# US Geological Survey Real-Time Monitoring of Suspended-Sediment Concentrations above and below the Willwood Diversion Dam on the Shoshone River near Powell, Wyoming

## SCOPE OF WORK

## August 1, 2017 through December 31, 2020

*Prepared by the U.S. Geological Survey*

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**Background**

The Willwood Diversion Dam on the Shoshone River is an important hydrologic structure that facilitates the delivery of water to local irrigators in Park and Big Horn Counties in Wyoming. The dam, located 13 miles northeast of Cody, has the capability to divert up to 400 cubic feet per second of water into the Willwood canal and services approximately 11,400 acres with 152 water users (Wyoming Water Development Commission, 1989; 2006). A consequence of impounding water behind the dam is the accumulation of sediment from upstream sources, which causes the gradual loss of reservoir storage capacity. According to the Willwood Irrigation District Master Plan, the removal of siltation upstream of the dam is needed to maintain the dam's reservoir capacity (Wyoming Water Development Commission, 2006). The Bureau of Reclamation (BOR), which owns the dam, and the Willwood Irrigation District that operates the dam have discussed various options with the Wyoming Department of Environmental Quality (WDEQ) and Wyoming Game and Fish Department (WGFD) to remedy the loss of reservoir storage capacity with no operational plan currently (2017) being implemented (Wyoming Department of Environmental Quality, 2010).

From the construction of the dam in 1924 to the present (2017), large discharges of sediment in storage behind the dam inadvertently have been released through the lower sluice gates into the main stem of the Shoshone River. In 2007, a malfunction in the dam caused a large mass of sediment to be released downstream, killing thousands of fish on the Shoshone River (Wyoming Department of Environmental Quality, 2010). Again, in October 2016, a large volume of sediment was released from behind the dam, causing catastrophic damage to aquatic habitat, resulting in large fish kills and triggering wide opposition from the public regarding dam operations.

Since 1982, the operation of the dam has been subject to an agreement executed by BOR, WDEQ, and the Willwood Irrigation District. A significant control required by the agreement is a limitation on the allowable turbidity increase of 10 nephelometric turbidity units (NTU) in the

Shoshone River from the upstream to the downstream side of the dam. The agreement stipulated that records be kept of the upstream turbidity, downstream turbidity, upstream water surface elevation, and gate openings during the time sluice gates are in operation. The Willwood Irrigation District Master Plan Level I Study recommended that turbidity test sites and permanent facilities should be investigated to help monitor the turbidity levels (Wyoming Water Development Commission, 2006).

Compliance with requirements of the operational agreement entails determining accurate suspended-sediment concentrations (SSCs) and loads to calculate fill rates for the reservoir behind Willwood Dam. Availability of SSC data would increase the ability of resource managers to manage and protect water resources in the Shoshone River. Currently (2017), monitoring data are lacking for SSCs on the Shoshone River upstream and downstream of Willwood Dam. Because this data does not currently exist, it is not possible to establish reliable estimates of SSCs needed to calculate fill rates for the reservoir behind Willwood dam or to monitor the variation in SSCs from the upstream to the downstream side of the dam. Recently (within the past decade), USGS scientists have demonstrated successful implementation of hydroacoustics and turbidimeters to accurately estimate continuous real-time SSCs (Topping and others, 2004; Wall and others, 2006; Gray and Gartner, 2009; Landers and others, 2016; Wood and Teasdale, 2013; Rasmussen and others, 2009). The use of hydroacoustics and turbidity as surrogates for SSCs is a timely, cost-effective approach to long-term monitoring of suspended sediment.

This project proposes to provide enhanced sediment monitoring by incorporating emerging technologies using surrogate methods to enable continuous real-time estimates of SSCs on the upstream and downstream sides of Willwood Dam. Potential stakeholders include the WDEQ, BOR, WGFD, Willwood Irrigation District, Park and Big Horn Counties, Wyoming Water Development Office (WWDO), Trout Unlimited, Wyoming Department of Agriculture, Natural Resources Conservation Service (NRCS), University of Wyoming, Bureau of Land Management (BLM), and the Wyoming State Engineers Office (WSEO). The U.S. Geological Survey (USGS) Wyoming-Montana Water Science Center (WY-MT WSC) proposes to begin a water-quality monitoring program to collect samples of SSC through this scope of work. Proposed activities include providing real-time continuous estimates of SSCs using SonTek 1500 SL (3G)® Acoustic Velocity Meter(s) (AVMs) and Forest Technology Systems DTS-12® turbidity sensor(s). These data will provide State and Federal agencies, the Willwood Irrigation District, natural resource managers, and other water-users important information regarding reservoir fill rates and will provide a measure of the spatial and temporal variability in SSCs above and below Willwood Dam. Real-time monitoring data will provide immediate notifications of inadvertent sediment spills associated with dam operations.

Proposed activities for this project include 3 tasks:

Task 1: Install suspended-sediment monitoring equipment above and below Willwood Dam.

Task 2: Collect streamflow and water-samples for SSC analyses to calibrate the monitoring equipment.
Task 3: Develop relations among streamflow, acoustic signals, turbidity, and sediment samples and provide real-time SSC and streamflow using the online USGS Real-Time Water Quality Data for the Nation portal (https://nrtwq.usgs.gov/).

**Objectives and Approach**

The objectives of this project are: 1) Provide real-time continuous SSCs and streamflow for the two sites using the online USGS Real-Time Water Quality Data for the Nation portal (https://nrtwq.usgs.gov/), and 2) Develop statistical model(s) using relations developed among acoustic signals, turbidity, streamflow, and SSC for one (1) site above and one (1) site below the Willwood Diversion Dam on the Shoshone River.

**Scope of Work**

**Task 1(FY 17):** Install monitoring equipment above and below Willwood Diversion Dam.
**Description:** Site reconnaissance will be accomplished to determine optimum placement of the AVM(s) and tubidimeter(s) in the stream channel. To do this, an acoustic Doppler current profiler (ADCP) will be deployed to determine variability of the acoustic backscatter in the stream cross-section at each site above and below the dam on the Shoshone River. The backscatter data will be evaluated to determine where the highest and most uniform backscatter values occur. For the permanent installations, an AVM will be deployed at each site below the water surface along the stream bank using a rail deployment system (fig. 1.).

Figure 1. Rail deployment system for Acoustic Velocity Meters (photo courtesy of Molly Wood).

In addition to the AVMs, turbidity sensors will be installed to evaluate the use of turbidity as a surrogate for SSCs. The turbidity sensor installations will augment the AVM installations by providing optically-based information relating to suspended sediment. The magnitude of turbidity, measured in formazin nephelometric units (FNUs), typically is proportional to SSC (Rasmussen and others, 2009). The turbidity data will serve as a contingency if there are periods when the AVMs experience problems in the Shoshone River environment.

At the top of the streambank, an enclosure containing a data transmitter (Sutron Satlink3®), voltage conditioner, solar panels, GOES transmitter and 12-volt battery(s) will be installed. The AVMs will be programmed to collect acoustic backscatter data in 5-10 cells. AVM and tubidimeter data will be transmitted to the USGS office in Helena, Montana. Installation of equipment is anticipated to be completed by September 30, 2017.

**Task 2 (FY 18 and 19):** Collect streamflow and water-samples of SSC to calibrate equipment.
**Description:** Approximately 72 water-samples (36 at each site plus 4 Quality Control (QC) samples at each site) will be analyzed for SSC above and below the Willwood Diversion Dam on the Shoshone River near Powell, Wyoming during the calibration period. Samples will be collected following USGS sampling procedures according to Edwards and Glysson (1999) and Davis (2005) between April 1, 2018 and September 30, 2019. Samples will be collected using isokinetic samplers and will be width/depth integrated. Two sets of samples will be collected at each site during each visit. Samples will be collected over a wide range of streamflow to encompass the rising and falling limbs of the streamflow hydrograph during the spring runoff period, summer precipitation events, and during base flow conditions. Sediment samples will be transported to the WY-MT WSC Sediment Laboratory in Helena, Montana for analysis. Laboratory analysis of each sediment sample will consist of analyses of SSC and the percentage of the material with particle sizes that are less than 0.062mm (fines size) following procedures according to Guy (1977). Sizes larger than 0.062mm in suspension will be assumed to be sand-sized particles. Once the results are received, the data will be quality controlled, formatted and inspected to determine if there are any outliers that require closer investigation. Once the data have been checked and approved, they will be made available to the public by accessing the USGS web site at http://waterdata.usgs.gov/wy/nwis.

**Task 3 (FY20):** Develop relations among streamflow, acoustic signals, turbidity, and sediment samples and provide real-time SSC and streamflow using the online USGS Real-Time Water Quality Data for the Nation portal (https://nrtwq.usgs.gov/).
**Description:** This will entail formatting the data for input into "R" language statistical software. Data will be quality controlled/checked prior to analysis. Standard statistical methods of simple and/or multiple linear regression analysis will be used to evaluate the relations among the parameters. Results from the analyses will be documented in table format. Graphs will be constructed to display the relations among parameters. Once the tables and graphs are completed, an analysis and interpretation of the data will be completed and documented, along with the raw data in a model archive following guidelines in Landers and others (2016) and Rasmussen and

others (2009). The model archive, including statistical summaries and model diagnostics will be reviewed by a minimum of 3 reviewers. Once the statistical models have been peer reviewed, an online web-based portal will be constructed for viewing real-time SSCs along with corresponding streamflow at each of 2 monitoring sites. An example of an online real-time water quality site for suspended sediment using acoustic signals as a surrogate can be viewed at https://nrtwq.usgs.gov/explore/dyplot?site_no=13342500&pcode=99409&period=31d_all&timestep=uv&modelhistory=.

**Quality Assurance**

All samples will be collected by trained USGS personnel according to established standard operating procedures. Additionally, a Sampling and Analysis Plan (SAP) describing how the sediment data are collected along with procedures for quality control measurements of field samples and laboratory analyses will be developed and provided to cooperating agencies to address the credible data law specified in the Wyoming Environmental Quality Act § 35-11-302 (b)(i) and (b)(ii). Information about the quality assurance to be applied during sample collection, processing, and analysis are described in the quality-assurance plans that are maintained in the USGS WY-MT WSC. Further information on methods and procedures are contained in applicable portions of a USGS series of publications called Techniques of Water-Resources Investigations (Guy, 1997; Edwards and Glyssen, 1999; Davis, 2005; Rasmussen and others, 2009; Landers and others, 2016) available at http://pubs.usgs.gov/twri/.

**Products**

An analysis and interpretation of the data will be completed and documented in a model archive (archive will include the raw data set) following guidelines in Landers and others (2016) and Rasmussen and others (2009). The model archive, including statistical summaries and model diagnostics will be reviewed by a minimum of 3 reviewers. Once the data have been checked and approved, they will be available to the public by accessing the USGS web site at http://waterdata.usgs.gov/wy/nwis and real-time SSC and streamflow will be available at the USGS Real-Time Water Quality Data for the Nation portal (https://nrtwq.usgs.gov/).

**Budget:** The USGS will provide equipment for one complete monitoring site at no cost to cooperating agencies and a partial set of equipment for the second monitoring site (equipment value estimated to be >$30K). The USGS will contribute 40 percent of the funding (subject to availability of funding) towards the total cost of the project. The cost of annual Operations and Maintenance (O&M) after the initial calibration period is estimated to be approximately $37K beginning in 2021, and includes equipment operations, maintenance, streamflow measurements and cross-section measurements to maintain the index-velocity relation, and maintaining the rating curve between hydroacoustic signals, turbidity, and suspended-sediment concentrations. The operation and maintenance costs beginning in FY2021 are not included in the cost of the initial calibration period of the project.

Table 1. Budget categories

| Category | Cost (FY 17) Equipment Installations | Cost (FY 18) Data Collection | Cost (FY 19) Data Collection | Cost (FY 20) Model Development | Cost Post Calibration Period (Begins in 2021) Annual O&M |
|---|---|---|---|---|---|
| Salary | $11,876 | $20,386 | $24,892 | $15,743 | $7,443 |
| Travel (Meals &Lodging) | $3,062 | $4,108 | $4,149 | $1,692 | $1,482 |
| Vehicles/Boats ($0.56/mile) | $525 | $2,893 | $2,919 | $597 | $608 |
| Equipment and Supplies | $15,907 | $3,654 | $4,885 | $4,862 | $4,827 |
| Laboratory Analytical | -- | $3,857 | $3,934 | $1,853 | $1,890 |
| Streamgage Operations | $4,079 | $24,384 | $14,462 | $14,831 | $15,208 |
| Indirect Costs | $13,712 | $14,600 | $17,467 | $10,238 | $5,844 |
| Total | $49,161 | $73,882 | $72,708 | $49,816 | $37,302 |
| USGS Contribution | $19,664 | $29,553 | $29,083 | $19,926 | $14,921 |
| Cooperating Agencies Contribution | $29,497 | $44,329 | $43,625 | $29,890 | $22,381 |
| Total Cost for FY | $49,161 | $73,882 | $72,708 | $49,816 | $37,302 |
| Total Cost of Project | | | | $245,567 | $37,302 |

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