COLORADO RIVER RECOVERY PROGRAM **Project No.: 85f**
FY-2017-2021 PROPOSED SCOPE-OF-WORK for:
Suspended-sediment monitoring in the Upper Green River

Reclamation Agreement number: R17PG0047
Reclamation Agreement term ________________

Lead Agency: UCREFR Program

Submitted by: Program Directors Office
P.O. Box 25486, DFC,
Denver, C0 80225-0486
Phone: (303) 236-9883
Fax: (303) 236-8739

Dave Topping
Research Hydrologist
USGS Grand Canyon Monitoring & Research Center
2255 North Gemini Drive Flagstaff, AZ 86001
Fax: 928.556.7100
928-556-7445
dtopping@usgs.gov

Date Last Modified: 11/16/2016

Category:
_ Ongoing project
_ Ongoing-revised project
_ Requested new project

Expected Funding Sources:
_ Annual funds
_ Capital funds
_ Other (explain)

SCOPE OF WORK

A. Purpose

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 at Jensen, Ouray, Mineral Bottom, and on the Colorado River at Potash. 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

B. 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 identified suspended sediment (SS) monitoring (Table 1.) 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 discharge associated with high flows from the Flaming Gorge are limited to the powerplant and outlet works.

Table 1. The Peak Flow Technical Supplement identified suspended sediment (SS) monitoring in the upper Green River with the highest priority category (LaGory et al 2015)

Fine Sediment Mass Balance	Prioritization from Peak Flow Supplement (LaGory 2015)		
Establish network of suspended sediment transport and fine sediment mass balance monitoring stations in critical reaches. Tiers off USGS-GCMRC approach.	Middle Green River (Split Mountain Canyon to Desolation Canyon), High priority		
	Jensen gage		
	Ouray gage		
	Lower Green River (Swasey to Colorado River), Medium priority		
	Near Green River, UT gage		
	Mineral Bottom		
	Colorado (Cameo to Green River confluence), High priority		
	Near Cameo gage, High priority		
	Near CO / UT Stateline gage, High priority		
	Near Potash, Medium priority		

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 focused on the highest prioritiy reach for the endangered fish from Jensen to Ouray 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/?>

which are collected and analyzed by the fine sediment measurement program led by Dr. David Topping of the USGS/GCMRC. Recent data indicate that paradigms about fine sediment transport in the channels are largely based on 1950s era measurements may need substantial revision. For example, Topping has pointed out that 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 Ned Andrews (1986), and other 1950s era data collected by the USGS, indicate that predam transport past Green River, UT, was ~15 million tons/year – approximately three times more than measured at Mineral Bottom in 2014. This disparity may be caused by many different phenomena: 1) the same amount of fine sediment may still passes Green River, UT, and may be mostly deposited in Labyrinth Canyon above Mineral Bottom, 2) only the largest snowmelt floods now transport most of the fine sediment past Mineral Bottom, 3) a large amount of fine sediment is potentially being stored within each of the tributary watersheds and therefore, main-stem Green River transport is much smaller, or 4) previous estimates of SS transport within the Green River were erroneous, because SS transport estimates were made using sediment rating curves that may include many orders of magnitude of uncertainty. In order to reconcile these potential disparities, measurements of SS transport must be expanded to a number of stations, the data must be collected continuously, at high temporal resolution, and free from the often inherently inaccurate sediment rating curves. 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.

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.

Additionally, sediment measurements on the Green River at Mineral Bottom, and the Colorado River at Potash will provide much needed information regarding the flow and sediment dynamics that create and maintain critical habitat in Canyonlands National Park.

<u>Monitoring sites</u>

Green River at Jensen: USGS 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 under ever-increasing threats of water development to support extraction of nearby oil and gas resources and potential transbasin export to satisfy municipal and industrial needs in eastern Colorado.

Green River at Ouray: USGS 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, and are where the proposed SS gaging stations would be collocated.

Lastly, there are monitoring station located on the Green (Green River at Mineral Bottom) and Colorado (Colorado River at Potash) Rivers above the confluence of the Green and Colorado Rivers near Canyonlands National Park. Native and endemic fish live and spawn on both of these rivers in Canyonlands National Park, and thus sediment transport data collected at these stations provide needed data regarding the flow and sediment dynamics that affect fish habitat in these important river reaches.

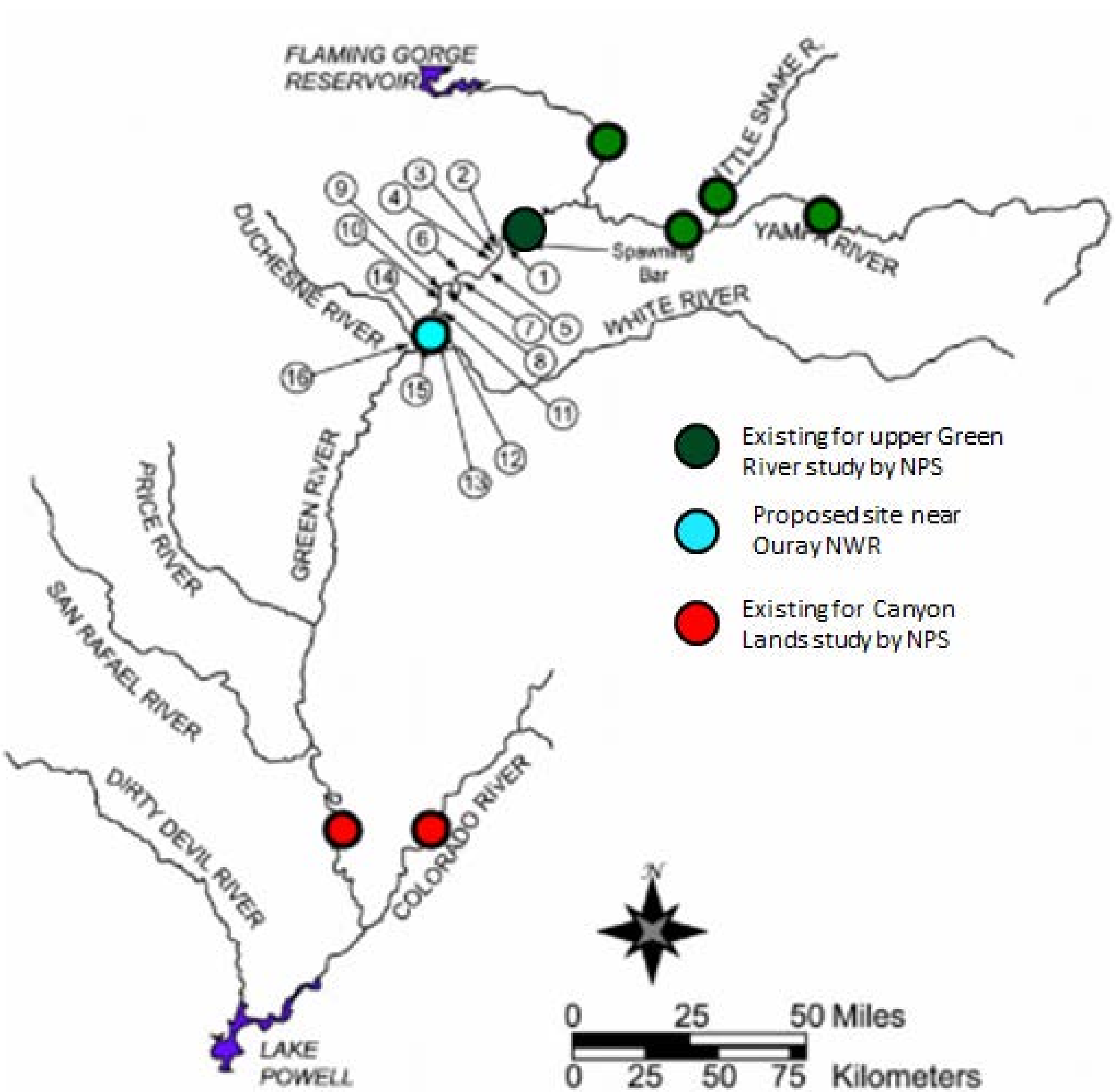

Figure 1. Green River study area showing locations of 16 priority flood plain wetlands (from Hayse et al. 2005, and Valdez and Nelson 2004). Location 1= Thunder Ranch, 2 = IMC, 3 = Stewart Lake, 4 = Sportsman's Lake, 5 = Bonanza Bridge, 6 = Richens, Slaugh, 7 = Horseshoe Bend, 8 = The Stirrup, 9 = Baser 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.

How the Recovery Program intends to use SS Monitoring Information:

Currently, the UCREFRP is engaged in multiple related efforts to understand relations between endangered fish, flow, 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. Fine sediment generally forms the physical template for aquatic and riparian ecosystems. Identification of fluvial geomorphic flow-thresholds below which physical processes (e.g., sediment transport, channel change, floodplain inundation) are 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. This 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.

The Green River Evaluation Analysis Team (GREAT) is responsible for reviewing flow and temp recommendations for Green River and will develop the future monitoring suggested from both the biologic and physical backwater synthesis reports. Below is the physical habitat monitoring recommendations from Grippo et. al (2016 draft) will help describe the relationship between flow and the physical characteristics of Colorado Pikeminnow backwater nursery habitats in the middle Green River.

1. Monitor channel narrowing in the middle Green River. High-resolution satellite imagery that is available U.S. Department of Agriculture's National Agriculture Imagery Program (NAIP) which could be adequate, resolution and is available free of charge. A similar assessment is recommended in LaGory et al. (2016).

2. Monitor fine sediment mass balance in the middle Green River. The formation and maintenance of backwater habitats are strongly dependent on fine sediment mass balance. To monitor the effect of flow regimes on fine sediment mass balance, we recommend installation of two gages: near the existing Jensen, Utah, stream gage (USGS 09261000) and near the existing Ouray, Utah, stream gage (USGS 09272400). These two gages should be used to monitor sediment flux in the middle Green River.

3. Continue to evaluate long-term trends in backwater number and size in the middle Green River. Aerial imagery from 2004, 2006, and 2013 indicated there has been a decrease in backwater number/RM and mean backwater size when compared

to analyses performed by Pucherelli and Clark (1989 and 1990). Analysis of new imagery of the middle Green River (Jensen to Ouray) as it becomes available will enable monitoring trends in backwater habitat and determining relationships to age-0 Colorado pikeminnow captures. Care should be taken to use a similar approach as in earlier studies and to archive the imagery, polygons of digitized backwaters, and data on the area of individual backwaters. Note: Western and Argonne National Labs are planning to continue backwaters.

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 (Muth et al. 2000).

C. Background

The proposed work 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 phenomenon. Potential plans for additional dams and water development projects on the Yampa and White Rivers 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.

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 and others, 2000a; Rubin and others, 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.

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 and others, 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.

Discharge-concentration hysteresis can arise from two distinctly different mechanisms: (1) supply regulation — in which the transport of a given grain-size fraction is at least partly regulated by temporal changes in its upstream supply (Topping and others, 2000a, 2000b; Rubin and Topping, 2001); and (2) lags between discharge and dune geometry — in which differences in dune geometry between the rising and receding limbs of a flood result in relatively greater dune form drag and thus reduced entrainment of coarser grain sizes of bed sand at the same discharge during the receding limb than during the rising limb. 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 and others, 2004, 2006, 2007, 2016; Wright and others, 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.

D. Description of Work

Objectives: The work proposed herein involves using the continuous sediment-transport monitoring program developed and operated on the Colorado River in Grand Canyon National Park by the USGS-GCMRC to understand the sediment budget in critical habitat in reach 2 of the Green River. The proposed work is a measurement framework for the Green River which is robust and can be adapted for regulated rivers to understand conditions sediment deficit or surplus.

Through this agreement, the USGS and UCREFR agree to a measurement program on the Green River in and near important floodplain habitats in the Green River. Funds identified under this agreement will be used primarily to pay for equipment, salary, field and data-processing time, and travel

Procedures/Methods: 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 and others, 2004, 2006, 2007; Wall and others, 2006; Wright and others, 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 and others, 2004, 2006, 2007; Wall and others, 2006; Wright and others, 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 and others, 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.

Task and Work Schedule:

1. This work proposes to install, operate and maintain a 15-minute 2-frequency-acoustic sediment-transport monitoring station at the USGS Green River at Ouray, UT station 09272400 and Jensen, UT, station 09261000 and.. Instrumentation at the Jensen site has been installed, and therefore, installation costs will not be required.
2. G will be visited multiple times each year for maintenance. In addition to yearly maintenance visits, visits will occur for collection of calibration and verification suspended-sediment samples, and to track bedform migration in order to estimate the bedload component of the sediment-transport regime. It is anticipated that 4-6 sample collection visits will occur during the year depending on field staff availability and the range in suspended-sediment concentrations. Access to the site will be by foot for maintenance visits and by foot or boat during sample collection visits.

Expected Results and Products:

1. Digital 15-minute sediment transport databases (with metadata) for the 2 stations on the Green River to be served at the www.gcmrc.gov website, and updated quarterly. In addition, user-interactive sediment budgets will be 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 acoustic installations on the Green and Colorado Rivers; 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 4 sites 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 a-b analyses (Rubin and Topping, 2001, 2008) will be provided to determine whether the bed sand at each of the 4 sites is coarsening or fining. These analyses are complimentary 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 the existing 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.

Technology /Information Transfer:

In addition to the Open-File Report, annual reports will be submitted using the UCREFRP format and placed in 85f Sed Mon which can be seen at this website: http://www.coloradoriverrecovery.org/documents-publications/work-plan-documents/project-annual-reports.html Updates will be provided to the UCREFRP on whether the bed sand at the sites has fined or coarsened. If possible, UCREFRP would like to understand relations between current verses historic suspended-sediment transport.

Technology/information transfer to UCREFR will occur via the www.gcmrc.gov website and in the above-mentioned Open-file report, annual written updates, and likely journal article. In addition one or more seminars will be held on-site in for the UCREFR to review key current findings as work progresses.

Personnell:

USGS: Principal Investigator (David Topping), two staff hydrologists, and one laboratory technician.

Budget:

Work under this Agreement will span five fiscal years (FY2017 through FY2021) (Table 2.) . Additional funding, tasks, and products will be developed in an annual work plan and detailed accordingly in future modifications to this Agreement. By means of this contract, UCREFR is providing the USGS-GCMRC $55,080 to install and run the sediment-monitoring equipment Green River at Ouray, UT in FY2017. In FY2018-2021 operation and maintenance costs at Green River near Jensen and the Ouray station will be approximately $40,000/yr. The above costs will include the preparation and delivery of a final Open-File Report, likely journal article, and annual written updates, as described above.

Table 2. The budget below provides for suspended-sediment monitoring and equipment Green River at Ouray, UT in FY2017 and operation and maintenance costs at Green River near Jensen and Ouray stations in FY2018-2021.

FY 2017 Costs:

Ouray Site		# of Pay Periods	Rate	Cost	Overhead (19.89%)	Net
Labor	Research Hydrologist	0	6124	0	0	0
	Hydrologist	0.75	4362	3271.5	651	3922
	Lab Technician	1	2240	2240	446	2686
Travel	Per diem (6 days)			120	24	144
	Vehicle (6 days)			0	0	0
Equipment	Acoustic Doppler Profilers (x2)			34072.5	6778	40851
	ISCO pump sampler			4937	982	5919
	Mount and shelter			800	159	959
	Solar panel and batteries			500	99	599
Ouray FY 2017 subtotal						***$55,080***
FY 2017 TOTAL						***$55,080***

FY 2018 Costs:

Ouray Site		# of Pay Periods	Rate	Cost	Overhead (23%)	Net
Labor	Research Hydrologist	1	6430	6430	1479	7909
	Hydrologist	1	4581	4581	1054	5635
	Lab Technician	1.25	2352	2940	676	3616
Travel	Per diem (10 days)			200	46	246
	Vehicle (5 days)			0	0	0
Database and Website	Server fee			2000	460	2460
Ouray FY 2018 subtotal						***$19,866***

Jensen Site		# of Pay Periods	Rate	Cost	Overhead (23%)	Net
Labor	Research Hydrologist	1	6430	6430	1479	7909
	Hydrologist	1	4581	4581	1054	5635
	Lab Technician	1.25	2352	2940	676	3616
Travel	Per diem (10 days)			200	46	246
	Vehicle (5 days)			0	0	0
Database and Website	Server fee			2000	460	2460
Jensen FY 2018 subtotal						***$19,866***
FY 2018 TOTAL						***$39,731***

FY 2019 Costs:

Ouray Site

Labor		# of Pay Periods	Rate	Cost	Overhead (23%)	Net
	Research Hydrologist	0.75	6752	5064	1165	6229
	Hydrologist	1.25	4810	6012.5	1383	7395
	Lab Technician	1.25	2470	3087.5	710	3798
Travel	Per diem (10 days)			200	46	246
	Vehicle (5 days)			0	0	0
Database and Website				2000	460	2460
Ouray FY 2019 subtotal						***$20,128***

Jensen Site		# of Pay Periods	Rate	Cost	Overhead (23%)	Net
Labor	Research Hydrologist	0.75	6752	5064	1165	6229
	Hydrologist	1.25	4810	6012.5	1383	7395
	Lab Technician	1.25	2470	3087.5	710	3798
Travel	Per diem (10 days)			200	46	246
	Vehicle (5 days)			0	0	0
Database and Website	Server fee			2000	460	2460
Jensen FY 2019 subtotal						***$20,128***
FY 2019 TOTAL						***$40,255***

FY 2020 Costs:

Ouray Site		# of Pay Periods	Rate	Cost	Overhead (23%)	Net
Labor	Research Hydrologist	1	7089	7089	1630	8719
	Hydrologist	0.75	5050	3787.5	871	4659
	Lab Technician	1.25	2593	3241.25	745	3987
Travel	Per diem (10 days)			200	46	246
	Vehicle (5 days)			0	0	0
Database and Website				2000	460	2460
Ouray FY 2020 subtotal						***$20,071***

Jensen Site		# of Pay Periods	Rate	Cost	Overhead (23%)	Net
Labor	Research Hydrologist	1	7089	7089	1630	8719
	Hydrologist	0.75	5050	3787.5	871	4659
	Lab Technician	1.25	2593	3241.25	745	3987
Travel	Per diem (10 days)			200	46	246
	Vehicle (5 days)			0	0	0

Database and Website	Server fee			2000	460	2460
Jensen FY 2020 subtotal						***$20,071***
FY 2020 TOTAL						***$40,142***

FY 2021 Costs:

Ouray Site		# of Pay Periods	Rate	Cost	Overhead (23%)	Net
Labor	Research Hydrologist	1	7444	7444	1712	9156
	Hydrologist	0.75	5303	3977.25	915	4892
	Lab Technician	1	2723	2723	626	3349
Travel	Per diem (10 days)			200	46	246
	Vehicle (5 days)			0	0	0
Database and Website				2000	460	2460
Ouray FY 2021 subtotal						***$20,103***

Jensen Site		# of Pay Periods	Rate	Cost	Overhead (23%)	Net
Labor	Research Hydrologist	1	7444	7444	1712	9156
	Hydrologist	0.75	5303	3977.25	915	4892
	Lab Technician	1	2723	2723	626	3349
Travel	Per diem (10 days)			200	46	246
	Vehicle (5 days)			0	0	0
Database and Website	Server fee			2000	460	2460
Jensen FY 2021 subtotal						***$20,103***
FY 2021 TOTAL						***$40,207***

E. Deliverables

All acoustic, and physical, suspended-sediment data will be uploaded to the GCMRC website quarterly as proof of the work completed. 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 D. Description of Work – *Expected Results and Products*" above.

F. Property Purchase and Transfer

The USGS agrees to transfer and return, and/or leave in-place all non-expendable property purchased under this Agreement when the project is completed.

G. Principle Contacts for Completion of Work

Dave Topping
Research Hydrologist

USGS Grand Canyon Monitoring & Research Center
2255 North Gemini Drive Flagstaff, AZ 86001
Fax: 928.556.7100
928-556-7445
dtopping@usgs.gov

Program Directors Office
P.O. Box 25486, DFC,
Denver, C0 80225-0486
Phone: (303) 236-9883
Fax: (303) 236-8739

Literature cited:

Andrews, E. D. (1986), Downstream effects of flaming gorge reservoir on the Green River, Colorado and Utah, *Geological Society of America Bulletin*, *97*(8), 1012-1023.

Bestgen, K. R., G. B. Haines, and A. A. Hill. 2011. Synthesis of flood plain wetland information: Timing of razorback sucker reproduction in the Green River, Utah, related to stream flow, water temperature, and flood plain wetland availability. Final Report to the Upper Colorado River Endangered Fish Recovery Program, Denver. Larval Fish Laboratory Contribution 163.

Dean, D. J., and J. C. Schmidt (2011), The role of feedback mechanisms in historic channel changes of the lower Rio Grande in the Big Bend region, *Geomorphology*, *126*, 333-349.

Dean, D. J., D. J. Topping, J. C. Schmidt, R. E. Griffiths, and T. A. Sabol (2016), Sediment supply versus local hydraulic controls on sediment transport and storage in a river with large sediment loads, *Journal of Geophysical Research: Earth Surface*.

Glysson, G.D., Gray, J.R., and Schwarz, G.E., 2001, Comparison of load estimates using total suspended solids and suspended- sediment data, in Phelps, D. and Sehlke, G., eds., Bridging the gap: Meeting the world's water and environmental resources challenges: American Society of Civil Engineers World Water and Environmental Resources Congress, Orlando, Florida, May 20-24, 2001, Proceedings, doi: 10.1061/40569(2001)123

Grippo, M. LaGory K.E., Hayse J.W., Walston L.J., Weber C.C.,Waterman D., Magnusson A.K., Jiang X.H., 2016 Draft Relationship between flow and the physical characteristics of Colorado Pikeminnow backwater nursery habitats in the middle Green River, Project FR BW-Synth **for** Colorado River Endangered Fish Recovery Program Project FR WB-Synth

Lagory K.L., et al, 2003, Recommended Priorities for Geomorphology Research in Endangered Fish habitats of the Upper Colorado River Basin http://www.coloradoriverrecovery.org/documents-publications/technical-reports/isf/geomorphologyfinal.pdf

Lagory K.L., et al, 2015, A Strategy to Evaluate Peak Flow Recommendations for Sediment Transport and Habitat Maintenance in the Upper Colorado River basin, A technical Supplement to the Green River and Aspinall Study Plans

Muth, R. T., et al. 2000, Flow and Temperature Recommendations for Endangered Fishes in the Green River Downstream of Flaming Forge Dam. Project FG-53, Upper Colorado River Endangered Fish Recovery Program.

Rubin, D.M., and Topping, D.J., 2001, Quantifying the relative importance of flow regulation and grain-size regulation of suspended-sediment transport (α), and tracking changes in bed-sediment grain size (β): Water Resources Research, v. 37, p. 133-146, doi: 10.1029/2000WR900250.

Rubin, D.M., Topping, D.J., Schmidt, J.C., Hazel, J., Kaplinski, K. and Melis, T.S., 2002, Recent sediment studies refute Glen Canyon Dam hypothesis. EOS, Transactions, American Geophysical Union, 83, 273 & 277–278.

Rubin, D.M., and Topping, D.J., 2008, Correction to "Quantifying the relative importance of flow regulation and grain-size regulation of suspended-sediment transport α, and tracking changes in bed-sediment grain size β": Water Resources Research, v. 44, W09701, 5 p., doi: 10.1029/2008WR006819.

Thorne, P.D., and Campbell, S.C., 1992, Backscattering by a suspension of spheres, Journal of the Acoustical Society of America, v. 92, n. 2, p. 978-986.

Thorne, P.D., and Hanes, D.M., 2002, A review of acoustic measurements of small-scale sediment processes, Continental Shelf Research, v. 22, p. 603-632.

Topping, D.J., Rubin, D.M. and Vierra, L.E., Jr., 2000a, Colorado River sediment transport 1. Natural sediment supply limitation and the influence of Glen Canyon Dam.Water Resour. Res., 36, 515–542.

Topping, D.J., Rubin, D.M., Nelson, J.M., Kinzel, III, P.J., and Corson, I.C., 2000b, Colorado River sediment transport 2. Systematic bed-elevation and grain-size effects of sand supply limitation: Water Resources Research, v. 36, p. 543-570.

Topping, D.J., Melis, T.S., Rubin, D.M., and Wright, S.A., 2004, High-resolution monitoring of suspended-sediment concentration and grain size in the Colorado River in Grand Canyon using a laser-acoustic system, in Hu, C.,and Tan, Y, eds., Proceedings of the Ninth International Symposium on River Sedimentation, October 18-21, 2004, Yichang, China: People's Republic of China, Tsinghua University Press, p. 2507-2514.

Topping, D.J., Wright, S.A., Melis, T.S., and Rubin, D.M., 2006, High-resolution monitoring of suspended-sediment concentration and grain size in the Colorado River using laser-diffraction instruments and a three-frequency acoustic system: CD-ROM Proceedings of the 8th Federal Inter-Agency Sedimentation Conference, Reno, Nevada, April 2-6, 2006, ISBN 0-9779007-1-1.

Topping, D.J., Wright, S.A., Melis, T.S., and Rubin, D.M., 2007, High-resolution measurements of suspended sediment concentration and grain size in the Colorado River in Grand Canyon using a multi-frequency acoustic system: Proceedings of the Tenth International Symposium on River Sedimentation, August 1-4, 2007, Moscow, Russia, v. 3, p. 330-339. ISBN 978-5-89575-124-4, 978-5-89575-127-5.

Topping, D. J., and Wright, S.A., 2016, Long-term continuous acoustical suspended-sediment measurements in rivers - Theory, application, bias, and error, U.S. Geological Survey Professional Paper 1823, 98 p., http://dx.doi.org/10.3133/pp1823.

Topping, D.J., Wright, S.A., Griffiths, R.E., and Dean, D.J., 2016, Long-term continuous acoustical suspended-sediment measurements in rivers – Theory, evaluation, and results from 14 stations on five rivers, *in* Constantinescu, G., Garcia, M., and Hanes, D., eds., *River Flow 2016*, CD-ROM *Proceedings of the International Conference on Fluvial Hydraulics*, St. Louis, Missouri, USA, July 11-14, 2016, ISBN 978-1-138-2913-2 for set of Book and CD-ROM, ISBN 978-1-315-64447-9 for eBook PDF, p. 1510-1518 on CD-ROM.

U.S. Department of the Interior, 2011, Environmental Assessment: Development and Implementation of a Protocol for High-Flow Experimental Releases from Glen Canyon Dam, Arizona, 2011 through 2020, Bureau of Reclamation, Upper Colorado Region, Salt Lake City, 496 p.

Urick, R.J., 1948, The absorption of sound in suspension of irregular particles, Journal of the Acoustical Society of America, v. 20, n. 3, p. 283-289.

Wall, G.R., Nystrom, E.A., and Litten, S., 2006, Use of an ADCP to compute suspended-sediment discharge in the tidal Hudson River, New York, U.S. Geological Survey Scientific Investigations Report 2006-5055, 16 p.

Walling, D.E., 1977, Assessing the accuracy of suspended sediment rating curves for a small basin: Water Resources Research, v. 13, n. 3, p. 531-538, doi:10.1029/WR013i003p00531.

Wright, S.A., Topping, D.J., and Williams, C.A., 2010, Discriminating silt-and-clay from suspended-sand in rivers using side-looking acoustic profilers: Proceedings of the 2nd Joint Federal Interagency Conference, Las Vegas, Nevada, June 27-July 1, 2010.