RECOVERY PROGRAM Recovery Program Project Number: 85f
FY 2020-2021 SCOPE OF WORK for:
Suspended-sediment monitoring in the upper Green River

Reclamation Agreement number *[if applicable & known]*: R17PG0047
Reclamation Agreement term: Oct 1, 2016 – Sept 30, 2021

Note: Recovery Program FY20-21 scopes of work are drafted in May 2019. They often are revised before final Program approval and may subsequently be revised again in response to changing Program needs. Program participants also recognize the need and allow for some flexibility in scopes of work to accommodate new information (especially in nonnative fish management projects) and changing hydrological conditions.

Lead agency: U.S. Geological Survey

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Date Last Modified: 4/30/2019 3:46:00 PM

Category:
X Ongoing project
__ Ongoing-revised project
__ Requested new project
__ Unsolicited proposal

Expected Funding Source:
X Annual funds
__ Capital funds
__ Other *[explain]*

I. Title of Proposal: Suspended-sediment monitoring in the upper Green River

II. Relationship to RIPRAP: Green River I.D.2.b.(2): Monitor changes in the magnitude, timing and size distribution of sediment.

III. Study Background/Rationale and Hypotheses:

This Scope of Work describes work to be completed by the U.S. Geologic Survey (USGS), Southwest Biological Science Center, Grand Canyon Monitoring and Research Center (GCMRC) for the Upper Colorado River Endangered Fish Recovery Program (UCREFRP) to collect high-resolution suspended-sediment data using multi-frequency acoustics on the Green River at the USGS gages near Jensen and at Ouray, UT. Work under this Interagency Acquisition Agreement (Agreement) will span fiscal years FY2017 through FY2021. Additional funding, tasks, and products will be developed in an annual work plan and will be detailed accordingly in future modifications to this Agreement.

Background and Introduction

Within the Green River basin, the highest reach-habitat scores for species and life stages are in the Split Mountain Canyon to Desolation Canyon reach. Habitats with high scores in this restricted-meander reach include connected backwaters, side channels, flooded tributary mouths, and flooded bottomlands (LaGory et al. 2003). All are low-velocity habitats that serve as critical nursery areas for Colorado pikeminnow and razorback suckers. The extremely dynamic nature of backwaters and side-channels demands a greater understanding of the geomorphic processes that form and maintain those habitats. Additional research is needed to verify the existing conceptual model of backwater formation and more fully understand underlying geomorphic processes. Studies are also needed to address the effects of both base-flow and high-flow variability (inter-annual, intra-annual, and within day), and the sediment-transport dynamics associated with those flows, on backwater and side-channel habitat availability and conditions. (LaGory et al. 2003).

The Peak Flow Technical Supplement (LaGory et al., 2015) identified suspended sediment (SS) monitoring in the upper Green River with the highest priority category (LaGory et al 2015). This monitoring would need to be conducted over a long enough period to cover the broad range of stream flow conditions that occur within the Green River, especially within the Split Mountain to Desolation Canyon reach. SS monitoring will need to be conducted at a minimum of 2 sites. These data will provide the ability to construct a sediment mass balance in order to determine whether reach-scale sediment accumulation or evacuation occurs within this important reach of the Green River. This monitoring will also provide the ability to investigate patterns in SS transport that occur during discrete flood events (e.g. spring snowmelt floods, high flows driven by convective thunderstorms) and whether those patterns are caused by conditions of sediment surplus or deficit, or by changes in channel sediment characteristics such as changes in grain size, and sand-area coverage. An important part of this work is evaluating the effects of peak flows on SS transport, especially since peak discharges associated with future Flaming Gorge operations may differ from past operations.

The study will determine whether the reach between Jensen, UT and Ouray, UT, is gaining or losing sediment, and whether those trends are driven by a reduction or increase in sediment supply, or changes in the in-channel sediment characteristics (Rubin and Topping, 2001, 2008). Accumulation of sediment within this reach would likely be associated with channel simplification and loss of backwater habitat for native and endemic fish.

Determination of whether segments of a river system are accumulating, or evacuating, fine sediment (sand, silt, and clay) depend on the ability to accurately measure the mass flux of sediment entering and exiting that reach. Continuous measurement of SS transport at high temporal resolution is the only way to accurately calculate the mass flux of SS (Topping and Wright, 2016; Dean et al., 2016). Continuous SS monitoring and the construction of a sediment budget using the measured mass flux will help determine the potential geomorphic and ecological effects of the flow regime on transporting the given supply of sediment. These data will also allow for prediction as to whether future changes to the stream flow regime will cause undesirable ecological impacts, such as sediment infilling of important habitats.

Continuous SS measurements will be collected to understand the formation and maintenance of in-channel habitats in the sand bedded segments of the river network. There is simply no way to determine how dam operations and stream flow diversions affect the physical channel and habitat condition over large spatial scales unless the continuous flux of fine sediment is measured.

The growing importance of continuous flux measurements of fine sediment transport is highlighted by examination of recent data published at:

<http://www.gcmrc.gov/discharge_qw_sediment/>.

Recent data and publications indicate that paradigms about fine-sediment transport in the Green and Colorado river systems are largely based on 1950s era measurements and may need substantial revision. For example, Topping et al. (2018) showed that natural changes in sand transport associated with changes in grain size arising from the downstream migration of sand waves have affected sand transport in the Green River downstream from the Yampa River confluence as much as have operations at Flaming Gorge Dam. In addition, they showed that sand transport in the Green River has decreased over time in response to the coarsening of the bed sediment associated with these sand waves, which were generated during rare large floods on a Little Snake River tributary during March of 1956, 1962, and 1966. Farther downstream on the Green River, substantial decreases in silt and clay transport and sand transport have occurred in response to both natural and human-exacerbated processes. For example, during the snowmelt runoff season of 2014, ~3.3 million metric tons of fine sediment was transported by the Green River past Mineral Bottom; ~5.9 million metric tons was transported past Mineral Bottom throughout the entire year. Pre-dam sediment transport data summarized by Andrews (1986), and other 1950s era data collected by the USGS, indicate that pre-dam transport past Green River, UT, was ~15 million tons/year – approximately three times more than measured at Mineral Bottom in 2014. Because sediment-transport changes over time in response to changes in the upstream sediment supply (owing to natural and human-exacerbated processes), river management requires contemporary continuous measurements of SS transport. Such measurements will be used to define the relative role of small, moderate, and large snowmelt floods, and to define the role of monsoon season floods, in supplying and transporting fine sediment, or in causing undesirable sediment accumulation in parts of the river that are ecologically essential.

Value of Data to be Collected

Currently, the UCREFRP is engaged in multiple related efforts to understand relations between endangered fish, flow, channel habitat, and the sediment transport processes that shape these systems. These efforts will benefit from an in-depth understanding of the sediment transport dynamics within the Green and Colorado Rivers, and how those dynamics affect the available critical habitat. Identification of fluvial geomorphic flow-thresholds above which physical processes (e.g., sediment transport, channel change, floodplain inundation) are significantly altered will help identify flow-thresholds associated with critical habitat features and the streamflows needed to maintain and improve riparian and aquatic ecosystems.

On the Green River the UCREFRP is interested in: (1) describing and quantifying the existing sediment equilibrium conditions (or range of equilibrium conditions) as a function of the magnitude and timing of inputs of sediment and water; and (2) understanding if/how sediment balance/imbalance propagate downstream. This requires developing a sediment mass balance as a function of historical and existing flows; and determining the annual flow volume and nature of streamflows required to transport sediment delivered to these river reaches, which in turnrequires a robust sediment monitoring campaign using continuous measurements at high temporal resolution, such that the sediment evacuation/accumulation can be measured independently without relying on inherently inaccurate sediment rating curves.

This Green River monitoring will complement similar monitoring efforts upstream and downstream of the subject river reach. On the Yampa and Green Rivers in Dinosaur National Monument, the National Park Service (NPS) and the GCMRC have worked collaboratively since 2012 to operate and maintain five suspended sediment (Yampa River near Maybell, CO, Yampa River at Deerlodge Park, CO, Little Snake River near Lily, CO, Green River above gates of Lodore, CO, and Green River above Jensen, UT). On the Green and Colorado Rivers near Canyonlands National Park, the NPS and GCMRC have worked collaboratively since 2014 to maintain 2 suspended sediment gages (Green River at Mineral Bottom near Canyonlands National Park, UT and Colorado River at Potash, UT). Operation of these gages is being used to develop relationships between Green River stream flow, sediment supply, and sediment transport capacity during both natural floods and upstream dam releases. However, given the long distance between Jensen, UT, and Mineral Bottom, UT, an accurate sediment budget is not currently able to be constructed. Installation and operation of a sediment monitoring gage at Ouray will improve this ability for the 16 priority floodplain/wetland reaches referenced above, and also specifically address sediment related habitat issues within the important habitats in the Uintah Basin (Fig. 1), and downstream in Canyonlands National Park. Ultimately, these data inform how water management actions, and reduced peak flows from Flaming Gorge Dam affect sediment routing throughout the Green River, and whether these sediment transport dynamics could negatively affect the distribution of essential aquatic habitat for native and endemic fish. This information will be an important tool to evaluate the Green River Flow recommendations (e.g., Muth, et al. 2000).

In cases where dams capture most of the upstream sediment supply, downstream regulated rivers are typically perturbed into a state of sediment deficit, resulting in sediment erosion and bed incision. The Colorado River in Glen Canyon National Recreation Area and the upstream parts of Grand Canyon National Park is an example of a river where an upstream impoundment—Glen Canyon Dam—has substantially reduced the quantity of fine sediment (~96% reduction); this reduction in sediment supply and changes in the flow regime caused by operation of the dam, initiated sediment erosion (Topping et al., 2000a; Rubin et al., 2002). In cases where most of the stream flow is diverted at upstream dams and the suspended sediment passes through, or significant inputs of sediment occur below the impoundments, downstream regulated rivers can be perturbed into sediment surplus, where there is too little water available to transport the sediment further downstream. In such a situation, sediment accumulates in the channel and on the channel banks, leading to possible channel narrowing and aggradation, as has occurred on the Rio Grande in Big Bend National Park (Dean and Schmidt, 2011; Dean et al., 2016). This is the condition that may occur on the Yampa River in Dinosaur National Monument, and downstream on the Green River if water development on the Yampa River occurs. Sediment accumulation, and channel narrowing associated with sediment surplus condition may lead to substantial loass of important aquatic habitat, through the infilling of backwaters and side-channels, the deposition of fine sediment in coarse-grained riffles, and the infilling of pools. Thus, it is essential to link the flow regime with the quantity of sediment transported and to account for changes in the sediment mass balance so that NPS managers can understand (1) whether sediment is being evacuated or whether it is accumulating, and (2) what the potential impacts of future proposals to withdraw water or change dam operations would be.

IV. Study Goals, Objectives, End Product(s):

Study Goals and Objectives

The purpose of this project is to collect suspended sediment data that will help the Program better understand geomorphic processes that form and maintain habitats important to Colorado pikeminnow and razorback suckers in the Green River, including connected backwaters, side channels, and flooded bottomlands.

This project addresses the need to improve our understanding of how changes in sediment supply and transport associated with river regulation affects the critical habitat and life cycles of endangered fish. Riverine ecosystems are shaped by the flow regime and supplied sediment, and water development and river regulation can substantially alter both of these phenomena. Potential additional water development projects on the Yampa and White Rivers (including potential new dams) highlight the need to understand how changes in flow and sediment transport will affect these ecosystems. In that context, the costs and benefits of changing flow regimes must be evaluated: (1) for the direct impact of flow on ecosystem function and (2) for the indirect impact that flow exerts on sediment transport that in turn determines the quantity and quality of aquatic and riparian habitats.

On the Green River, the Recovery Program is interested in: (1) describing and quantifying the existing sediment equilibrium conditions (or range of equilibrium conditions) as a function of the magnitude and timing of inputs of sediment and water; and (2) understanding if/how sediment balance/imbalance propagate downstream. This requires developing a sediment mass balance as a function of historical and existing flows, and determining the annual flow volume and nature of streamflows required to transport sediment delivered to these river reaches. This in turn requires a robust sediment monitoring campaign using continuous measurements at high temporal resolution, such that the sediment evacuation/accumulation can be measured independently without relying on inherently inaccurate sediment rating curves. For this purpose, this project collects high-resolution suspended-sediment data using multi-frequency acoustics, calibrated pump samples, and conventional equal-width-increment (EWI) measurements near the USGS gages on the Green River near Jensen and at Ouray, UT.

End Products

1. Digital 15-minute sediment transport databases (with metadata) for the two stations on the Green River are served at the http://www.gcmrc.gov/discharge_qw_sediment website, and updated quarterly. In addition, user-interactive sediment budgets are served at this website for the reach of the Green River between the Jensen and Ouray stations;
2. Digital databases (with metadata) containing the laboratory analyses of all physical suspended-sediment samples collected to calibrate and verify the 2-frequency acoustical installations on the Green River; and
3. USGS Open-File Report to be submitted at the end of the period of performance in FY2021 describing the results from the work will be completed for site once data have been collected and analyzed:

This USGS Open-File Report will contain error analyses, calculations of the loads and grain-size distributions of suspended sediment, and analyses of the flow relations between the two stations and conditions most important for the transport of different quantities and grain-size distributions of the sediment forming the templates of the Green River. In addition α−β analyses (Rubin and Topping, 2001, 2008) will be provided to determine whether the bed sand at each of the two stations is coarsening or fining. These analyses are complementary to the user-interactive sediment budgets described above. Fining of the bed sand is generally associated with channel infilling and loss of backwater habitat, whereas coarsening would be associated with possible enlargement of backwater habitat.

This Open-File Report will contain the relevant information that can be used by UCREFR to evaluate environmental flow recommendations for the Green River. In addition, data and analyses from this project will likely be published in one or more peer-reviewed journal articles in the open scientific literature.

In addition to the Open-File Report, annual written updates are provided to the UCREFRP. Since our study started in spring 2017, flows have been more than sufficient to convey the upstream sediment supply through the Jensen-Ouray river segment. During both 2017 and 2018, there was net erosion of silt and clay and net erosion of sand from this long river segment, although this erosion occurred during different parts of the annual hydrograph. During both FY 2017 and 2018, most of the erosion of silt and clay occurred during periods of higher discharge, whereas most of the erosion of sand occurred during periods of lower and moderate discharge.

V. Study Area:

This study is conducted in river reaches at sediment monitoring stations located upstream from the USGS Green River near Jensen, UT, and Green River at Ouray, UT gaging stations. These sediment monitoring stations are referred to as the Green River above Jensen, UT, and Green River above Ouray, UT, stations and are located on the map at: https://www.gcmrc.gov/discharge_qw_sediment/stations/DINO. The above Jensen station is located at the downstream end of the Split Mountain Campground in Dinosaur National Monument and the above Ouray station is located at the fish observation deck in the Ouray National Wildlife Refuge. The sediment data collected at these two sediment monitoring stations is used in conjunction with the streamflow data collected at the near Jensen and at Ouray gaging stations to the calculate continuous sediment fluxes and loads used in sediment budgeting.

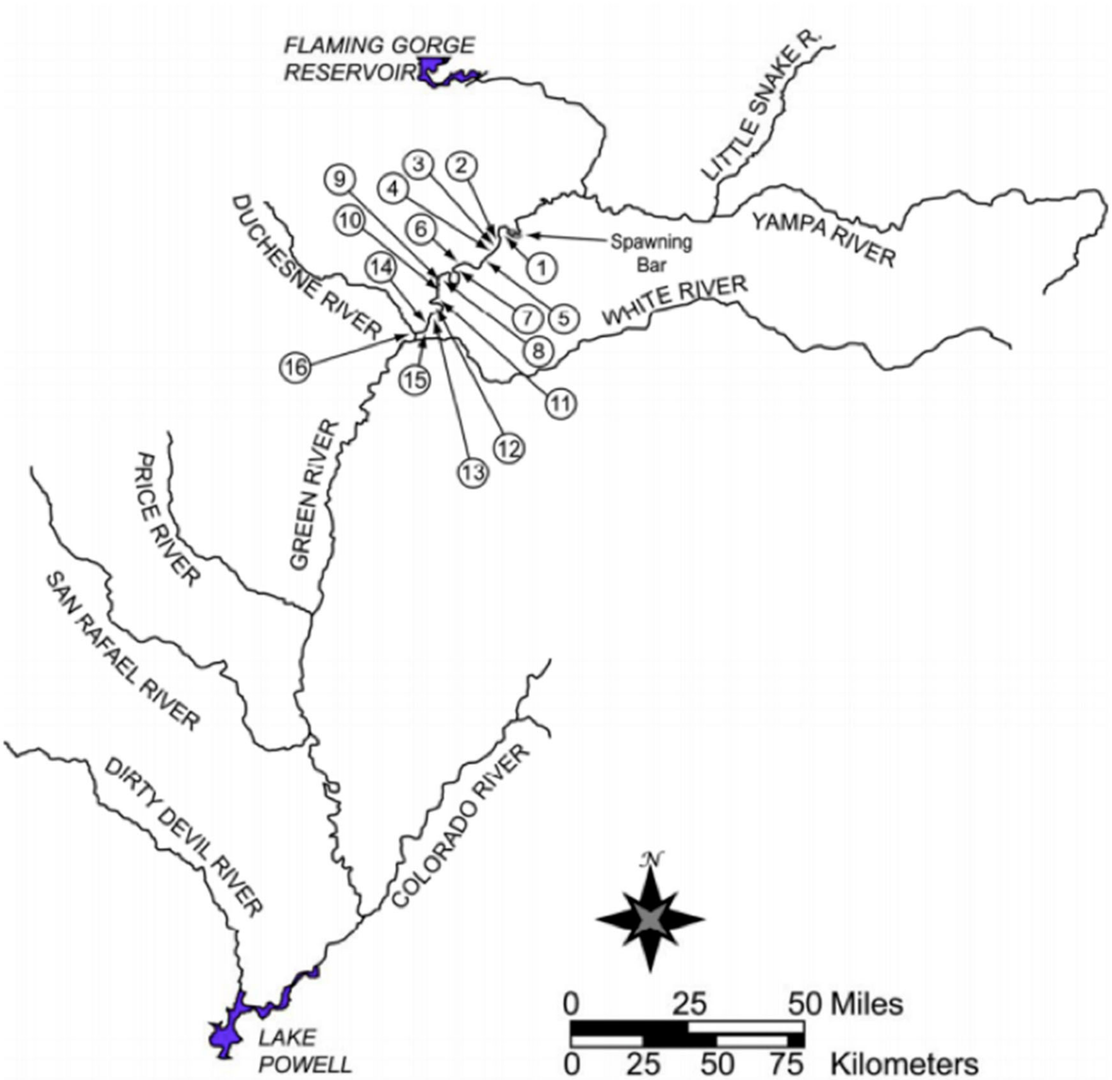

Figure 1. Green River study area showing locations of 16 priority flood plain wetlands (from Hayse et al. 2005, and Valdez and Nelson 2004). Location 1= Thunder Ranch, 2 = IMC, 3 = Stewart Lake, 4 = Sportsman's Lake, 5 = Bonanza Bridge, 6 = Richens, Slaugh, 7 = Horseshoe Bend, 8 = The Stirrup, 9 = Baser Bend, 10 = Above Brennan, 11 = Johnson Bottom, 12 = Leota ponds, 13 = Wyasket Lake, 14 = Sheppard Bottom, 15 = Old Charley Wash, 16 = Lamb Property. From Hayse et al. (2005) with permission.

Figure from: Bestgen, K. R., G. B. Haines, and A. A. Hill. 2011.

The USGS Green River near Jensen, UT, streamflow gaging station is operated by the U.S. Geological Survey as part of the National Streamflow Information Program in cooperation with the Central Utah Water Conservancy District and the U.S. Fish and Wildlife Service. It is in Uintah County, Utah, with a drainage area of 29,660 square miles and a contributing drainage area of 25,400 square miles just downstream of the confluence of the Green and Yampa Rivers.

Both the Green and Yampa Rivers are subject to potentially substantial new water development to support extraction of nearby oil and gas resources and potential trans-basin export to satisfy municipal and industrial needs in eastern Colorado.

The USGS Green River at Ouray, UT, streamflow gaging station is operated by the U.S. Geological Survey as part of the National Streamflow Information Program in cooperation with the U.S. Fish and Wildlife Service. It is in Uintah County, Utah, with a drainage area of 31,060 square miles and a contributing drainage area of 26,800 square miles. It is upstream from the confluences of the White and Duchesne Rivers. The reach between Jensen and Ouray, UT is home to 16 priority flood plain wetlands. The Jensen and Ouray stream flow gaging stations are shown as blue dots in Figure 1.

VI. Study Methods/Approach:

The work proposed herein takes advantage of (1) new insights into how sediment is transported in rivers, and (2) new technologies available to measure suspended-sediment transport at sufficiently high resolutions to calculate accurate sediment loads. In the past, it has been common to use time-invariant relations between water discharge and sediment concentration (i.e., sediment rating curves) to estimate sediment loads. This simple and convenient approach, however, can easily result in errors in sediment transport that exceed 900% (Walling, 1977) and in errors in daily sediment loads as high as 4000% (Glysson et al., 2001) because the concentration of suspended sediment and the instantaneous discharge of water are not well correlated in most rivers. This poor correlation arises because of discharge-concentration hysteresis in one or more size classes of the suspended load during floods or periods of higher discharge.

Because of the existence of discharge-concentration hysteresis in some grain-size fraction of the suspended load, the only *a priori* accurate method to calculate sediment loads in rivers is to use suspended-sediment measurements that are independent of water-discharge data, and not use the time-invariant sediment-rating-curve approach that requires that the variation in suspended-sediment concentration be random at a given discharge of water. These new insights demonstrate the need for near-continuous measurement of suspended-sediment transport if one is to measure sediment accumulation or evacuation or to predict the impact of future water developments with the accuracy required for making sound management decisions and recommendations.

Scientists at the U.S Geological Survey (USGS) Grand Canyon Monitoring and Research Center (GCMRC) have developed an innovative program using acoustic-Doppler profilers to continuously measure sediment transport at high (15-minute) resolutions (Topping et al., 2004, 2006, 2007, 2016; Wright et al., 2010; Topping and Wright, 2016). These measurements, coupled with episodic calibration and verification field measurements using conventional depth-integrating samplers, have resulted in a state-of-the-science sediment-mass balance accounting system that now informs management of Glen Canyon Dam (U.S. Department of the Interior, 2011). This technology is also being used to inform river management on the Rio Grande in Big Bend National Park, the Green and Yampa Rivers in Dinosaur National Monument, and the Green and Colorado rivers in Canyonlands National Park.

This project collects, analyzes, and serves continuous 15-minute acoustical suspended-sediment measurements, calculated bedload measurements based on episodic measurements of dune migration, bed-sediment measurements, and episodic suspended-sediment measurements made using conventional depth-integrating samplers deployed across the full width of the river (i.e., EWI measurements) and calibrated automatic pump samplers. To facilitate the collection of these data, 1MHz and 2MHz acoustic-Doppler side-looking profilers and automatic pump samplers are deployed at the two sediment monitoring stations described in the previous section. The conventional EWI measurements to calibrate and subsequently verify the acoustical and pump data are made during site visits 4 times per year. The details of this approach to making continuous suspended-sediment measurements are described in Topping and Wright (2016), with only a brief theoretical overview provided in the next few paragraphs. The details of how bedload is calculated on the basis of episodic bedform-migration measurements and EWI measurements is described in Topping et al. (2018).

Theory and measurements of underwater acoustics indicate that, at a given frequency of sound, broad grain-size distributions of suspended sediment can be segregated into two acoustic size classes: (1) a finer acoustic size class in which increasing concentration (or decreasing grain size at a constant concentration) results mainly in increased attenuation of sound due to viscous losses (Urick, 1948; Flammer, 1962; Gartner, 2004; Topping et al., 2004, 2006, 2007; Wall et al., 2006; Wright et al., 2010; Topping and Wright, 2016), and (2) a coarser acoustic size class in which increasing concentration (or increasing grain size at a constant concentration) results mainly in increased backscatter of sound (Thorne and Campbell, 1992; Thorne and Hanes, 2002; Gartner, 2004; Topping et al., 2004, 2006, 2007, 2016; Wall et al., 2006; Wright et al., 2010; Topping and Wright, 2016).

The grain-size distributions of suspended sediment in the Green River are broad and typically bimodal, with silt and clay mode and a sand mode, making them ideal rivers in which to use acoustic attenuation and backscatter to measure suspended sediment concentration and grain size. The acoustical approach developed by Topping and Wright (2016) is the only high-resolution approach that can accurately measure suspended-sediment over the wide range of concentrations and grain sizes as documented in the Rio Grande (Dean et al., 2016). This approach yields silt and clay concentrations over the range from less than 10 mg/l to at least 20,000 mg/l, and yields sand concentrations over the range from about 10 mg/l to at least 3,000 mg/l that are typically within ±10 to 30% of the values measured using conventional suspended-sediment samplers. Multi-frequency-acoustic measurements of the median grain size of the suspended sand are typically within ±10 to 20% of the values of the median grain size measured by conventional methods.

In addition, work conducted on the Colorado River and Rio Grande has shown that acoustic instruments are the most dependable, lowest-maintenance instruments (for example, they are not prone to biological fouling like optical instruments) to deploy in remote settings. These results, in conjunction with the fact that orders of magnitude more data can be collected each day by a multi-frequency acoustic-Doppler profiler array, indicates that a much more complete, and therefore more accurate record of sediment transport on the Green River can be collected by multi-frequency acoustics than by conventional sampling methods alone.

VII. Task Description and Schedule:

This project operates and maintains 15-minute two-frequency-acoustical sediment-transport monitoring stations located upstream from the USGS Green River near Jensen, UT, and Green River at Ouray, UT, streamflow gaging stations (as described above). These sediment monitoring stations are visited multiple times each year for maintenance. During these visits, EWI calibration and verification suspended-sediment measurements, bedform-migration measurements are made. It is anticipated that 4-6 sample collection visits will occur during the year depending on field staff availability and the range in streamflow and suspended-sediment concentrations. Access to the sites will be by vehicle/foot for maintenance visits and by foot or boat during sample collection visits.

VIII. Deliverables, Due Dates, and Budget by Fiscal Year:

- All acoustical, and physical, suspended-sediment data are uploaded to the GCMRC website at http://www.gcmrc.gov/discharge_qw_sediment/ quarterly as proof of the work completed.
- Annual written reports will continue to be provided to the UCREFRP .
- The results of all work under this agreement will be available for publication by the USGS. Final product will be a scientific paper or papers and/or USGS series as described in Section IV above.

FY 2020
Budget Total [*see attached budget for details*]: ***$39,736***

FY 2021
Budget Total [*see attached budget for details*]: ***$44,479***

FY 2022

Budget Total [*see attached budget for details*]: ***$45,361*** *[if continued; current contract terminates FY2021]*

FY 2023
Budget Total [*see attached budget for details*]: ***$46,260*** *[if continued; current contract terminates FY2021]*

FY 2024
Budget Total [*see attached budget for details*]: ***$47,175*** *[if continued; current contract terminates FY2021]*

[To comply with Bureau of Reclamation contracting requirements, all Program scopes of work must contain 5-year budgets. Years 3-5 may be percent (we recommend no more than 2%) increases over years 1 and 2, but must still contain detailed budget break-outs.]

IX. Budget Summary: *[Provide total AND subtotals by funding target (e.g., office/station)]*[*]

X. Reviewers: Don Anderson, Kevin McAbee

XI. References:

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