the Central Utah Water Conservancy District, and USGS are partnering on this project. The The USGS is represented by Rollin Hotchkiss per David Tarboton's recommendation.
- Are the partners contributing cost-share (cash or in-kind)? Are partners contributing other resources (e.g., expertise, or input and feedback to the project)?
    - Yes. Please refer to Table 2 and Table 3.
- Are there team members from these partners involved in the project?
    - Yes. Rollin Hotchkiss and Gus Williams work regularly with their students to perform the drone surveys and data processing. Carl Ege, Leila Ahmadi, and other DWRe employees have assisted in the sonar surveys by operating the boat and sonar equipment and serving as a lookout in shallow waters. CUWCD provided several employees to help with operating the boat and aiding as a lookout.
- How will the project results be made available and communicated to project partners, to Reclamation staff, and to interested stakeholders and water resources managers in the area, if appropriate?
    - Progress reports will be sent to project partners regarding the survey and drone work. Upon completion, digital and hard copies of the survey report will also be distributed. The information gathered from the sonar and drone surveys will help create new storage-capacity tables which has a direct influence on reservoir operations. This data will be reviewed and then passed on to our dam tenders.
- Explain why the chosen approach is the most effective way to disseminate the information to end users in a usable manner.
    - The TSC set forth the survey report as a standard for pertinent information to included in most bathymetric surveys. This is, however, a general report and individual cases may deviate from or include more than the standardized report. In our case, we are measuring reservoir sedimentation following the Dollar Ridge Fire, so we will include information containing pre- and post-survey capacities, how many acres were burned, how much of the fire rested in the watershed, and so on.

Evaluation Criterion E—Department of the Interior and Bureau of Reclamation Priorities

Department Priorities

1. **Creating a conservation stewardship legacy second only to Teddy Roosevelt**
    - Utilize science to identify best practices to manage land and water resources and adapt to changes in the environment;
        - Teddy Roosevelt said, "The nation behaves well if it treats the natural resources as assets which it must turn over to the next generation increased and not impaired in value" (speech by Theodore Roosevelt in Osawatomie, Kansa, August 31, 1910). Regarding the world's reservoirs, Annandale (2013) defined water as an exhaustible or renewable resource—exhaustible if storage capacity loss exceeds the rate of replenishment or the rate of added new storage; renewable if storage loss is less than the rate of replenishment or addition. If we are unaware of the sedimentation problem, we will not be able to properly address and resolve sedimentation concerns. Through the use of this sonar system and drone technology, we will have quantifiable data telling us how much sediment entered the reservoir following the fire and how much total capacity remains. We will be better equipped to address sedimentation concerns and perpetuate this renewable resource—unimpaired in value—for years and years to come.
2. **Utilizing our natural resources**
3. **Restoring trust with local communities**
    - Expand the lines of communication with Governors, state natural resource offices, Fish and Wildlife offices, water authorities, county commissioners, Tribes, and local communities.
        - Throughout the duration of this project, we've been privileged to work with state and federal offices, as well a BYU, a university with prestigious professors in sediment management and monitoring. We've also reached out to local tribal communities to ensure our work does not infringe on their territory or is acceptable in cases it does.
4. **Striking a regulatory balance**
5. **Modernizing our infrastructure**

Budget

The following sections describe the proposed budget and cost-share contributions from project partners.

Budget Proposal Table

Table 2 indicates expenses incurred in FY 1, 2, and 3 (refer to Table 1), with FY 2 and 3 included together. Costs are priced using a combination of market research, incurred expenses, and quotes from suppliers. Employee billable rates were priced at $100 per hour.

Equipment items include options to improve our surveying technology and create an easier and safer working environment. A second HYPACK license permits data processing within hours of

collecting it, allowing real-time corrections. The sonar mount and protective case are used in conjunction to provide rigidity and security to the device. The mount includes a safety pin to act as a break-away point in the event of a collision. The protective case includes front and rear 'bumpers' made of hard, marine-grade plastic to absorb shock from collision. The electric downrigger will be used to raise and lower the CastAway CTD at approximately 1m per second—the recommended speed for gathering accurate SVPs. The RTK GPS provides the sonar with real-time elevation, longitudinal, and latitudinal data. The high-nit monitor displays allow boat and equipment operators to view their screens unimpaired by daylight.

Table 2: Budget Proposal

Budget Item Description	Computation		Quantity Type	Fiscal Year 1	Fiscal Year 2-3	Total Cost
	$/Unit	Quantity				
Reclamation Labor Costs						
Planning and Preparing Survey Areas	$400	2-3/year	Map and survey prep.	$1,200	$1,200	$2,400
Collecting Data	$13,800	2-3/year	Sonar survey	$27,600	$41,400	$69,000
Processing Data	$8,000	2-3/year	Data processing	$16,000	$24,000	$40,000
Preparing Reports, Graphs, and Data	$12,000	2-3/year	Reports	--	$24,000	$24,000
Reclamation non-Labor						
Equipment						
DT 101xi	$41,200	1	Multi-beam sonar	$41,200	--	$41,200
DT 100 SIR Box	$2,620	1	Power supply / timing box	$2,620	--	$2,620
Spare: 15m Underwater Cable	$600	1	Cable	$600	--	$600
Hemisphere Smart Antennae	$3,600	1	GPS	$3,600		$3,600
Pelican Transport Case	$300	1	Case	$300	--	$300
Ruggedized Laptop	$2,000	1	Field laptop	$2,000	--	$2,000
CastAway CTD	$6,250.00	1	SVP sensor	$6,250.00	--	$6,250.00
HYPACK License	$17,725	1-2	License, USB	$17,725	$17,725	$35,450
Sonar Mount	$1,500	1	Aluminum side-mount	--	$1,500	$1,500

Sonar Underwater Protective Case	$800	1	Protective case	--	$800	$800
Electric Downrigger	$600	1	Downrigger	--	$600	$600
RTK GPS	$5,000	1	GPS	--	$5,000	$5,000
Portable Generator	$600	1	Generator	--	$600	$600
High-Nit Monitor (Daylight Viewable)	$700	1-2	Monitor	--	$700-1,400	$700-1,400
Mult-beam Sonar (Type TBD)	$60,000-$150,000	1	Multi-beam sonar	--	$60,000-$150,000	$60,000-$150,000
Transportation of things						
Truck fuel, maintenance, and repairs	$200	2-3/year	Vehicle	$600	$600	$1,200
Boat fuel, maintenance, and repairs	$2,350	2-3/year	Boat	$7,000	$7,000	$14,000
Printing and Reproduction						
Reports (hard copy)	$100/report	4/survey	Report	--	$400	$400
Reports (digital)	$5/copy	4/survey	CD	--	$20	$20
Reclamation Travel						
Per diem	$56/day	~1 week/ survey	Per diem rates	$2,000	$2,000	$4,000
Hotel	$100/night	~1 week/ survey	Hotel rates	$3,000	$3,000	$3,000
TOTAL RECLAMATION COSTS						$384,540
Contractors or Agreements (i.e., non-Reclamation costs)						
BYU						$110,000
DWRe						$20,000
CUWCD						$15,000
USGS						$25,000
TOTAL ESTIMATED PROJECT COSTS						$460,290

Cost Share Contributions

Table 3 indicates project partners, contacts for each, contributions made and type, and contribution amount.

Table 3: Cost-Share Contributions

Organization	BYU	DWRe	CUWCD	USGS
Organization Type	Non-federal	Non-federal	Non-federal	Federal

Contact	Gus Williams Rollin Hotchkiss	Craig Miller Carl Ege	Jared Hansen Linda Ivie	David Tarboton
E-mail	gus.p.williams@byu.edu rhh@byu.edu	craigmiller@utah.gov carlege@utah.gov lahmadi@utah.gov	jhansen@cuwcd.com lindai@cuwcd.com	david.tarboton@ usu.edu
Contributions	Drone surveys Consulting	Sonar survey assistance	Sonar survey assistance and reservoir access	Grant funding and research
Commitment Type	In-kind services	Cash and In-kind services	Cash	Cash
Contribution Amount	$110,000	$20,000	$15,000	$25,000

References

Annandale, G. (2013). Quenching the thirst: sustainable water supply and climate change. CreateSpace

Independent Publ. Platform.

BYU (2019, October 29). Ira A. Fulton College of Engineering, Civil and Environmental Engineering.

Modern Bathymetric Methods and Experiential Learning: https://ceen.byu.edu/modern-bathymetric-methods-and-experiential-learning

De Miranda, R. B., & Mauad, F. F. (2015). Influence of sedimentation on hydroelectric power generation: Case study of a Brazilian reservoir. *Journal of Energy Engineering*, *141*(3), 04014016.

Schellenberg, G., Donnelly, C. R., Holder, C., & Ahsan, R. (2017). Dealing with Sediment: Effects on Dams and Hydropower Generation. *Hydro Review Worldwide*.

Appendix A. Letter of Supervisor Approval

To Whom it May Concern;

I am Chris Garcia's immediate supervisor, and I manage the "Operations and Emergency Management" in the Provo Area Office for the United States Bureau of Reclamation (USBR). I approve of this proposal to obtain funds for accomplishing bathymetric surveys to our forty-nine high hazard dams that are within our jurisdictional area and to help support our memorandum of understanding (MOU) established with our partners (Brigham Young University, Central Utah Water Conservancy District, United States Geological Survey, and Utah Division of Water Resources) and others.

As clearly portrayed in this proposal, the funding from this grant will be put to good use. It will address sedimentation effects to reservoirs due to wildfires and normal reservoir operations. Furthermore, it will provide more accurate reservoir operations resulting in more accurate water and power deliveries, provide more accurate reservoir capacities, help management of fish and wildlife habitat, provide better flood control management, and improve overall reservoir safety issues related to reservoir boating and other recreations.

The studies that come out of these reservoir surveys may also help the scientific community to better understand reservoir sedimentation. A better understanding of these sedimentation concepts may lead to more improved tools, technologies, and methodologies of eliminating sediment deposition in reservoirs. Downstream users, operating partners and other stakeholders, decision makers throughout the Bureau of Reclamation and other entities will be greatly benefited from this work.

Thank you for this opportunity to compete, we do appreciate it.

Best Regards,

Scott Elliott PE Civil Engineer for Reclamation

Appendix B. Letters of Support

The following project partners provided support letters: BYU, DWRe, and CUWCD.

DEPARTMENT OF CIVIL AND
ENVIRONMENTAL ENGINEERING

April 16, 2020

WaterSMART Applied Science Grant Program
U.S. Bureau of Reclamation
Policy and Administration
Denver, CO 80225

Dear Grant Reviewers:

This letter certifies our support for the application "Quantifying Sedimentation in Starvation Reservoir following the Dollar Ridge Wildfire Using Sonar and Drone Technologies." We have already been collaborating with Mr. Chris Garcia and the Provo office on foundational data collection for this project, and we will continue to do so as explained below.

We have been working under a contract from the U.S. Geological Survey with collaboration from the Bureau and matching funds from the Utah Division of Water Resources and the Central Utah Water Conservancy District to collect both bathymetric and drone data at Starvation Reservoir to combine the data for a complete reservoir survey. We have also collected similar data from two smaller reservoirs. We have made good progress, establishing field and data processing protocols as we've gained experience together. The project, frankly, has been hampered by delays in obtaining necessary equipment, winter weather, and now, COVID-19. Nonetheless, we are close to breaking through with our data processing to knit the data together.

The proposed work builds on our current experience and takes advantage of research equipment already purchased: multi-beam sonar equipment and software; a drone appropriate for use on federal projects, and a desktop computer capable of processing the dense data clouds from our drone work.

As further incentive to continue and expand this research, we will

- Use internal BYU funding to support students for this work (total value estimated at $35,000)
- Use one month of salary for each of the two years as an in-kind match from Dr. Williams and Dr. Hotchkiss towards the project (value estimated at $75,000)
- Incorporate an underwater drone into the project as conducted by a new faculty member joining the College of Engineering's Electrical and Computer Engineering Department.

The undergraduate students will provide valuable field and data processing support and will be supervised by Dr. Williams and Dr. Hotchkiss. The underwater drone work will be overseen by Dr. Joshua Mangelson.

Sincerely,

Rollin H. Hotchkiss, Ph.D., P.E., D.WRE, F.ASCE
Professor

(801) 422-6234 *email rhh@byu.edu*

BRIGHAM YOUNG UNIVERSITY · 430 ENGINEERING BUILDING · PROVO, UTAH 84602

(801) 422-2811

GARY R. HERBERT
Governor

SPENCER J. COX
Lieutenant Governor

State of Utah
DEPARTMENT OF NATURAL RESOURCES

BRIAN C. STEED
Executive Director

Division of Water Resources

Todd D. Adams
Division Director

April 10, 2020

WaterSMART Applied Science Grant Program
U.S. Bureau of Reclamation
Policy and Administration
Denver Co, 80225

Dear WaterSMART Grant Program Reviewers,

On behalf of the Division of Water Resources (DWRe), I would like to express my support for the grant proposal being submitted by the Bureau of Reclamation Operations and Energy Management group to the WaterSMART Applied Science Grant Program.

The mission of the Division of Water Resources is to plan, conserve, develop, and protect Utah's water resources. Preparing for Utah's future water needs will be met through a combination of multi-varied innovative solutions that include conservation, efficiency, optimization, agricultural conversion, and water development. Sedimentation surveys, using a combination of sonar and drone technology, represent one of these important solutions. These surveys enable us to calculate the total deposition of sedimentation and the storage loss in a reservoir system. Significant work has been done over the past year to advance our accuracy and knowledge using this technology. The proposed project represents an opportunity to continue the progress that has been made and to further advance these tools that are being developed.

In 2019, we partnered with BYU and the Bureau of Reclamation (BOR) to work on the Starvation Reservoir sedimentation survey. The purpose of this study was to determine the amount of sediment and debris Starvation Reservoir received following the 2018 Dollar Ridge Fire. We previously partnered with BYU and the BOR on other reservoir sedimentation studies at Newcastle and Gunlock. In each of these studies, our staff gleaned valuable onsite training; however, we also discovered the limitations of the equipment. Improving this equipment will increase our ability to maximize our available time in the field and make our measurements more precise allowing all parties involved to make better water management decisions. We look forward to the opportunity to further advance this effort.

Sincerely,

Todd D. Adams, PE
Director
Utah Division of Water Resources

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*

CENTRAL UTAH WATER
CONSERVANCY DISTRICT

1426 East 750 North Suite # 400
Orem, Utah 84097
801.226.7100
www.cuwcd.com

April 16, 2020

WaterSMART Applied Science Grant Program
U.S. Bureau of Reclamation
Policy and Administration
Denver, CO 80225

Dear Grant Reviewers,

I am writing to support the application of the Provo Area Office of the U.S. Bureau of Reclamation (PAO) to the WaterSMART Applied Science Grant Program. The proposed project will increase the accuracy and efficiency of performing bathymetric surveys.

Central Utah Water Conservancy District (CUWCD) operates and maintains the Bonneville Unit of the Central Utah Project (CUP). One of the major features of the CUP is Starvation Dam and Reservoir which was completed in 1970 with a storage capacity of 164,118 acre-feet. In 2009 CUWCD in cooperation with the PAO completed a bathymetric survey using GPS and a single-beam, Odom echosounder of Starvation Reservoir in order to measure reservoir capacity and compare with the original area-capacity tables. At that time, we were not able to determine how the original area-capacity tables were developed. The 2009 survey became a baseline moving forward for measuring sedimentation impacts to the reservoir.

On July 1, 2018 the Dollar Ridge Fire wildfire started in the watershed for Starvation Reservoir and ultimately burned nearly 70,000 acres. The fire destroyed or damaged 80 homes and nearly 400 trailers, sheds, and vehicles. Later on, in that same year a series of monsoonal thunderstorms over the burn scar created devastating flash flooding in the area. These floods carried significant amounts of sediment and ash into Starvation Reservoir.

In 2019 the PAO partnered with CUWCD, the State of Utah Division of Water Resources, and Brigham Young University to complete a bathymetric survey of Starvation Reservoir to measure the impacts of the Dollar Ridge Fire and the associated flood events. The data from this survey is an important part of understanding the effects of the wildfire on reservoir operations and will help to guide future decisions regarding the management of the water shed.

It appears that one of the effects of climate change may be an increase in wildfire events in the future. The ability to complete accurate bathymetric surveys in an efficient manner will become an increasingly important part of measuring impacts. We strongly support this project and are willing to partner with PAO and others to complete bathymetric surveys at other CUP reservoirs to be better prepared to measure the effects of future events in the watersheds associated with these facilities.

If you have any questions please feel free to contact me by email at jhansen@cuwcd.com or by telephone at (801) 226-7152.

Sincerely,

Jared D. Hansen, P.E.
Central Utah Project Manager

GARY R. HERBERT
Governor

SPENCER J. COX
Lieutenant Governor

State of Utah
DEPARTMENT OF NATURAL RESOURCES

BRIAN C. STEED
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April 10, 2020

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U.S. Bureau of Reclamation
Policy and Administration
Denver Co, 80225

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Best Regards,

Scott Elliott PE Civil Engineer for Reclamation