BUREAU OF RECLAMATION

Guidelines for Developing Reservoir Sedimentation Monitoring Plans

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Disclaimer

Cover Photo: Paonia Reservoir, Colorado. Sedimentation has accumulated around the 70-foot-high intake tower. (Reclamation).

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Acronyms and Abbreviations

ft^2	square feet
ft^3/s	cubic feet per second
GIS	Geographic Information System
GPS	Global Positioning System
hr/day	hours per day
IFSAR	Interferometric Synthetic Aperture Radar
LiDAR	Light Detection and Ranging
mi^2	square miles
Mg	Mega-grams (1,000,000 grams = 1 metric tonne)
mm	millimeters
NAD 1983	North American Datum, established 1983
NAVD 1988	North American Vertical Datum, established 1988
NED	National Elevation Dataset
NRCS	Natural Resources Conservation Service
NGVD 1929	National Geodetic Vertical Datum, established 1929
PFR	Periodic Facility Reviews
Reclamation	Bureau of Reclamation
RISE	Reclamation Information Sharing Environment
RO&M	Review of Operation and Maintenance
RSI	Reservoir Sedimentation Information
RTK	real-time kinematic
s/hr	seconds per hour
SGMC	State Geologic Map Compilation
TSC	Technical Service Center
UTM	Universal Transverse Mercator
USGS	U.S. Geological Survey
USSD	United States Society on Dams
WGS	World Geodetic System
yd^3	cubic yards

Glossary

Bathymetric survey: Survey of the reservoir bottom and valley walls or side slopes that are below the water surface

Delta foreset slope: Steep slope of the sediment delta front, which is usually submerged and at the downstream end of the delta.

Delta pivot point: Location at the downstream end of the sediment delta surface where there is a distinct slope transition between the flatter upstream topset slope and the steeper downstream foreset slope.

Delta topset slope: Longitudinal slope of the delta surface upstream from the pivot point.

First reservoir sedimentation survey: This refers to the first reservoir survey after the reservoir began operations.

Original reservoir survey: This refers to the topographic survey of the reservoir valley (often before the dam was constructed) prior to the original filling of the reservoir.

Reservoir pool elevation: Reservoir water surface elevation.

Topographic survey: Above water survey of the reservoir overbanks, valley walls or side slopes, delta, and bottom.

Contents

Executive Summary

Over time, sedimentation is reducing the project benefits of the Bureau of Reclamation's (Reclamation) water-storage reservoirs through the continual loss of storage capacity and the eventual burial of dam and reservoir facilities. The Reservoir Sedimentation Monitoring Program is established as an important best management practice at Reclamation's water-storage reservoirs to periodically update water storage capacity data and measure sedimentation rates.

A sedimentation monitoring plan for each Reclamation water storage reservoir will enable Reclamation to systematically schedule and conduct periodic surveys to measure current storage capacity and the rates of sedimentation. Periodic sedimentation monitoring will provide the following information:

- Sedimentation volume and spatial distribution within the water storage reservoir and along the primary upstream river channels
- Current reservoir surface areas and storage capacities for the full range of water storage reservoir elevations based on the sediment volumes
- Estimates of when future sedimentation, in the absence of sediment management, would impact dam and water storage reservoir facilities (this requires at least two reservoir surveys with consistent methods)
- A foundation for determining needs and prioritizing sedimentation management actions at water storage reservoir facilities

This guideline covers the following topics:

- Why reservoir sedimentation is an issue and why monitoring is critical for continued operations (See *Section 1. Sedimentation Monitoring*)
- How to think through and develop a comprehensive and effective sediment monitoring plan (See *Section 2. Reservoir Survey Planning)*
- How to implement a reservoir survey (*Section 3. Reservoir Survey Implementation, Section 4. Reservoir Sediment Sampling)*
- When and how to recommend sediment load monitoring (*Section 5. Sediment Load Monitoring)*
- How to report and manage data (*Section 6. Data Management)* and maintain a sediment monitoring plan (*Section 7. Monitoring Plan Updates*)

1. Introduction

Periodic reservoir sedimentation monitoring is needed for all Bureau of Reclamation (Reclamation) water storage reservoirs to determine the current surface area and storage capacity tables for reservoir operations and to help estimate when dam and reservoir facilities may be impacted by sedimentation. Reservoir sedimentation monitoring plans are not necessary for small dams (e.g., diversion dams) where the specific water storage volume behind the dam is not important.

Sedimentation monitoring typically includes bathymetric (below water) surveys and topographic (above water) surveys of the reservoir bottom and valley side slopes. Monitoring may also include collecting sediment samples and may include the measurement of sediment loads into and out of the reservoir.

1.1. Sedimentation Monitoring

1.1.1. Sedimentation Impacts to Storage Capacity and Infrastructure

All rivers transport sediment (clay, silt, sand, gravel, and cobble) in widely varying amounts and reservoirs tend to trap this sediment (Strand and Pemberton, 1982; Morris and Fan, 1998; Randle et al., 2006; Annandale, 2013; and Randle et al., 2019). The coarsest sediment particles (sand, gravel, and cobble) deposit first and form a delta at the upstream end of the reservoir pool (Figure 1). Finer particles typically deposit farther downstream along the reservoir bottom between the delta and dam. Over time, deltas increase in size and progress downstream towards the dam as well as upstream along the inflowing river channel. Fine sedimentation between the dam and delta increases in thickness over time. Sedimentation affects all elevations of the reservoir and the upstream river channel.

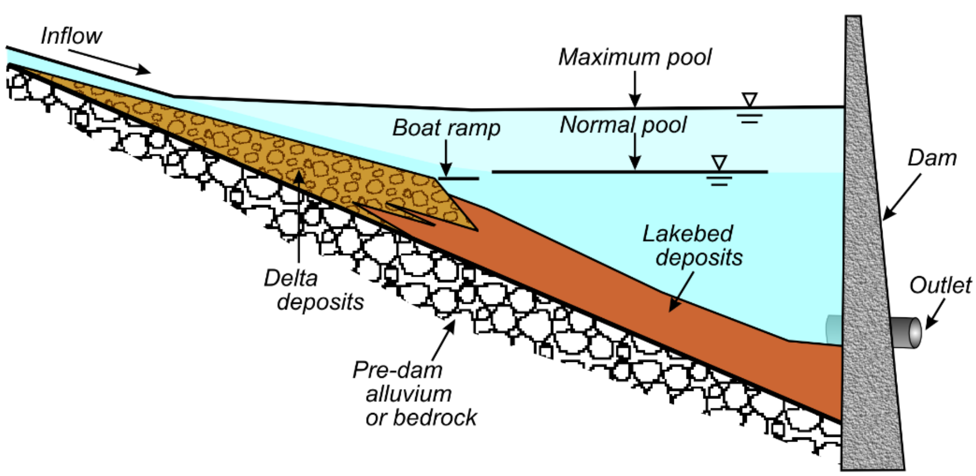

Figure 1. Reservoir sedimentation typically consists of an upstream delta composed of coarse sediment and finer sediment particles along the reservoir bottom or lakebed between the delta and dam.

Dams were designed so that intakes for the dam's outlet were above the sedimentation level over the reservoir sediment design life (Reclamation, 1987 and Reclamation, 2016). The total volume of reservoir sedimentation and its spatial distribution were estimated over the sediment design life (Figure 2). Once the sedimentation levels reach the intakes, these intakes can become plugged by woody debris and sediment. In addition, reservoir water intakes and boat marinas and boat ramps eventually will be buried by sedimentation. The surface area for boat recreation will also be reduced over time. These impacts will occur long before the reservoir has filled with sediment. For example, the outlet works intake at Paonia Dam near Paonia, Colorado became plugged after only 20 to 25 percent of the reservoir had filled with sediment (Collins and Kimbrel, 2015).

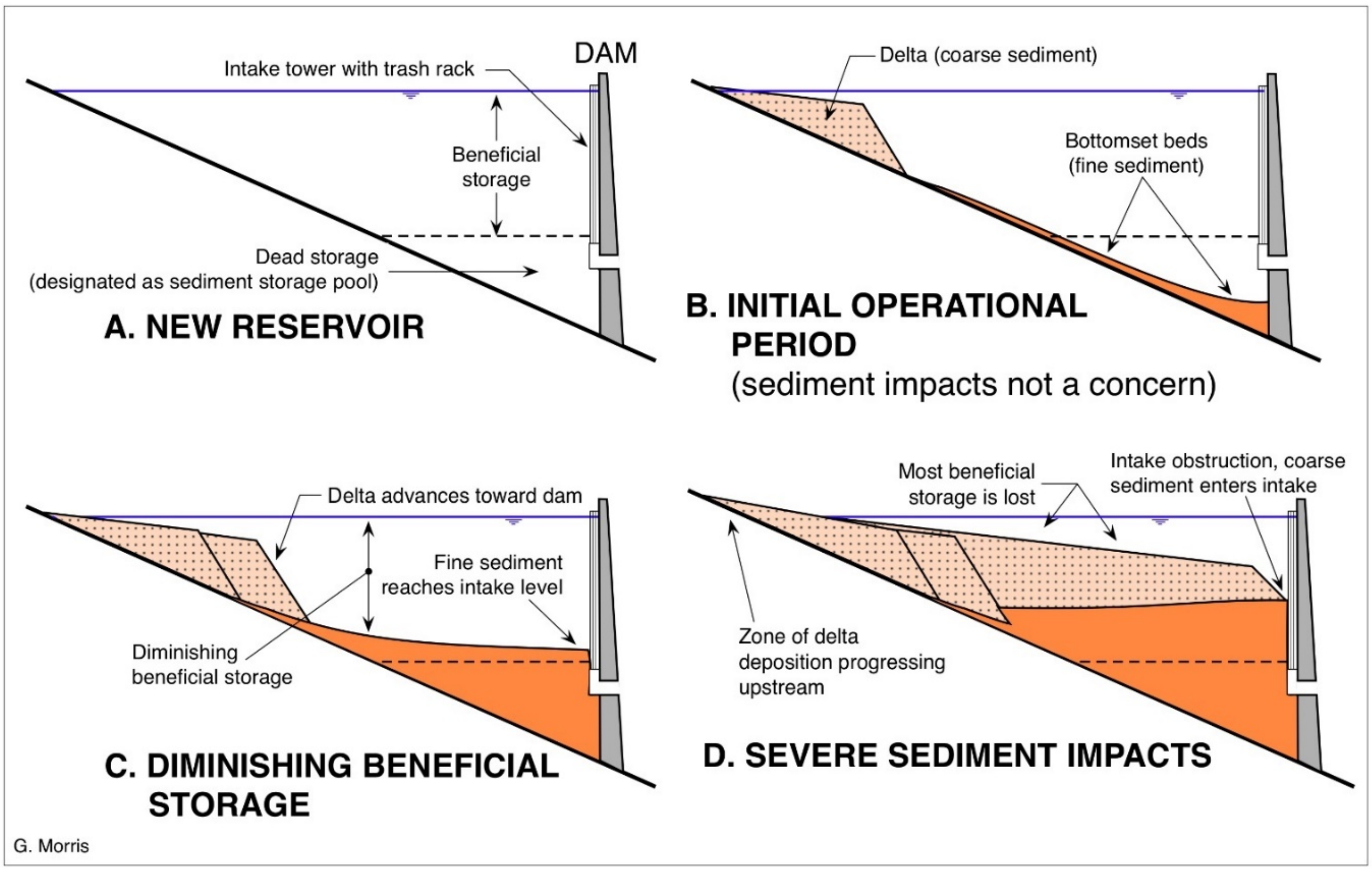

Figure 2. Process of reservoir sedimentation. A) new reservoir showing zone of beneficial storage and the designated sediment storage pool; B) initial operational period with minimal sediment impacts, showing the deposition pattern for both coarse and fine sediments; C) end of sediment design life with significant sediment encroachment into the beneficial pool with substantial growth of the delta; and D) severe sediment impacts including loss of beneficial storage, intake obstruction and upstream progression of the delta (Randle et al., 2019, used by permission, all rights reserved).

1.1.2. Reservoirs Are Nearing the End of their Sediment Design Life

Reclamation water storage dams, and most water storage dams throughout the world, were planned with a sediment design life, typically 50 or 100 years. Diversion dams were typically designed to pass sediment downstream. Nearly all Reclamation water storage dams were planned with a 100-year sediment design life.

As of 2021, Reclamation's inventory of dams and dikes included 56 diversion dams and 263 water storage reservoirs (impounded by 426 dams and dikes). As of 2020, 35 Reclamation water storage reservoirs were already at least 100 years old. By 2030, 54 reservoirs will be at least 100 years old and, by 2040, 87 reservoirs will be at least 100 years old. For some reservoirs, the actual sedimentation rate has been slower than originally planned, while for other reservoirs, the actual sedimentation rate has been faster than originally planned. Monitoring is needed to document the actual sedimentation rate.

1.1.3. Reservoir Sedimentation Surveys are Critical to Reclamation's Operations

Reservoir sedimentation surveys are needed to periodically measure and document the reservoir's decreasing surface area and storage capacity and the remaining time before dam and reservoir facilities are impacted by sedimentation.

Daily reservoir operations depend on accurate calculations of surface area and storage capacity for the full range of reservoir elevations. The reservoir water surface elevations are continuously monitored with stage recorders. The surface area and storage capacity tables are then used to look up the current reservoir surface area and storage volume on a continual basis. Reservoir surface area can be used to estimate evaporation. Reservoir inflow is often computed from the changes in reservoir storage volume, water releases from the dam, and estimates of reservoir evaporation. As sedimentation accumulates over time, reservoir surveys are needed to update these surface area and storage capacity tables for accurate inflow computations.

Accurate storage capacity is also needed for seasonal operations. Stakeholders need to have accurate estimates of the volume of water available for municipal, irrigation, environmental purposes. Operators also need to know the volume of space available for incoming flows, especially during periods of high inflow. During times of drought, is it equally important to know the volume of water available. Current knowledge of storage capacity is also important for seasonal planning of target water surface elevations that affect environmental and recreation conditions.

1.1.4. Sediment Management Options Are Available

Knowing the extent of sedimentation issues within a reservoir is the first step in determining the need for action to maintain storage capacity and infrastructure. Sedimentation monitoring provides a foundation for potential future sediment management actions. These concepts are introduced in a 6-minute-long Reclamation video at: https://www.youtube.com/watch?v=HQ-Y8ClEpgw&feature=youtu.be.

General strategies for managing reservoir sedimentation are:

- Prevent sediment erosion from the upstream watershed and prevent eroded sediment from reaching the reservoir
- Bypass sediment through or around the reservoir
- Removing sedimentation from the reservoir
- Adaptive strategies

The National Reservoir Sedimentation and Sustainability Team has produced a white paper and recorded a series of webinars on sedimentation monitoring and management, available at: https://www.sedhyd.org/reservoir-sedimentation/.

Several references provide much more information about sustainable management of reservoir sedimentation (Morris and Fan, 1998; Graf et al., 2010; Annandale, 2013; Kondolf et al., 2014; Morris, 2015; Sumi et al., 2015; Annandale et al., 2016; Reclamation, 2016; Randle et al., 2017; Sumi et al., 2017; Randle et al., 2018, and Randle et al., 2019).

1.2. Sedimentation Monitoring Plans

The reservoir sedimentation monitoring plans will be used by region and area offices to schedule and budget periodic reservoir surveys. The monitoring plans will also be used by reservoir sedimentation survey teams as they implement the monitoring plans. These survey teams may consist of engineers, scientists, surveyors, and technicians.

1.3. Monitoring Goals and Objectives

Monitoring goals and objectives for a specific reservoir or system of reservoirs may include:

- Periodic updating of reservoir surface area and storage capacity tables
- Measuring reservoir sedimentation rates
- Possible compliance with a water compact
- Estimating when (without intervention) sedimentation would impact dam and reservoir facilities
- Providing data for the eventual planning and design of sustainable sediment management practices

In your plan, list any other monitoring goals and objectives that may be unique to the reservoir or system of reservoirs.

1.4. Monitoring Plan Development

Use the monitoring plan template to develop a sediment monitoring plan. A separate monitoring plan could be written for each reservoir or a monitoring plan could be prepared for multiple reservoirs. However, the details for each reservoir should be provided in a plan for multiple reservoirs. Each reservoir sedimentation monitoring plan should address:

(1) Goals and objectives of the reservoir sedimentation monitoring plan.

(2) Brief description of the reservoir's beneficial uses and storage allocations, brief description of the dam and reservoir facilities, and summary of historical reservoir operations.

- This brief description would include the dam and reservoir location, the type of dam (e.g., earth embankment, concrete gravity, concrete arch), the entity that operates the dam, and the purpose of the reservoir. This information will help orient sedimentation survey teams who will be implementing the monitoring plan, including the preparation of sedimentation survey reports.
- The plan should also describe any special events that should be measured and documented by the sedimentation monitoring, including large inflowing sediment yields from recent floods, landslides, or wildfires, recent reservoir sedimentation impacts on infrastructure or property, or sediment management actions.

(3) General description of reservoir survey methods, including the types and frequency of surveys, vertical and horizontal datums, spatial extent of surveys, and analysis methods (*Section 2. Reservoir Survey Planning*).

(4) Description of methods to compute the reservoir surface areas and storage capacities for the range of reservoir elevations and the sedimentation volumes (*Section 3. Reservoir Survey Implementation*).

(5) Reservoir sediment sampling strategy (*Section 4. Reservoir Sediment Sampling*).

(6) Sediment load monitoring strategy, if any (*Section 5. Sediment Load Monitoring*).

(7) Reporting practices to document reservoir survey methods, results, and evaluation of temporal trends (*Section 6. Data Management*).

- Data results from the reservoir sediment surveys will be used to update the surface area and storage capacity tables for reservoir operations. These tables may also be used to update reservoir capacity allocations.
- Survey reports and data will be included in the Reclamation Information Sharing Environment (RISE) and the National Reservoir Sedimentation Information (RSI) database (*Section 6. Data Management*).

2. Reservoir Survey Planning

Every reservoir will have unique circumstances that need to be considered when determining the most effective methods and strategies to measure the reservoir storage capacity and survey important facilities and features along the dam and reservoir. The information suggested in this guideline will be used for the planning of the reservoir survey or in the reports that document the actual surveys. For some reservoirs, the monitoring plan information may already be known. For other reservoirs, some of the information will require additional investigation, which can be deferred until the first sedimentation survey (first survey since original reservoir filling).

Developing the monitoring plan should not be delayed for months or years while trying to determine all the details. The plan should be developed using the best available information and then updated after subsequent reservoir surveys and other monitoring activities.

2.1. Watershed Characteristics Influencing Sediment Yield

Reservoir sedimentation survey reports typically include a “Watershed Description” section to provide context for the sediment yield produced by the upstream watershed. The watershed description will have to be complied eventually, either at the time the monitoring plan is written or later when the sedimentation survey report is written. Including the watershed description in the monitoring plan is optional. However, providing a watershed description in the monitoring plan helps provide the proper context to the Sedimentation

Prioritizing Multiple Reservoir Surveys

List water storage reservoirs for each region and area office. These are the reservoirs that need to be surveyed. If Reclamation surveys each of its water storage reservoirs at an average frequency of once every ten to twenty years, one to two dozen Reclamation water-storage reservoirs would need to be surveyed every year. Prioritize and schedule these reservoir surveys depending on available budgets and the availability of crews, equipment, and contractors to conduct the surveys by considering these and other factors for each reservoir:

- Any known reservoir sedimentation issues
- Recommended frequency of reservoir survey
- Years since the last reservoir survey
- Qualitative estimate (e.g., scale from 1 to 5) for the economic value of the reservoir storage capacity

The Technical Service Center maintains a spreadsheet listing of water storage reservoirs, their age, and the year of the previous reservoir survey. For Reclamation users, this spreadsheet may be used to help prioritize and schedule reservoir surveys: (https://intra.usbr.gov/tsc/techreferences/reservoir.html).

Team and their crews performing the monitoring. This context can then be used in subsequent survey and monitoring reports.

Briefly describe the watershed characteristics (sediment contributing drainage area, geology, soils, vegetation, land use, climate and runoff, and dam and reservoir operations) to give the reader an idea of how much sediment is produced, the seasonal timing, and how the reservoir responds. Provide references for any values.

- **Drainage Area.** Report the total drainage area and the sediment contributing portion of that drainage area. Present a map of the dam and upstream watershed. The sediment contributing-drainage area is determined by subtracting the drainage area from any upstream reservoirs that trap all, or nearly all, of the inflowing sediment from the total drainage area. The drainage area and stream flow statistics at the dam can be estimated using the U.S. Geological Survey (USGS) streamflow stats tool at https://streamstats.usgs.gov/ss/.
- **Geology.** Briefly describe the geology of the watershed, focusing on the sediment-contributing drainage area. Sediment is derived from weathered rock—some rock types are more susceptible to erosion while other rock types are more erosion resistant. The State Geologic Map Compilation (SGMC) database at: https://www.sciencebase.gov/catalog/item/5888bf4fe4b05ccb964bab9d provides an overview of general geology. Use these maps to summarize the most common geologic types in the watershed. Consider including a pie chart showing the drainage area proportions comprised by each geology type.
- **Soils, Vegetation, and Land Use**. Briefly describe the soils, vegetation, and land use characteristics of the watershed with a focus on the sediment-contributing drainage area. Qualitatively describe the range of vegetation types and land use covers in the watershed.

  Silt-sized sediments tend to be more erosive than cohesive clays or coarser sands and gravel. Watershed sediment yields decrease with increases in vegetation density. Consider including geology and soils maps. For soils, use the Natural Resources Conservation Service (NRCS) Soil Data Viewer, which is an ArcGIS extension at:

  - https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/survey/geo/?cid=nrcs142p2_053620
  - https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053621

  This web-based viewer allows users to display various soil properties as a thematic map. The viewer contains fifty soil attributes that identify the major component of the soils for a given area. Attributes include: physical properties, land classification, and soil erosion factors, among others. Soils data are typically mapped at an approximate 1:24000 scale. For soils, summarize the most common soil types that comprise a large portion of the watershed. Consider including a pie chart showing the drainage area proportions for each soil type.

- **Climate and Runoff.** Qualitatively describe the watershed climate and use a USGS stream gage or stream stats to describe the runoff characteristics. Rainfall produces greater sediment erosion from the upstream watershed than snowmelt. Sediment erosion increases with rainfall intensity.
    - The mean annual runoff volume (acre-ft/year) = (average annual flow rate from all inflow gages, ft^3/s[1]) × (3600 s/hr) × (24 hr/day) × (365.25 days/year) × (acre/43,560 ft^2)
    - The mean annual runoff depth, inches = [(mean annual runoff volume, acre-ft/year) / (gaged drainage area, mi^2)] × (1 mi^2/ 640 acres) × (12 in/ft)
    - Present plots of historic reservoir inflow for the gaged streams. Plots of daily mean discharge may be too busy. Annual flow volumes and annual peak discharge may be easier to comprehend
    - Describe any floods, wildfires, upstream dam construction, upstream dam removal, or significant land use changes that would have affected sediment yields.
- **Dam Operations and Reservoir Characteristics.** Describe the dam and range of reservoir operations. The range of reservoir water surface elevations (seasonal and annual) and the rate of fluctuations will influence the spatial distribution of sedimentation. Lower reservoir water surface elevations allow coarse delta sediment to advance farther downstream toward the dam. See Reclamation's project overview page for a particular dam on Reclamation's internet site (https://www.usbr.gov/) by selecting the dam from the gold buttons on the right-hand side.
    - Describe the historic range of reservoir levels by including a plot of the reservoir elevations versus time.
    - Describe any previous reservoir sediment management activities, any changes to dam or reservoir operations, dam repair requiring reservoir drawdown, or changes to dam height that would affect sedimentation volume or its spatial distribution.
    - Explicitly state if past reservoir sediment management activities are known or if they are not known. If they are known, describe the types of activities, when they occurred, and the source of information, which may be oral history.
    - Provide a full reference in the reference section. Cite personal communications as (Name, Personal Communication, Date).
- **Previous Reservoir Sediment Management.** For reservoirs with sediment management activities, the monitoring plan should recommend a greater density of survey data in areas affected by the management activities.

[1] ft^3/s= cubic feet per second, s/hr = seconds per hour, hr/day= hours per day, ft^2 = square feet, mi^2 = square miles.

2.2. Previous Reservoir Surveys

Knowing the original (predam) reservoir survey and past sedimentation surveys is important for planning the next reservoir survey. Estimates of sedimentation volume and spatial extent are based on the subtraction of recent and past digital terrain surfaces if these digital surfaces exist. Otherwise, the sedimentation volume can be estimated by subtraction of recent and past reservoir storage capacity curves. These methods work well when the digital surfaces or storage capacities are based on surveys performed using similar methods. Modern reservoir surveys using multi-beam depth sounders and Light Detection and Ranging (LiDAR) provide much denser data sets than older surveys that used single beam depth sounders, or plane tables (*Section 3. Reservoir Survey Implementation*). Before the 1990s, reservoir surveys tended to focus on pre-established range lines, or cross sections, spaced longitudinally about the same distance as the reservoir width.

Digital surfaces from modern surveys can be produced using the entire data set. However, a subset of the data could be used to replicate the method of an older survey (e.g., range line survey). Data from many of the predam reservoir surveys were used to develop contour maps with contour intervals of 10 feet or greater. The data from modern surveys can be used to produce accurate contour maps at intervals closer to 1 or 2 feet. Even without any reservoir sedimentation, the elevation difference in the surfaces from these two types of maps could be several feet due to the differences in contour resolution and accuracy. Therefore, the elevation difference in maps, due to different surfaces, sometimes can be greater than the elevation difference due to sedimentation.

The monitoring plan should note the year of the predam reservoir survey and qualitatively describe the available survey maps and the survey methodology if known. When the predam survey methodology is not known, the general methods used during the time of survey can be assumed as the most likely methodology:

- Plane table surveys before the 1950s
- Photogrammetry surveys after the 1950s
- LiDAR surveys after 2000s

The monitoring plan should include a table listing any past reservoir sedimentation surveys (Table 1). Most all of Reclamation's past sedimentation surveys are on the TSC web page at https://www.usbr.gov/tsc/techreferences/reservoir.html. Where applicable, include the web links for individual reservoir survey reports.

Table 1. Previous Reservoir Surveys

Survey Year	**Survey Type** *(full, partial, or reconnaissance)*	**Survey Method** *(range line or surface mapping)*	**Depth Sounder** *(single beam or multi-beam)*	**Above and Below Water Survey Methods** *(type & year)*	**Survey Notes** *(monuments, datum, spatial extent)*

2.3. Survey Coverage

The monitoring plan should consider the types of reservoir surveys (*Section 3.1. Survey Coverage*):

- Full survey with data coverage for the entire reservoir and upstream deltas.
- Partial survey with data coverage for selected areas of the reservoir.
- Reconnaissance survey with data coverage to create a longitudinal profile of the reservoir.

A full reservoir survey is needed at a frequency that is based on the sedimentation rate and at least once every 20 years. A partial reservoir survey may be needed between full surveys when there is a special interest in the bathymetry or topography related to the dam or reservoir facilities or selected areas of the reservoir. Reconnaissance surveys may be conducted in between full reservoir surveys to measure the longitudinal sedimentation profile. The data from reconnaissance surveys may be used to prioritize surveys among reservoirs that have not been surveyed since the original filling.

2.3.1. Survey Near Dam and Reservoir Facilities

Unless otherwise managed, sedimentation will eventually bury structures or facilities (e.g., dam outlet works, sluiceways, penstock intakes, spillway inlets, reservoir water intakes, boat marinas, boat ramps, and recreation areas). A greater density of survey data is likely needed in the vicinity of these dam and reservoir facilities. Thus, the sedimentation monitoring plan should list the important dam and reservoir facilities where a greater density of survey data is warranted.

2.3.2. Survey Control and Monuments

If known, the monitoring plan should identify the locations and elevations (in the local project datum) of all known permanent survey monuments (e.g., brass caps) at or near the dam or along the reservoir shoreline. A sufficient number of these monuments should be surveyed in the field to properly determine the difference between the modern vertical datum and the local project datum.

If known, the World Geodetic System (WGS) coordinates of these survey monuments (latitude, longitude, and ellipsoid height) should be listed along with any state plane or Universal Transverse Mercator (UTM) coordinates (e.g., northing, easting, and ground elevation) and any corresponding local project datum coordinates.

2.3.3. Vertical Datum

The monitoring plans should describe the vertical datum that the final survey results should be reported in. Some dams and reservoirs use the National Geodetic Vertical Datum, established 1929 (NGVD 1929), but many dams and reservoirs use a local project datum. Global Positioning System (GPS) surveys are conducted using latitude, longitude, and ellipsoid height and these coordinates are converted to modern horizontal and vertical datums such as state plane or UTM coordinates (e.g., North American Datum, established 1983 [NAD 1983] and North American Vertical Datum, established 1988 [NAVD 1988]). However, the final elevation results for reservoir surveys are typically reported in the local project datum. The local project datum is used for final reporting so that elevations are consistent with design drawings, standard operating procedures, and reservoir water surface elevations.

Reservoir survey elevation results may be reported in local project datums, but the field survey should be conducted using a modern datum (e.g., state plane and UTM). Include a conversion from the local project datum to the modern datum (e.g., Reclamation Project Vertical Datum is so many feet higher or lower than the NAVD 1988).

2.3.4. Delta Survey

Reservoir deltas need to be surveyed with enough detail to document the sedimentation volume and estimate the extent of upstream effects on ground water and flood stage. Not every reservoir has a delta, but deltas are often formed at the upstream end by the deposition of sand and gravel. When deltas exist, reservoir sedimentation extends upstream along inflowing stream channels that transport sand and gravel (Figure 3). Upstream from the reservoir pool, deltas increase groundwater levels and flood stage. In some cases, these increases may only occur in remote canyons. In other cases, these increases may impact upstream properties, infrastructure, and communities.

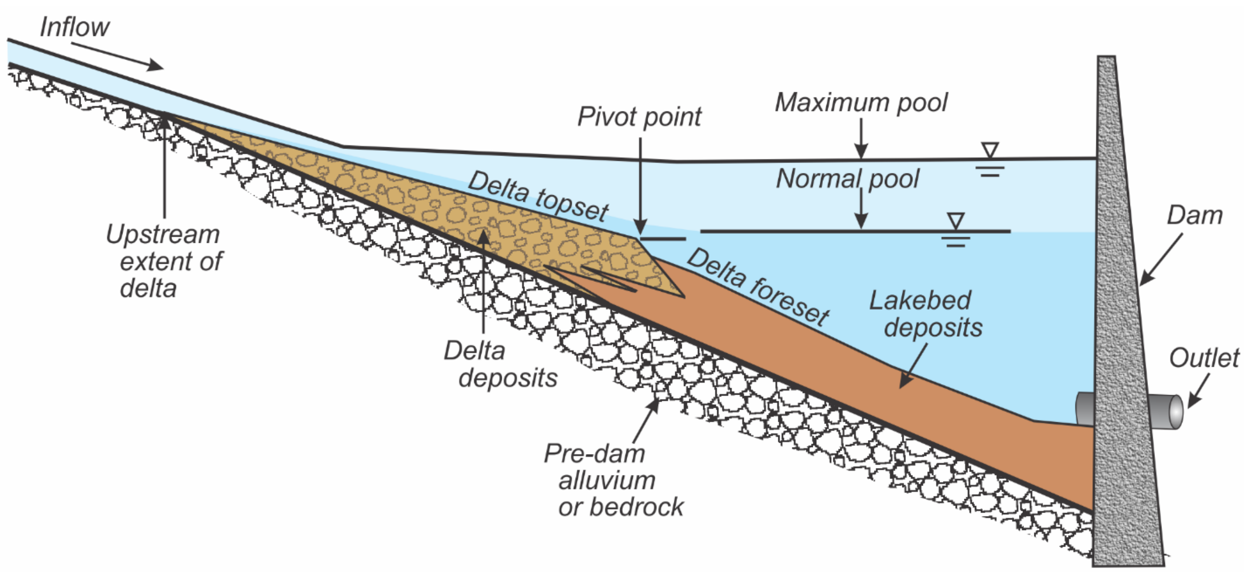

Figure 3. Longitudinal profile illustration of the reservoir delta and lakebed sediments showing the upstream extent of the sediment.

The longitudinal slope of the delta surface (topset) extends upstream from the pivot point at roughly half the slope of the upstream river channel (Strand and Pemberton, 1982 and Randle et al., 2006) (Figure 3). The delta pivot point is where topset of the delta surface transitions to the steeper foreset slope of the delta front. The elevation of the pivot point tends to match the median or normal reservoir pool elevation.

The length of the delta can be estimated from the longitudinal slopes of the upstream river channel and delta topset and the maximum delta thickness at the pivot point.

$$L = \frac{\Delta Z}{(S_R - S_D)}$$

$$S_D = a\, S_R$$

Where:

L = length of delta
ΔZ = maximum sediment thickness of delta at the pivot point
S_R = longitudinal river channel slope
S_D = longitudinal delta topset surface slope
a = ratio of delta topset surface slope (S_D) to upstream river channel slope (S_R)

For example, a delta with a maximum thickness of 40 feet and longitudinal slopes of 0.005 for the river channel and 0.0015 for the delta surface would have a total length of 11,400 feet or 2.2 miles. This and other examples are provided in Table 2.

Table 2. Table of Delta Lengths for Example Cases

S_R	0.0001	0.0010	0.0050	0.0100
a	0.3	0.3	0.3	0.3
ΔZ (feet)	**Delta Lengths, L (miles)**			
20	54	5	1.1	0.5
40	108	11	2.2	1.1
60	162	16	3.2	1.6
80	216	22	4.3	2.2
100	271	27	5.4	2.7

2.4. Coordination

Bathymetric reservoir surveys need to be coordinated with LiDAR or photogrammetry surveys, reservoir operations, dam operators, and land managers. Ideally, topographic (above-water) surveys will be conducted when the reservoir water surface is seasonally low, and the bathymetric (below-water) surveys will be conducted when the reservoir is seasonally high. This will provide necessary overlap between the above-water and below-water data sets.

The monitoring plan should identify the seasons when reservoir water surface elevations are normally highest and lowest. The plan should also identify who the sedimentation survey team should coordinate with at the dam or project office. This will be especially important when a boat needs to be navigated between the dam and log boom. The monitoring plan should identify boat ramps, boat docks, and access routes, that can be used during monitoring activities.

The sedimentation survey team will need access to reservoir boat ramps, available boat docks, overlook sites to set up GPS base stations on, and survey monuments on the dam, abutments, and along the reservoir shoreline. The monitoring plan should identify areas along the reservoir shoreline and dam that will be accessible to the sedimentation survey team or identify any areas where access is not permitted due to concerns for safety, security, land ownership, cultural, or sensitive species. The monitoring plan should provide any instructions for accessing areas with locked gates or contacts for crossing private property. The plan should also document any required permits and coordination with other agencies.

3. Reservoir Survey Implementation

Reservoir survey technology and practices greatly advanced and will continue to advance in the future. These topics are addressed in this chapter of the guidelines:

- Different types of survey coverage (full, partial, or reconnaissance) can be scheduled, depending on the need and frequency (*Section 3.1)*.
- Different survey methods are employed above and below the reservoir water surface (*Section 3.2)*.
- The recommended frequency of surveys is based on the sedimentation rate, but a minimum of once every 20 years (*Section 3.3).*
- The cost of a bathymetric survey is a function of the reservoir water surface area and perimeter, depth, and type of depth sounder (*Section 3.4)*.
- Remaining reservoir storage capacity is determined from a digital terrain surface produced from the reservoir survey data (*Section 3.5)*.

Fortunately, the cost of topographic and bathymetric surveys has been decreasing over time while the quantity and quality of data has increased. Older surveys were more labor intensive and only measured data along widely spaced range lines or cross-sections of the reservoir identified by permanent field monuments. Modern methods employ topographic (red) LiDAR from aircraft to survey the ground (above water) surface. Bathymetric, or green LiDAR has been used to survey the underwater surface at some reservoir surveys, but the water must be clear and shallow to obtain accurate results. There can also be accuracy problems for thermally stratified reservoirs, which are common at Reclamation reservoirs. At least some depth sounding measurements from a boat are recommended to verify LiDAR results. Modern bathymetric surveys require just two people on a survey boat using GPS survey-grade instruments for positioning and “multi-beam” depth sounders. Together, these instruments measure the reservoir bathymetry over a wide width as the boat travels along the reservoir.

Continued technological advancements in survey methods can be expected in the future. However, some consistency in reservoir survey and analysis methods is needed at a given reservoir to accurately measure how storage capacity and sedimentation rates are changing over time. Therefore, the monitoring plan should describe the general survey methods to be employed, the data analysis methods, and how to incorporate future technological advancements (e.g., analysis with both old and new methods).

3.1. Survey Coverage

A combination of reconnaissance, partial, and full reservoir surveys can provide a cost-effective means of sedimentation monitoring.

3.1.1. Full Surveys

A full reservoir survey would include the reservoir bottom, valley walls and shoreline, deltas, and tributary arms. The sedimentation level must be measured near the inverts of various dam outlets (sluiceway, outlet works, and penstock), spillway sills, reservoir water intakes, and boat ramps. The highest elevations surveyed would include all areas inundated by the full-reservoir pool. In addition, there is a need to survey the upstream extent of major deltas to determine the entire sedimentation volume and estimate any upstream sedimentation impacts to people, property, and/or infrastructure (*Section 2.3.4 Delta Survey*).

Although more expensive than reconnaissance surveys, full reservoir surveys provide a more accurate measurement of the reservoir storage capacity. Full reservoir surveys are typically accomplished by combining topographic information collected for the portion of the reservoir area above the reservoir pool level with a bathymetric survey for the portion below water. Reservoir sediment volumes are determined by comparison with past reservoir surveys or by analysis of reservoir sediment thickness measurements made with vibracores, drilling equipment, probes, or acoustic waves (*Section 4. Reservoir Sediment Sampling*).

3.1.2. Reconnaissance Surveys

The reconnaissance surveys are less expensive than full surveys and could be conducted more frequently (Ferrari, 2006). A reconnaissance survey measures a longitudinal profile from the dam, along the primary upstream river channel, to the top surface of the reservoir delta (not just channel thalwegs along the delta surface). Additional survey profiles along any major tributary arms of the reservoir would provide more complete sedimentation information. When compared with the predam topography, the longitudinal profile can be used to determine the sedimentation thickness and spatial distribution and to estimate the remaining storage capacity and sedimentation volume. The elevations along the longitudinal profile can be extrapolated laterally to the reservoir valley walls to approximate the sedimentation surface. This approximated surface can then be compared with the predam surface to estimate the sedimentation volume. The approximated sedimentation surface, combined with the valley-wall surface, can be used to estimate the remaining reservoir storage capacity.

3.1.3. Partial Surveys

Partial reservoir surveys would be employed to measure certain areas of the reservoir. This type of survey might be needed to measure the sedimentation level at and near dam and other reservoir facilities. Partial surveys may also be needed to assess the performance of sediment management activities.

3.2. Survey Methods

Survey methods are briefly described for topographic (above water) and bathymetric (below water) surveys.

3.2.1. Topographic (Above Water) Surveys

Aerial LiDAR or photogrammetry are often the most cost-effective way of surveying the above-water portion of reservoirs. Piloted aircraft are typically used for LiDAR or photogrammetry surveys of large areas. Drones can be used cost effectively for smaller areas. Ground surveys can also be a cost-effective method for localized areas of the reservoir. Aerial data collection is best performed during the late fall when vegetation leaves are off and when the reservoir is seasonally low. LiDAR can more effectively measure the ground surface beneath vegetation than photogrammetry. Existing data sources can be used (e.g., Interferometric Synthetic Aperture Radar [IFSAR], USGS National Elevation Dataset [NED]), but the accuracy will not be as good as LiDAR. For contract LiDAR surveys, the monitoring plan must specify the data quality, density, and acceptable sun angles. The data point density should be enough to delineate the steep terrain conditions of any canyon walls and vegetated delta areas that may exist along the reservoir shoreline (specify quality level 1 with at least 8 points per square meter). Figure 4 illustrates the standard components, method, and coverage achieved during a typical LiDAR survey.

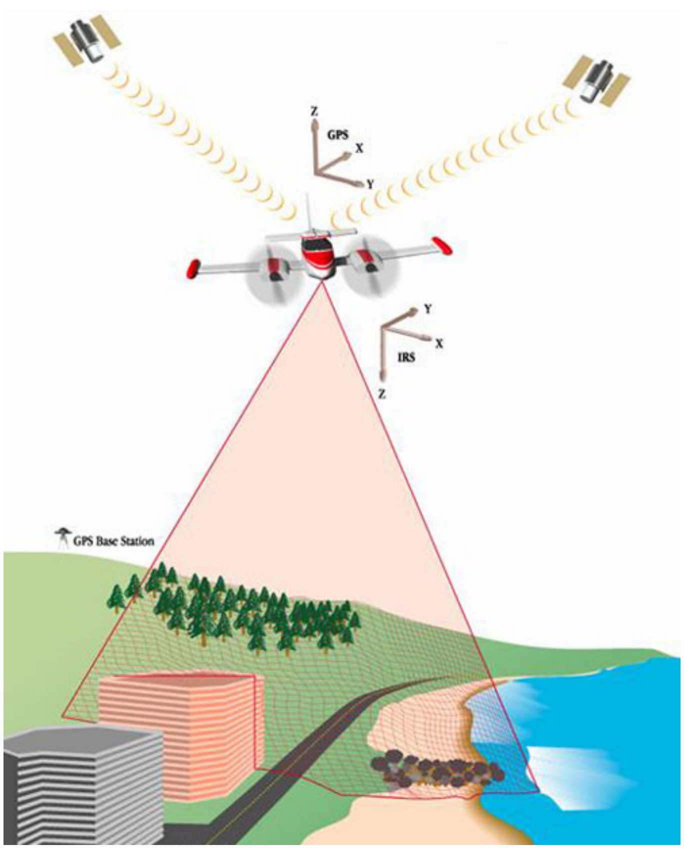

Figure 4. Typical components and technique for collection of topographic, or red, LiDAR survey data (Courtesy of RJN Group, all rights reserved).

3.2.2. Bathymetric (Below Water) Surveys

Typically, bathymetric surveys are conducted by boat using real-time kinematic (RTK) GPS and either a single beam or multi-beam depth sounder (Reclamation, 2019). Surveys should be conducted when reservoir water surface elevations are seasonally high to provide overlap in data collection with the LiDAR or photogrammetry data. By using modern multi-beam depth sounders in deep water (>20 feet or >7 meters), the reservoir bottom can often be efficiently surveyed in enough detail with complete and overlapping coverage. Typical multi-beam survey system components and coverage are shown in Figure 5. For shallow water (<20 feet or <7 meters), single beam depth sounders are typically used. Parallel lines can be surveyed along the reservoir axis, across the reservoir axis, or both. Survey lines along the reservoir shoreline are also necessary to produce an accurate surface of the reservoir bottom along the margins.

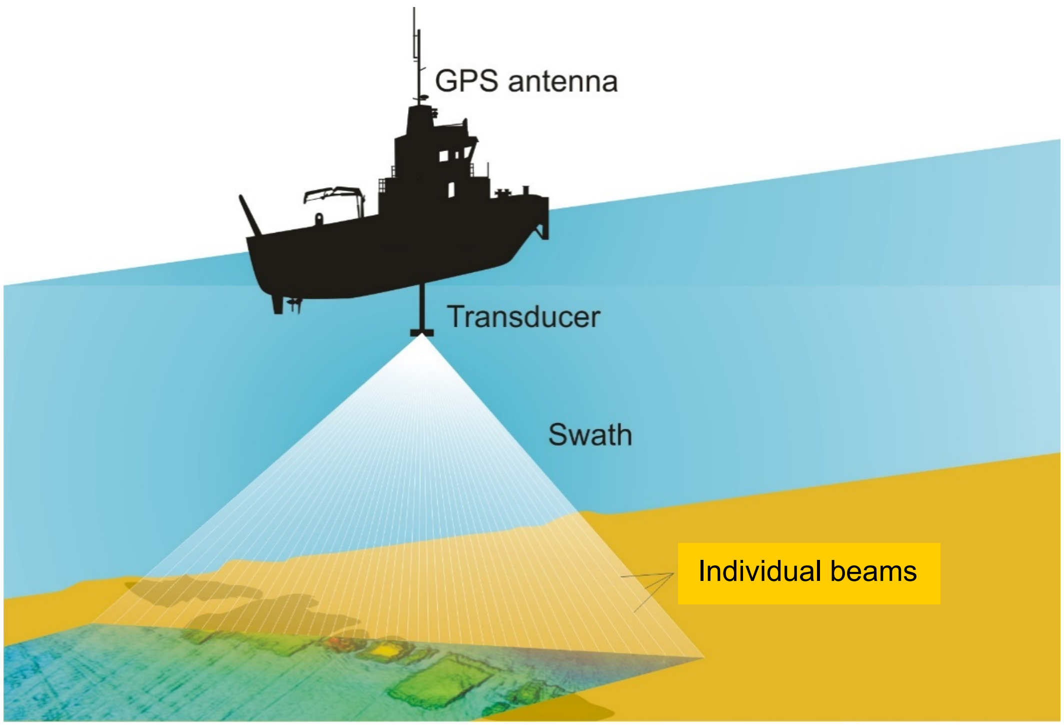

Figure 5. Example of components of and coverage from a multi-beam survey system.[2]

3.2.3. Surface Area from Satellite Photographs

The reservoir surface area can be measured from satellite images that correspond to the reservoir water surface elevation on that date and time (Eckhardt, 2019). There may be opportunities to acquire 6 to 12 usable satellite images per year during spring and summer when sun angles are high enough and measure reservoir surface areas over a range of elevations. From these surface-area measurements, the surface area at certain reference elevations can be interpolated. The reservoir surface area at these reference elevations can then be plotted over time to determine the rate of decline. The temporal trends from this monitoring information can be used to infer the rates of sedimentation.

[2] Figure 5 is courtesy of Karen Nichols, Wessex Archaeology, used under an attribution, non-commercial creative commons license, no changes made.

3.3. Reservoir Survey Frequency

The frequency of reservoir surveys should be at least once every 20 years and should correspond to the rate of sedimentation and the projected reservoir age (when sedimentation will reach the dam's lowest outlet or other important dam or reservoir facility).

The National Reservoir Sedimentation and Sustainability Team recommends that the frequency of reservoir surveys correspond to the rate of sedimentation and storage loss (Randle, et al., 2019 and Randle et al., 2021). A suggested frequency for complete reservoir sedimentation surveys is provided by the equation below:

$$Frequency = \frac{Projected\ Reservoir\ Age}{10\ Surveys}$$

Where:

Frequency = survey frequency in years per survey,

Projected Reservoir Age = Estimated age of reservoir, in years, when sedimentation will reach the dam's lowest outlet or other important dam or reservoir facility. Do not use the expected age when the reservoir will have completely filled with sediment.

For example, if a reservoir is expected to be 150 years old when sedimentation would reach the dam outlet, the recommended frequency of surveys would be once every 15 years.

3.3.1. First-Time Reservoir Sedimentation Surveys

For reservoirs that have not been surveyed since the original filling of the reservoir, the frequency of one sedimentation survey per decade should be assumed. At least two complete reservoir surveys, using the same method, will be needed to accurately estimate the age of the reservoir when sedimentation will reach the dam's lowest outlet or other important dam or reservoir facility.

3.3.2. Event-Driven Surveys

Reservoir surveys are also recommended after large floods (>25-year flood peaks) or after floods following wildfire in significant portions of the upstream watershed. Reservoir surveys would also be needed after large and deep-seated landslides within the upstream watershed or along the reservoir shoreline. For more information on how to monitor reservoir sedimentation see Chapter 9 of Reclamation's Erosion and Sedimentation Manual (Ferrari and Collins, 2006).

3.4. Bathymetric Survey Cost Estimates

Reclamation's Technical Service Center is developing a reservoir survey cost estimating guideline (expected in 2022) that will describe methods based on the reservoir surface area, storage capacity, water depth, shoreline length, depth sounder type, and assumptions of boat speed and data coverage.

The cost of bathymetric surveys depends primarily on the water surface area, perimeter of the reservoir, water depths, type of depth sounder, and boat speed. A survey crew of three people may be ideal:

1. boat pilot;
2. operator of depth sounder, GPS instruments, and data collection software; and
3. data processor and ground support.

With this three-person crew, data processing may occur while the survey data are being collected. Data processing in the field will ensure adequate data coverage and good data quality before leaving the reservoir. Additional staff days in the office will be required for final data processing, development of the digital terrain surface, computation of the storage capacity tables, and writing of the sedimentation survey report.

The greater the surface area and perimeter, the longer the distance a survey boat will have to travel to complete the survey. A key factor in determining the field data collection cost is the number of days needed by the survey crew to measure and collect the data.

A multi-beam depth sounder provides far greater data coverage than a single beam depth sounder along a given survey line. The greater the water depth, the greater the width of data coverage. Parallel survey lines should be spaced close enough to provide overlapping coverage between survey lines. In shallow areas of the reservoir, such as deltas, it may not be practical to achieve 100 percent overlap between survey lines.

3.5. Reservoir Storage Capacity and Sedimentation Volume Computations

The remaining reservoir storage capacity and sedimentation volume are determined from a digital terrain surface produced from the reservoir survey data. The reservoir storage capacity is determined from planimetric surface area and volume calculations, using a Geographic Information System (GIS), for specified elevation increments, typically 1 or 2 feet (0.3 or 0.6 meters). A computer program (e.g., ACAP) is then used to calculate interpolated surface area and storage capacity at finer elevation increments (e.g., 0.01 feet or 0.03 meters). Contact the Technical Service Center's (TSC) Sedimentation and River Hydraulics Group for the latest version of the ACAP program (https://www.usbr.gov/tsc/tscorganization/8200.html).

The reservoir sedimentation volume can be estimated by subtracting the most recent storage-capacity curve (curve relating storage capacity to reservoir elevation) from the reservoir's original storage-capacity curve. However, this method does not explicitly reveal the spatial distribution of the sedimentation volume.

Alternatively, the reservoir sedimentation volume and spatial distribution can be determined from a surface subtraction of the original reservoir topography from the current reservoir topography and bathymetry. This requires that digital surface models be generated for the current reservoir and for the original reservoir surface topography or other reference surface.

If a topographic map does not exist to represent the original reservoir topography, then the measured topography from the first reservoir survey may have to be used. If the first reservoir survey is decades after the initial reservoir filling, then the original reservoir topography would have to be developed from a current survey and measurements of the sediment thickness from drill holes and other geophysical methods.

4. Reservoir Sediment Sampling

Periodic reservoir sediment sampling is needed to measure physical and chemical properties: unit weight or bulk density, grain size distribution, and the presence of any contaminants.

4.1. Sampling Data Needs

Sediment management needs will determine the types of data to be collected from sediment sampling. For example, measuring the sediment particle grain size is important for estimating bulk density, locations of possible contaminants, and cohesive and abrasive qualities. Measuring the bulk density is important for computing sediment mass from the measured sedimentation volume. Measuring for concentrations of contaminants is important for understanding the chemical quality of the sediments and identifying the upstream sources and potentially responsible parties.

4.1.1. Sediment Grain Size

Sediment grain size distributions can be determined from laboratory analysis. The American Geophysical Union scale is preferred:

- Fine Sediment (<0.062 millimeters [mm])
    - Clay (< 0.004 mm)
    - Silt (0.004 to 0.062 mm)

- Coarse Sediment (> 0.062 mm)
    - Sand (0.062 to 2 mm)
    - Gravel (2 to 64 mm)
    - Cobble (64 to 256 mm)
    - Boulder (> 256 mm)

Coarse sediments are typically found in the reservoir deltas (main stem or tributaries) at the upstream ends of the reservoir. Coarse sediments from the delta can be quite abrasive if they reach reservoir water intakes or the dam outlet works or power penstocks.

4.1.2. Bulk Density

Bulk density or unit weight of the sediment is needed to convert the sedimentation volume to a mass (e.g., convert acre-feet to tons or m^3 to Mega-grams [Mg] or tonnes). The bulk density can be inferred from the sediment grain size distribution and assumed specific gravity (e.g., 2.65). Reclamation's *Erosion and Sedimentation Manual*, Chapter 2 (Randle et al., 2006) provides equations to compute the bulk density, both initially and over time as the sediments compact (Equations 2.39 and 2.40). Direct measurements are more accurate because fine sediments tend to consolidate—and compaction rates can vary over time. In addition, specific gravities of the sediment particles may be different than 2.65.

4.1.3. Contaminants

Detecting contaminants within the sediment is important to manage reservoir water quality. Contaminants are detected from laboratory analysis of sediment samples collected from the reservoir. Reservoir sediment sampling can help determine if there are contamination sources from within the reservoir or upstream watershed and who may potentially be responsible for their mitigation. Contaminants, should they exist, are more likely to exist in areas of the reservoir that are predominantly composed of fine sediment.

The concentration of contaminants above background levels would be of most concern, especially if those concentrations would have harmful effects on humans or the aquatic environment. Eventually, as deposition continues some type of reservoir sediment management will likely be necessary, either to preserve the remaining storage capacity or during dam decommissioning (United States Society on Dams [USSD], 2015; Randle and Bountry, 2017; and Randle, et al., 2021). Knowing whether and where contaminants are within the reservoir sediment deposits will likely be required to obtain sediment management permits.

4.2. Sampling Methods

Sediment sampling can be accomplished using dredges, gravity cores, piston cores, vibracores (Figure 7), and drill rigs. In their *Reservoir Sedimentation Handbook,* Morris and Fan (1998) provide more information in Section 10.11 “Sampling Sediment Deposits”. The number of samples needed to adequately define sediment properties is a function of the reservoir sedimentation volume. For example, three or four samples are recommended for a relatively small sedimentation volume of 10,000 cubic yards (yd^3). Step 3 of the *Dam Removal Analysis Guidelines for Sediment* provides information to evaluate the potential for contaminants in reservoir sediments (Randle and Bountry, 2017).

Figure 6. Photograph of sediment sampling from Paonia Reservoir near Paonia, Colorado using the VibeCore-4D vibrating core (vibracore) sampler (manufactured by Specialty Devices Incorporated).

The cost of sediment sampling tends to increase with depth. The sampling of thick reservoir sedimentation, accumulated over decades, is more expensive than the sampling of thinner sedimentation, accumulated over years. Sediment sampling costs can be reduced by periodically sampling the sediment to depths that at least equal the sedimentation deposition thickness since the previous sampling effort. Sediment bulk density and chemical quality can change over time as additional sediments accumulate. Periodic sampling can detect those changes over time. If new contaminants, or increased concentrations of contaminants, are detected, then there may be an opportunity to identify the source of any potentially responsible parties while they are still operational.

4.3. Frequency and Coordination of Sediment Sampling

Reservoir sediment sampling, performed in conjunction with reservoir surveys, would provide the most useful and complementary data. Sediment sampling requires different equipment than reservoir surveys and may occur during separate field trips, hopefully during the same year. It may be beneficial to conduct sampling during low reservoir levels to reduce the water depth at selected sampling sites, increasing efficiency and reducing collection costs. The locations of sediment samples can be identified on bathymetric or topographic reservoir maps and at their proper elevations. The combination of survey and sampling data can be used to identify zonal areas of sedimentation with common characteristics. Collecting sediment samples in conjunction with reservoir surveys allows for measuring sediment grain size distribution, bulk density, sedimentation thickness, and the concentration of any contaminants. This information provides a foundation for developing and implementing sediment management plans.

5. Sediment Load Monitoring

Monitoring sediment loads being transported into and out of the reservoir can be very useful for sediment management and to measure the timing of sediment entering the reservoir. Monitoring sediment loads may be necessary for sediment management operations such as sediment sluicing, flushing, or dredging.

Measurements of sediment concentrations downstream of the dam will often need to be compared with sediment concentrations entering the reservoir. Comparing periodic reservoir surveys will provide data on the average sedimentation rates between surveys. However, the rates that sediment enters the reservoir are highly variable and depend on streamflow (discharge), precipitation intensity, and the changing vegetation characteristics of the upstream watershed.

5.1. Sediment Load Data Needs

Sediment management operations often need near real-time monitoring of the sediment loads entering and leaving the reservoir. For example, if reservoir operations were used to sluice or flush sediment from a reservoir, then real-time monitoring of downstream sediment loads (or concentrations) would be needed to determine how long to conduct the sediment sluicing or flushing operations. If inflowing sediments are passing through the reservoir, then there may be a need to monitor concentrations both upstream and downstream from the reservoir.

If sediment were dredged from a reservoir and delivered to the downstream river channel, then sediment load or concentration monitoring may be needed for permitting. Real-time monitoring of upstream and downstream sediment concentrations may be needed for long-term dredging operations.

Long-term monitoring of sediment loads entering a reservoir could be used to be used to determine when to schedule the next reservoir sedimentation survey.

5.2. Methods

Direct and discrete measurement of sediment loads or concentrations by traditional methods can be expensive and is generally infrequent (Diplas et al., 2008). However, monitoring sediment loads into and out of a reservoir could be continuous. Surrogate methods, such as turbidity, hydro-acoustic (Figure 8), or optical instruments now exist to indirectly and continuously measure sediment loads entering or leaving the reservoir (Wood and Teasdale, 2013). These methods are less expensive than direct measurement methods and provide high resolution time-series data (Landers, 2010 and Gray et al., 2010). The instruments can provide turbidity or suspended sediment concentration at 15-minute intervals. The data can be stored in data loggers and displayed real-time on RISE or reservoir operator dashboards.

A side-looking acoustic doppler current meter was used to monitor sediment concentrations inflowing to Paonia Reservoir near Paonia, Colorado in 2013 (Williams et al., 2015) (Figure 8).

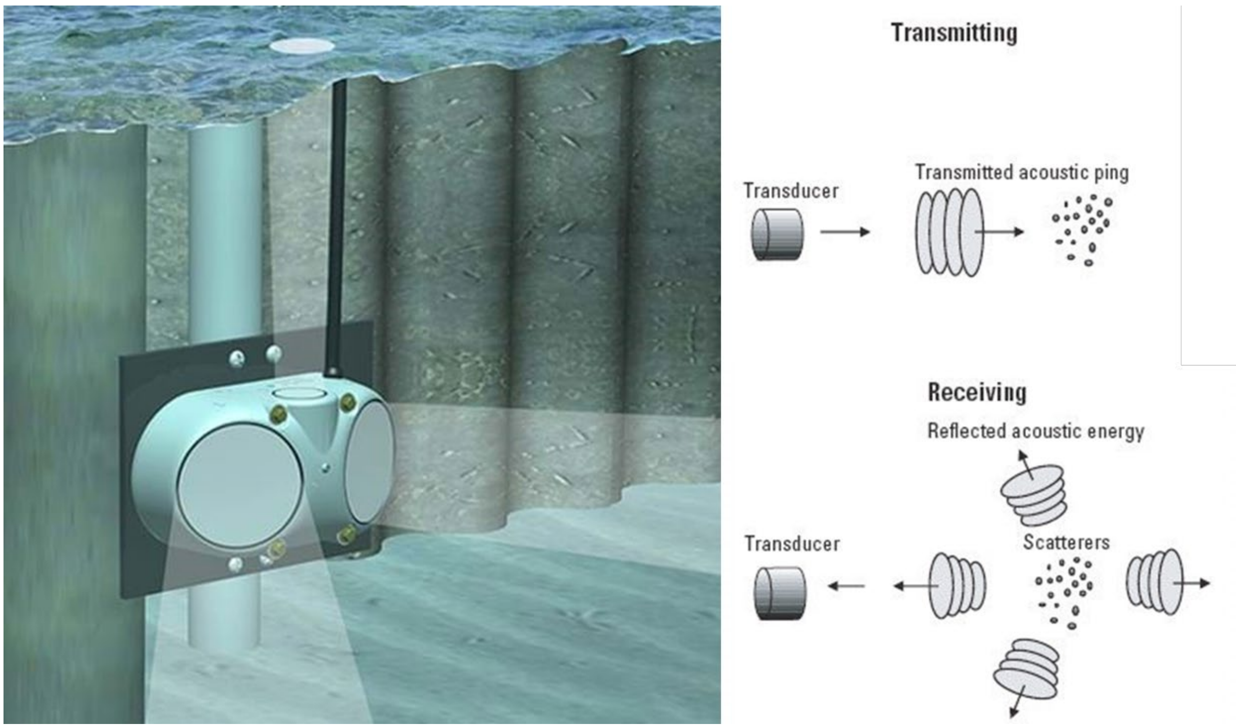

Figure 7. The left side of the figure is an example of a side-looking acoustic doppler current meter similar to the instrumentation used to monitor sediment inflows and outflow from Paonia Reservoir (courtesy of Xylem). The right side of the figure is a general sketch of how acoustics can be used for indirect measurement of suspended sediment concentrations (courtesy of Sandia National Labs: Gunawan and Neary, 2011).

5.3. Frequency of Sediment Load Monitoring

Sediment load monitoring would likely be needed during sediment management operations and for a few days to weeks preceding and following those operations. The frequency of measurements during sediment management operations depends on the rate that sediment loads (or concentrations) are changing. The necessary frequency could range from once every 15 minutes to once per day.

Sediment load monitoring to understand the temporal variation of sediment inflow would be needed during periods of high flow (e.g., when reservoir inflows exceed the average annual flow). The necessary frequency during these high-flow periods ranges from once every 15 minutes to once per day.

6. Data Management

All monitoring data and reports must be managed in accordance with Reclamation records retention requirements. Reservoir survey reports and data should be entered into the Reclamation Information Sharing Environment (RISE) and the National Reservoir Sedimentation Information (RSI) database. The RSI database is used to assess reservoir sedimentation and storage capacity trends at individual reservoirs and reservoirs systems on a watershed, regional, and national basis. This interagency database is maintained by the U.S. Army Corps of Engineers and it is linked to the National Inventory of Dams (2017).

Upon completion of each reservoir survey, the suggested best practice is to provide reports and data to the Asset Management Division, Attention: 86-67200 for inclusion in the RSI database. The Technical Service Center (TSC), Sedimentation and River Hydraulics Group (86-68240) can work with the Asset Management Division in Denver and the sedimentation survey teams to ensure that sedimentation survey data from Reclamation reservoirs are entered and maintained in the RSI database.

A reservoir sedimentation survey report should be prepared after each reservoir survey that documents the survey methods, results, and evaluates temporal trends. Reclamation's Technical Service Center's (TSC) Sedimentation and River Hydraulics Group has prepared a template to help prepare reservoir survey reports. For Reclamation users, report templates are in the 8200 Nav, under Report Templates.

- The survey report should document the reservoir surface area and water storage capacity for a range of reservoir elevations.
- Longitudinal profiles of the reservoir bottom for the original and most recent reservoir surveys should be included.
- Profile plots from previous reservoir surveys (if available) should be provided.
- The sedimentation volume and spatial distribution within the reservoir should be described.
- The reservoir sedimentation level at or near dam outlets, spillway sills, any reservoir water intakes, and boat ramps should be documented.
- The rate of sedimentation at these facilities should also be noted along with estimates as to when sedimentation is projected to reach the intake elevations of these facilities (e.g., years or decades).

- Sedimentation data and estimates of future impacts should be made available during Comprehensive Reviews, Regional Periodic Facility Reviews (PFR) or reviews under the Associated Facilities Review of Operation and Maintenance (RO&M) Program.

- Data tables from reservoir sediment sampling results can be included in the reservoir survey reports or provided in separate reports. The coordinate locations where sediment samples were taken in the reservoir should be clearly identified and plotted on a map.

- Data tables and plots from sediment load monitoring could be included in the reservoir survey reports or provided in separate data reports.

- Coordinates of any sediment samples should be clearly identified, and the collection methods described with references to standard measurement methods.

7. Monitoring Plan Updates

The reservoir sedimentation monitoring plan should be updated, as necessary, after each reservoir survey. New information gained from each survey will facilitate the planning and execution of the next survey. For reservoirs where the monitoring plan was developed prior to the first sedimentation survey, important new information will have likely been developed or discovered and should be used to update the monitoring plan.

Future technological advancements are likely to occur that will improve the accuracy and efficiency of sedimentation monitoring. For reservoir surveys, these advances could result in cost reductions, greater data coverage and density, and greater data accuracy and precision. For sediment sampling, future technological advancements could allow the collection of more and deeper sediment samples and at less cost. For sediment load monitoring, future advancements could provide greater accuracy and precision and more portability. These types of future advancements are likely to increase capabilities and reduce cost. As the future technological advancements are incorporated into sedimentation monitoring, thought should be given as to how data measured or collected using new technologies will be compared with data obtained using older technologies. The analysis of new data using older analysis methods may be one way to compare new data with older data.

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