ASSESSMENT, REVIEW, AND PLANNING FOR RESERVOIR SEDIMENTATION INFORMATION UPDATES FOR GLOBAL CHANGE SUSTAINABILITY

Martin J. Teal, Vice President, WEST Consultants, San Diego, CA, mteal@westconsultants.com
Paul M. Boyd, Hydraulic Engineer, U.S. Army Corps of Engineers, Omaha District, Omaha, NE, paul.m.boyd@usace.army.mil
Vicki Tripolitis, Hydraulic Engineer, WEST Consultants, San Diego, CA, vtripolitis@westconsultants.com
Daniel B. Pridal, Chief, Sedimentation and Channel Stabilization Section, U.S. Army Corps of Engineers, Omaha District, Omaha, NE, daniel.b.pridal@usace.army.mil
John I. Remus, Chief, Hydrologic Engineering Branch, U.S. Army Corps of Engineers, Omaha District, Omaha, NE, john.i.remus@usace.army.mil

Abstract: Global and climate changes, in addition to local land use changes, are altering hydrology that affects runoff and sedimentation. The U.S. Army Corps of Engineers (USACE) wishes to evaluate the effects of these changes to its project performance and reservoir storage capacity by updating reservoir sedimentation information (RSI, including sedimentation surveys, sediment load measurements, and other investigations related to sedimentation) to account for global and climate change. The goals of the current study are to assess the state of existing RSI, review and update existing methods and policies to support updated RSI, develop a strategy to update RSI, make broad estimations of the associated costs to update RSI, and prioritize needs for RSI updates.

Current RSI status was reviewed for five USACE districts using a list of specific RSI needs identified by the team of experienced engineers. Available RSI data were investigated and cataloged through interviews, site visits and conference calls with the selected districts. Costs were estimated to update RSI for the five districts and then extrapolated to the entire U.S. Army Corps of Engineers yields portfolio. This estimated amount would fill current data gaps, but does not include funding for ongoing RSI updates, which should also be considered. This amount also does not include any funds directed specifically at addressing impacts of global climate change on reservoir sedimentation, an issue which has not been considered in a significant way to date.

Additionally, a strategy was developed to update RSI that reflects new and changing conditions that impact the ability of RSI to meet intended objectives.

INTRODUCTION

Global and climate changes are altering hydrology that manifests as changes in the form (snow vs. rain), intensity (peak, seasonal, average), and duration of precipitation. In addition, ground state (frozen, saturated, unsaturated), evapotranspiration, and other factors have a significant effect on runoff. These changes may lead to and/or exacerbate modification of land use and land cover – including changing agricultural practices – that are major contributors to sedimentation in U.S. Army Corps of Engineers (USACE) reservoirs. The monitoring of sedimentation in USACE reservoirs is a vital part of a sustainable management plan for these projects. It is

essential that USACE establish baseline information on reservoir sediment levels and remaining storage capacity, and determine how future global and climate changes will impact sedimentation.

In 1981, USACE published Engineer Regulation (ER) 1110-2-4001, *Notes on Sedimentation Activities*. This regulation provides policy and guidance for the preparation of an annual report on sedimentation activities, including sedimentation surveys, sediment load measurements, and other investigations related to sedimentation. In 1989, USACE published Engineer Manual (EM) 1110-2-4000, *Sedimentation Investigations of Rivers and Reservoirs*, which provides details on the annual sediment report and also describes the Sediment Studies Work Plan (SSWP). The changes that have occurred over the intervening 30 years since the publication of ER 1110-2-4001 – especially changes in land use and land cover driving runoff and erosion – make it imperative that USACE update its understanding of the current state of reservoir sedimentation to support sustainable water management. Prioritizing reservoir sedimentation information (RSI) data gaps, and filling those gaps, is essential in developing a sustainable path forward while continually evaluating and adapting to future sedimentation impacts at all USACE reservoirs. Development of a RSI update and collection strategy will be vital to minimizing reservoir vulnerability to sedimentation impacts.

REVIEW AND ANALYSIS OF RSI

RSI Data Types: RSI study team members reviewed the current status of RSI within the five districts and analyzed the types of RSI, storage methods and organization. A team brainstorming session identified the types of RSI describing past or current conditions in district reservoirs. During this brainstorming session, the group identified a list of RSI datasets, shown in Table 1. The first four items on the list are considered the most important RSI items to fill district RSI data gaps and have the highest priority when funding requests are made. The other items have different levels of importance that depend on the authorized purposes of the district reservoirs, sedimentation issues, and overall RSI needs.

The RSI list was used as a guide during site visits and phone interviews with the districts. The following sections describe the RSI data collection methods and current RSI status by district.

RSI Data Collection Methods: During the initial review process, team members discussed RSI needs and a few districts provided a summary of their RSI status. The information was used to create RSI spreadsheet templates to be filled-in by district managers or staff participating in the study. The goal of the spreadsheets was to help account for and catalogue the RSI data for each district (including documenting the existence of sedimentation surveys, sediment load measurements, etc.) as well as present the information from various districts in a standard format. Apart from the data collection spreadsheets, interviews were conducted with five districts. During these interviews, the list of specific RSI needs (see Table 1) was used as a guide to help collect and characterize the state of the RSI.

Table 1 District Specific RSI Needs

Most important	1.	Topographic and/or Hydrographic Sedimentation Surveys – how collected, when, datum
	2.	Area-capacity analysis, changes with time
	3.	Aerial imagery/photography
	4.	Sediment samples/characteristics – cores vs. surface samples
	5.	Studies that include climate change
	6.	Sediment chemistry/quality
	7.	Project information (pools, authorized purposes, water control)
	8.	Anecdotal evidence/observations
	9.	Measured sediment load, inflow
	10.	Sediment rating curves
	11.	Gage/sediment gage locations, information
	12.	Sediment management activities (e.g., dredging, flushing, sluicing, etc.)
	13.	Past sediment studies
	14.	Sediment models
	15.	Volume depletion at different pools
	16.	Original design information
	17.	Funding over time, sources (especially alternative sources)
	18.	Sediment Studies Work Plan (SSWP)
	19.	Environmental factors driving data collection
	20.	Operational impacts, e.g., stage-frequency shifts, reallocation of pools/storage
	21.	Water surface profiles

RSI Spreadsheet Templates: Two types of spreadsheets were prepared for each district: (1) a Project Summary Form and (2) a set of individual project forms. The number of individual project forms matched the number of reservoir projects within a particular district (e.g., if a district has 35 reservoirs, then the set of forms contained 35 sheets). The following sections present a brief summary of the RSI spreadsheet templates.

Project Summary Form. The project summary form is designed to be a brief synopsis of all district projects. Table 2 describes some of the data fields included in the form while Figure 1 shows an example of the form (truncated).

A space is included at the bottom of each sheet to list any annual sedimentation reports, such as Notes on Sedimentation Activities, Sediment Studies Work Plan – SSWP, etc.

Table 2 Summary of RSI Spreadsheet Project Summary Form Fields

Data Type Field	Field Information
Authorized Project Purpose(s):	▪ Project authorized and/or operational purposes
Sediment Survey:	▪ Date of the latest and previous sediment surveys ▪ Survey method
Reservoir Pool and Spillway Information:	▪ Original reservoir storage ▪ Reservoir storage calculated from the most recent survey ▪ Volume lost between the original and most recent surveys ▪ Percentage loss between the original and most recent surveys
Permanent/Dead Storage:	▪ Permanent or dead storage volume (if applicable)
Sediment Allowance:	▪ Reservoir sediment allowance in years - number of years until reservoir is expected to be full of sediment and no longer operational

Project Name	Authorized Project Purpose(s)									Date of Dam Closure	Sediment Survey		
	F	N	I	WS	WQC	R	H	FA	FW		Date of Latest Survey	Date of Previous Survey	Survey Type
Raystown Lake	X					X	X			Oct-73	Oct-96	1973	Single Beam
Bush Dam	X												
Sayers Dam	X												
Tioga Dam	X												

Conservation Pool				Spillway Crest			
Original Storage (ac-ft)	Per Latest Survey (ac-ft)	Loss (ac-ft)	Loss (%)	Original Storage (ac-ft)	Per Latest Survey (ac-ft)	Loss (ac-ft)	Loss (%)
514,000	513,021	979	0.2	762,000	---	---	---
1,740	1,864	+ 124	+ 7.1	75,000	74,941	59	0
				9,000	100,505	+1505	+ 1.5
				2,000	62,307	+ 307	+ 0.5

Spillway Design Surcharge						Permanent/ Dead Storage (ac-ft)	Sediment Allowance (years)
PMF Max WSE	Date of PMF	Original Storage (ac-ft)	Per Latest Survey (ac-ft)	Loss (ac-ft)	Loss (%)		
821.5	---	871,000	---	---	---	1,373	---
962.7	---	117,000	117,000	0	0	0	---
677.8	---	186,600	188,100	+ 1,500	+ 0.8	13	---
1165.8	---	143,000	143,500	+ 500	+ 0.4	0	---

Figure 1 Project Summary Form Spreadsheet Example (truncated)

Individual Project Forms. Individual project forms were created for each project within a district and the files were named for that project. The forms are meant to include a more detailed summary of the RSI data for the project, including the data collection year, methods, and format in which the data are stored. There are two tabs within each individual project spreadsheet: (1) Project Information and (2) Data Types. Each of these sheets is described below.

(1) Project Information: The Project Information sheet includes a brief summary of the project. An example of the data sheet form is shown in Table 3. At the bottom of the form is space to list any data gaps, sources of funding, and an estimate of funding required to fill the gaps.

Table 3 Project Information Spreadsheet Example

Project Name:	Coldbrook							
Location of Reservoir/Dam								
Latitude:	43° 27' 14" N (Google Earth)							
Longitude:	103° 29' 21" W							
City, State, County:	Hot Springs, South Dakota, Fall River County							
Basin:	Missouri River/Cold Brook							
District:	Omaha – NWO							
Division:	Northwestern – NWD							
Dam Description								
Date of Dam Closure:	1953							
Type of Dam:	Rolled Earthfill							
Dam Length:	925 ft							
Top of Dam Elevation:	3675.0 ft (NGVD29)							
Drainage Area:	70.5 sq. miles							
Reservoir Surface Area:	(1972) 279 acres at elevation 3667.2 ft (NGVD29)							
Spillway Length:	200 ft							
Reservoir Pool Elevation	Main reservoir pools and maximum elevations (NGVD29)							
Flood Surcharge:	3667.2 ft							
Flood Control:	3651.4 ft							
Multipurpose:	3585.0 ft							
Spillway Pool:	Not applicable							
Storage Capacity	Storage capacity per latest survey (based on 1972 survey)							
Flood Surcharge:	10,898 acre-ft							
Flood Control:	7,250 acre-ft							
Multipurpose:	520 acre-ft							
Spillway Pool:	Not applicable							
Sediment Gage(s):	No sediment gages							
Authorized Project Purpose:	Flood Control	Navigation	Water Supply	Water Quality Control	Recreation	Hydropower	Flow Augmentation	Fish & Wildlife
	X				x			x

List data gaps:
(1) There are no sediment data of any type or water surface profile data for this project.
(2) Area & capacity tables for early survey years cannot be located. Tables for these years need to be recalculated.
(3) Elevation data are presented in vertical datum NGVD 29. This data should be converted to NAVD 88 per USACE standards.

Describe sources of funding, and provide an estimate of additional funding required to fill in the data gaps:
Funding sources include O&M Base Line, O&M Non-Routine, and O&M End-Of-Year Reprogrammed Funds.

Additional information (e.g. sediment management activities):

(2) Data Types: The Data Types sheet includes a more detailed description of the RSI data for each project. The Year of Data Collection is included with a time sequenced history of sediment surveys and other RSI data. In addition to identifying the year of data collection and method, the type of format the data are stored in is also included, such as DSS, PDF, Excel, paper, etc. Data

fields included in the Data Types sheet are Topography & Survey, Aerial Imagery/Photography, Sediment Measurement and Sediment Chemistry/Quality. At the bottom of the each Data Types form is a list of relevant sediment reports and any related sediment models. An example spreadsheet is shown in Table 4.

DATA GAP SUMMARY

A review of the current status of District RSI was completed for five of the six districts participating in this study. The purpose of this phase of the study was to investigate and catalog the available RSI data through interviews, site visits and conference calls with the selected districts. A summary of findings by RSI category is provided in this section.

Summary by RSI Category. In general, the districts indicated that there has not been funding to support critical RSI needs or even to maintain a routine sediment survey schedule. None of the Districts interviewed have ever prepared a SSWP as outlined in EM 1110-2-4000 (1989). The original purpose of preparing a SSWP was to document and identify potential sediment problems, including reservoir sedimentation. These work plans were meant to be used at the district level to include cost estimates to complete routine sediment surveys or any other sediment study. Although SSWPs have not been prepared by the five districts interviewed, most prepare an annual report of sedimentation activities that is sent to the respective USACE division office. In general, these reports identify sediment activities for the year, and describe RSI needs for the upcoming year. The reports typically include associated costs for the critical RSI needs, or the estimates are included in the Operations and Maintenance Work Request in which RSI updates are prioritized by need for the upcoming year.

Sediment Surveys: Overall, districts have not had the funding to update topographic or bathymetric surveys (or both) on a regularly scheduled basis to estimate sedimentation rates as suggested in EM 1110-2-4000. However, over the last few years, the Omaha District has received funds from multiple business lines to update all the mainstem project surveys and about half of the tributary projects. The Baltimore District receives funding for sediment surveys from federal and local sponsors. All their permanent pool reservoirs were resurveyed in 1996-2000. The surveys included both bathymetric and topographic surveys. Since this time, five of the wet dams were resurveyed by boat between 2010 and 2012. The Los Angeles District has only been able to survey about half of the reservoirs over the last 10 years. The District has all dry dams, except for one wet dam. Survey methods for the past 10-12 years have primarily been photogrammetry and LiDAR for the dry dams, and single-beam hydrographic surveys for the wet dams. A few of the dams in the District have not been surveyed in more than 40 years.

Hydrographic single-beam surveys are used for the Fort Worth and Huntington Districts. For Fort Worth, there are nine reservoirs requiring new surveys. Some of these are not meeting the terms of their water supply contracts to be resurveyed every 15 years. The Huntington District has been able to fund several sediment surveys over the last few years, but there are still 13 reservoirs that have not been resurveyed within the past 10 years, and require updates.

Table 4 Data Types Spreadsheet Example

Data Type	Year of Data Collection					
	1958	1960	1962	1964	1968	1973
TOPOGRAPHY & SURVEY						
Pre-dam Topography	N/A					
Hydrographic Survey	P/R/E/SB	P/R/E/SB	P/R/E/SB	P/R/E/SB	C/R/E/SB	C/R/E/SB
Datum	NGVD29	NGVD29	NGVD29	NGVD29	NGVD29	NGVD29
Area-Capacity Analysis	E				E	E
LiDAR						
Photogrammetry						
AERIAL IMAGERY/ PHOTOGRAPHY						
Vintage Black/White Film						
Color (film or digital)						
SEDIMENT MEASUREMENT						
Sediment Sampling Method(s)						
Surface Samples		E		E	E	
Core Samples						
Sediment Analysis						
Grain Size Distribution		E		E	E	
Density Analysis						
Sediment Transport						
Measured Sediment Load (Inflow)						
Sediment Rating Curve						
SEDIMENT CHEMISTRY/ QUALITY						
Metals						
Solids						
pH, Temperature, DO						
ADDITIONAL DATA						
Water Surface Profiles		E	E	E		E
Datum		NGVD29	NGVD29	NGVD29		NGVD29

Datum: In general, most of the Districts use the 1929 vertical datum to store data. However, the Los Angeles District indicated that there have been some datum issues. Original surveys may have been done using MSL, NGVD29, NAVD88, or some local datum. The elevations used in the District's area-capacity tables have been converted to NGVD29 datum in order for all dams to have consistent vertical datums.

Sediment Studies and Models: In general, sediment studies have not been conducted, unless project based. There have been no studies related to climate change apart from a Garrison Dam study that included some climate change data. Also, districts indicated that models have not been used for sediment management activities or to dictate management decisions.

Area-capacity Analysis: In general, area-capacity or elevation-capacity curves are updated once a survey has been completed, unless funding is unavailable. Curve data since the 1990s are stored in electronic format for all districts. The Fort Worth and Los Angeles Districts use DSS to store the data, while the other districts use Excel. Most districts also store the data in water control manuals, sedimentation survey reports and/or binders set-up for each project. Historic area-capacity data or pre-1990s data are mostly in paper format – apart for the Los Angeles District where all storage data has been transferred to DSS. Several districts also indicated that much of the original area-capacity data or historic data have been lost or misplaced. For example, most area-capacity and survey information for the Baltimore District prior to 1993 was lost after an office move. The Omaha District has historic area-capacity data still in microfiche or paper format.

Water Surface Profiles (WSP): Data for WSP have only been collected at the Omaha and Huntington Districts. The Omaha District collects most WSP data in-house, but occasionally uses WSP data collected by the U.S. Geological Survey (USGS) or an outside contractor. The Huntington District collected WSP data as part of original reservoir design, but have not been updated since that time.

Sediment Sampling: Sediment cores and bed material samples are no longer collected in-house by any of the districts. The only districts that once collected sediment data on a routine basis were Omaha and Fort Worth. Omaha stopped collecting in-house suspended sediment samples and density measurements in the 1980s. Suspended sediment data for the District are now collected by the USGS at six sediment gages. The District collects bed material under contract when funding permits. Fort Worth collected sediment data until the early 1990s. The other districts have collected little or no sediment data.

Sediment Management Activities: Sediment management activities are generally reflected in O&M records for project maintenance. Shoaling and dredging operations have occurred at some of the Omaha District projects. Operations management requests money through "non-routine funding," then issues a request for proposal before contracting out the work. Fort Worth indicated that dredging is done only to keep intakes open for water supply – not for regaining storage capacity. Studies showed that removing sediment was ineffective based upon the cost to dredge versus the amount of storage gained. Erosion at banks is an issue with some of the Fort Worth reservoirs. Although the eroded areas provide more storage in the flood pools, volume is lost in the conservation pools. The only other district surveyed where dredging has been used is in Baltimore, at Hammond Lake for boat access. The Baltimore District indicated that other management activities included raising the normal water level about 5 feet due to sediment issues at Almond Lake. There has been some discussion that the water surface elevation may need to be raised again. Los Angeles District reservoir gates are checked and cleaned annually. There are also some gravel removal activities that take place, but this is not a routine activity. The District also indicated that there are some sediment issues with seasonal flooding.

Huntington District indicated there are no current or past dredging activities. Dillon Lake, however, has lost most of its conservation pool to sediment, but this only affects recreation – not flood control. Another sediment issue occurs at Beach City Lake (completed 1936) where the reservoir is full of sediment.

RSI Data Gaps and Funding Sources: Overall, the districts identified routine execution of sediment surveys to be the main RSI need. Other needs are sediment gages and funding to support topographic studies to supplement bathymetric surveys. Most districts identified O&M as the main source of funding. The Baltimore and Fort Worth Districts indicated that there has also been some project-based sponsorship from state or local sources. An overall cost of approximately $7.5 million was estimated to fill high priority data gaps.

Scaling of Findings. One of the goals of the current study is to scale these findings to the whole of USACE and make estimations of the data gaps. This is a challenging task, as those USACE commands with major reservoir responsibilities have a wide array of geographic, climatic, operational, and political differences. Nevertheless, the five districts from which detailed RSI information was gathered form the basis for our projections.

The inventory of USACE dams shows 704 structures at 556 projects. Out of the 556 dam projects, it appears that about 409 are for traditional impoundment rather than navigation or other purposes (about 75% of inventory). The five districts providing detailed RSI data have 119 dams collectively, and therefore represent about 30% of the total.

There are some items specific to certain districts that need to be considered when trying to extrapolate findings USACE-wide. For example, Omaha District has some of the largest dams, located on one of the largest rivers in the country (Missouri River). Los Angeles District has mostly dry dams. Fort Worth District is concerned with losses in the conservation pool due to water supply obligations.

Based on the study results to date and WEST Consultants past work with multiple other USACE districts, our judgment is that the five surveyed districts are probably above average with regards to collection and management of RSI.

Taking the above into account, and applying it to the $7.5 million needed to close the RSI gap for the five districts and their 119 dams, our estimate is that $25 million would be needed to fill current RSI data gaps USACE-wide. This estimated amount would fill current gaps but does not include funding for ongoing RSI updates, which should be part of the conversation. This amount also does not include any funds directed specifically at addressing impacts of global climate change on reservoir sedimentation, an issue which has apparently not been considered in a significant way to date.

RSI UPDATE STRATEGY

Working together the project team developed a strategy to prioritize and update RSI that reflects new and changing conditions that impact the ability of RSI to meet intended objectives. The strategy includes a characterization of classes of projects that may require similar level of effort

to update, characterization of changes on a regional or national basis that may apply to groups of projects, development of methods and processes to assist in updates, and required new policy and guidance updates (mainly USACE Engineer Regulations [ER] and Engineer Manuals [EM]).

The update strategy is built around a three-tier decision tree that builds from (a) baseline data, (b) data needs for purpose, geography, and size; and (c) possible future data needs based on climate change.

a. The review of the current status of RSI was used to support the update strategy. RSI common to all reservoirs was identified as the baseline data required for each project.

b. Commonalities in collected data associated with the project purposes were identified. Datasets were then classified in a manner to support the specific project purposes. Geography, reservoir size, and environmental issues and constraints were also considered when identifying data to collect.

c. Because a goal of the overall project is to consider reservoir response to climate change, data that may be needed in the future but is not currently collected was also addressed. This may not be a specific data set but the type of data necessary.

The update strategy identifies data collection methods, resolution, and frequency that need to be considered for the update of the USACE Sedimentation EM (1110-2-4000) and writing a new ER that will address collecting reservoir data.

Individual Project Data Needs. In addition to a baseline data set, each project may require additional RSI data specific to the project purpose(s), geographic location, reservoir size, etc. The project purpose impacts both the type of RSI collected and frequency of data collection while the other considerations have more of an effect on frequency and methods of data collection. For example, 3 of the 15 projects within the Baltimore District have an authorized project purpose of water supply. The District indicated that these projects have been made the highest priority for data updates in order to monitor the amount of storage loss due to sediment deposition and the resulting storage available for water supply. Specific data collection needs may be based project authorizations such as Navigation, Flood Risk Management, Ecosystem/Water Quality/Fish & Wildlife, Hydropower, Recreation, and Water Supply/Irrigation and were identified as part of the study. A decision tree was developed to cover the range of project uses with RSI data needs defined based on those uses. All USACE projects have an authorized purpose of flood risk management. Therefore, the minimum baseline RSI should include two topographic/bathymetric surveys and area-capacity computations to determine the total volume occupied by sediment, sedimentation patterns, and the shift in the stage-area and stage-storage curves. Ideally, the first survey will have occurred before filling of the reservoir, and the second at a point in time that will allow estimation of deposition rates, identification of spatial and temporal deposition patterns, and recognition of potential sedimentation issues. Guidance on reservoir sedimentation investigations is given in EM 1110-2-4000 (USACE, 1989).

Workplan and Sediment Management Strategies. The project team recognized that RSI feeds into development of a sediment work plan, including management strategy, as shown in Figure 2.

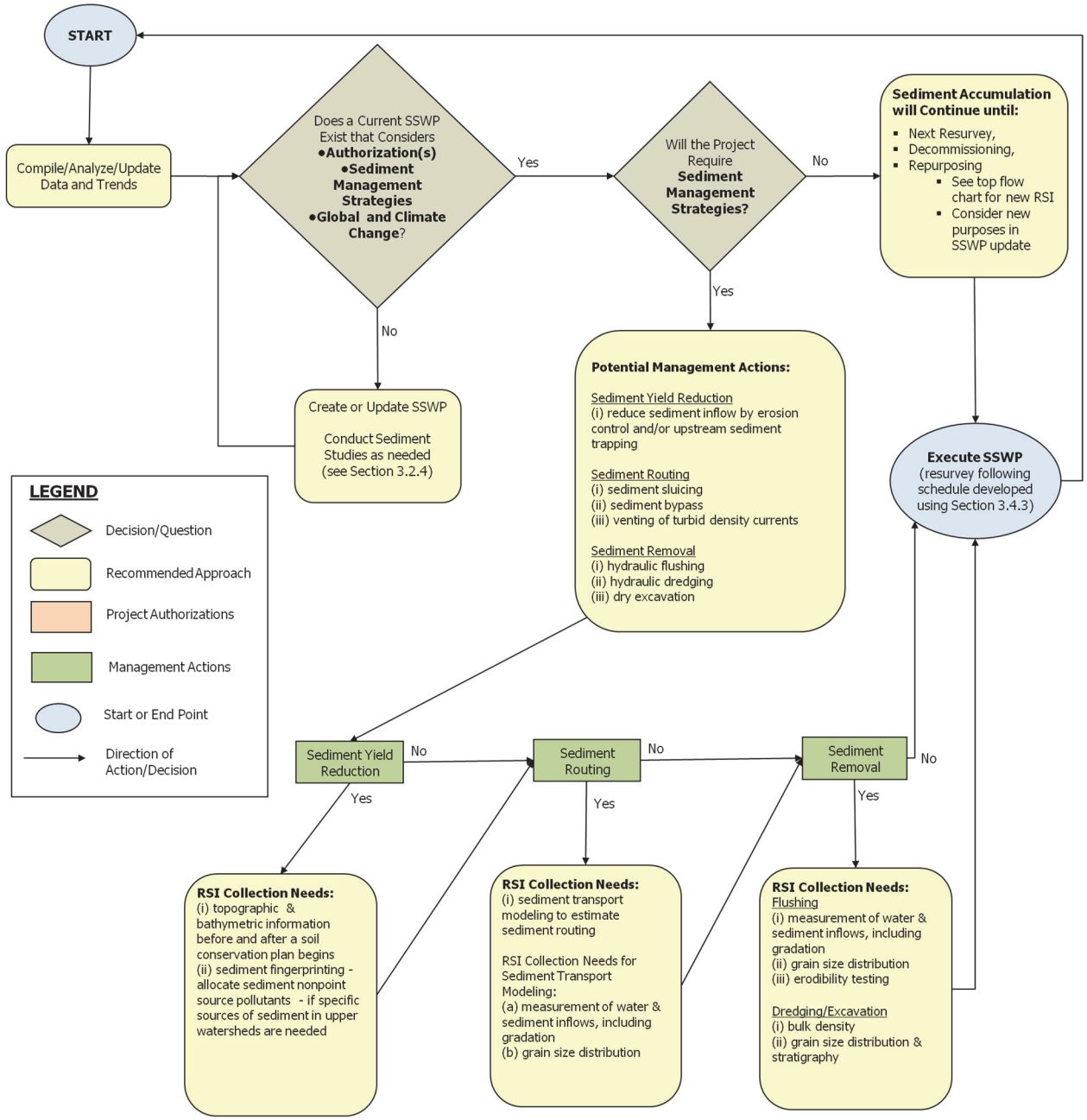

Figure 2 Workplan and Strategy Development

Sediment Studies Work Plan. EM 1110-2-4000 describes the purpose of the SSWP. Potential sediment problems and opportunities should be identified in a project SSWP. Any problems identified in the document become the basis for developing and organizing a sediment investigation. The SSWP should consider project authorizations, sediment management strategies, and global and climate changes; if not, the SSWP should be updated and any needed

sediment studies should be conducted. Reservoir sustainability should also be addressed within the SSWP. Sustainability planning should be conducted in accordance with ER 1110-2-8153 (USACE, 1995) using a staged approach. Sustainability planning may involve consideration of sediment management activities (and the RSI necessary to carry these out) or, if no feasible sustainable actions are identified, planning for reoperation or decommissioning.

Sediment Management Strategies. Different strategies for management of reservoir sedimentation are abundant in the literature. Selection of the best management strategy or action is not always straightforward, even in the present. However, given the physical characteristics of a reservoir or system and projected future conditions (e.g. future with hydrology and sediment inputs identical to the past, or future with the same affected by climate change, etc.) it may be possible to identify one or more potential future management strategies.

Sediment management methods may be broadly separated into three categories:

1. Sediment Yield Reduction – reduce sediment inflow to the reservoir
2. Sediment Routing – pass sediment around or through the reservoir
3. Sediment Removal – remove deposited sediment via hydraulic or mechanical means

Further subcategories are defined based on timing, location, and details of individual measures.

If none of the above actions are feasible or will not result in a sustainable reservoir, other management options should be considered, such as reservoir reoperation, repurposing, dam removal, or returning the dam to a run-of-river system. Most USACE dams are used for multiple purposes. As the different reservoir zones begin to fill, management practices in the future may change to account for the lost storage. For example, managers of a multipurpose reservoir with little conservation pool left may be able to increase the capacity by decreasing the capacity of another, higher, zone, or by raising the dam. Another example is a reservoir commissioned for purposes of water supply and flood risk management may be reauthorized for ecosystem management, changing from a multi-purpose to single-use reservoir. A reservoir that is reauthorized to serve a different purpose will also have new RSI needs. If a reservoir no longer serves a useful purpose, removal should be considered to restore the river to its natural pre-dam condition to the extent possible. In cases where the dam is not removed, managers may let a reservoir fill, which would eventually allow more sediment to pass over the spillway and lead to increased sediment loading to downstream reaches, including any downstream reservoirs.

REFERENCES

USACE (1981). *Notes on Sedimentation Activities,* Engineer Regulation 1110-2-4001, Washington, DC.

USACE (1989). *Sedimentation Investigations of Rivers and Reservoirs* Engineer Manual 1110-2-4000, Washington, DC (including Change 1, October 1995).

USACE (1995). *Sedimentation Investigations,* Engineer Regulation 1110-2-8153, Washington, DC.