

## **DEVELOPMENT OF A NATIONAL, DYNAMIC RESERVOIR-SEDIMENTATION DATABASE**

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**Abstract** The importance of dependable, long-term water supplies, coupled with the need to quantify rates of capacity loss of the Nation's reservoirs due to sediment deposition, were the most compelling reasons for developing the **REServoir-SEDimentation** survey information (RESSED) database and website. Created under the auspices of the Advisory Committee on Water Information's Subcommittee on Sedimentation by the U.S. Geological Survey and the Natural Resources Conservation Service, the RESSED database is the most comprehensive compilation of data from reservoir bathymetric and dry-basin surveys in the United States. As of March 2010, the database, which contains data compiled on the 1950s vintage Soil Conservation Service's Form SCS-34 data sheets, contained results from 6,616 surveys on 1,823 reservoirs in the United States and two surveys on one reservoir in Puerto Rico. The data span the period 1755–1997, with 95 percent of the surveys performed from 1930–1990. The reservoir surface areas range from sub-hectare-scale farm ponds to 658 km<sup>2</sup> Lake Powell. The data in the RESSED database can be useful for a number of purposes, including calculating changes in reservoir-storage characteristics, quantifying sediment budgets, and estimating erosion rates in a reservoir's watershed.

The March 2010 version of the RESSED database has a number of deficiencies, including a cryptic and out-of-date database architecture; some geospatial inaccuracies (although most have been corrected); other data errors; an inability to store all data in a readily retrievable manner; and an inability to store all data types that currently exist. Perhaps most importantly, the March 2010 version of RESSED database provides no publically available means to submit new data and corrections to existing data. To address these and other deficiencies, the Subcommittee on Sedimentation, through the U.S. Geological Survey and the U.S. Army Corps of Engineers, began a collaborative project in November 2009 to modernize the RESSED database architecture; provide public online input capability; and produce online reports. The ultimate goal of the Subcommittee on Sedimentation is to build a comprehensive, quality-assured database describing capacity changes over time for the largest suite of the Nation's reservoirs.

### **INTRODUCTION**

Sedimentation rates in reservoirs have long been and continue to be of interest to member organizations of the Advisory Committee on Water Information's (ACWI, 2010) Subcommittee on Sedimentation (SOS, 2010), as well as others. Much of the original impetus for conducting surveys to calculate sedimentation rates in reservoirs was to gain a better understanding of the role(s) of reservoirs on watershed sediment-transport processes, so that systems of watershed structures and supporting conservation land treatment systems could be designed efficiently to provide floodwater retention and other uses of the stored water. This information has ancillary benefits, including increasing our understanding of how sediment moves, is deposited, and is

subject to erosion and subsequent transport as a consequence of dam removal, rehabilitations, or changed operations. Other reasons for quantifying reservoir-sedimentation rates include:

- calculating changes in reservoir-storage capacity, thus estimating the useful lifespan of reservoirs,
- designing reservoir sediment-storage allocations,
- managing sediment deposits,
- rehabilitating aging or damaged structures,
- designing sediment-slucing and other sediment-management structures,
- estimating the mass of captured solid-phase constituents, such as carbon, and selected sediment-bound chemical constituents, and
- assessing resource conditions related to land cover, land use, and rates of erosion and sediment production.

In many cases, the most important reason for tracking sedimentation rates in reservoirs is to quantify changes in capacity over time for water-supply purposes. Reservoir-capacity reduction from sediment accumulation is mirrored by a rise in concern over the long-term availability of water for human consumption, agriculture, industry, recreation, and other uses.

In light of the importance of information on reservoir capacity-loss rates, the SOS has supported the development and dissemination of the historical, static **REServoir-SEDimentation** survey information (RESSED) database and website (RESSED, 2010). Additionally, the SOS is in the process (March 2010) of enhancing the database to enable addition of new reservoir-sedimentation and related data, and generate user-specified statistics toward development of a dynamic national reservoir-sedimentation database. These data can be useful for a number of purposes, including calculating changes in reservoir-storage characteristics, quantifying sediment budgets, and estimating erosion rates in a reservoir's watershed.

The purposes of this paper are to describe the:

1. Background and selected attributes of the static RESSED database, developed as part of a SOS-sanctioned project led by the U.S. Geological Survey (USGS) and the Natural Resources Conservation Service (NRCS) (Gray and others, 2009a, 2009b).
2. Need, plans, and initial progress toward development of a national, dynamic RESSED database, including SOS-sanctioned efforts in 2009-2010 by the U.S. Army Corps of Engineers and USGS to render the database updatable and capable of producing useful reports on capacity-loss rates and related reservoir information.

## **BACKGROUND AND ATTRIBUTES OF THE RESERVOIR-SEDIMENTATION (RESSED) DATABASE AND WEBSITE**

**RESSED Database Description** The RESSED database, developed in April 2009 from its predecessor RESIS-II (Ackerman and others, 2009), is the most comprehensive compilation of historical (pre-1998) data from reservoir bathymetric and dry-basin surveys for the U.S (Gray and others, 2009a; 2009b). As of December 2009, the Microsoft Access® RESSED database contained results from 6,616 surveys on 1,823 reservoirs in the conterminous United States and

two surveys on one Puerto Rico reservoir (figure 1) (any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government). No reservoirs are included from Florida, Vermont, Rhode Island, Delaware, Hawaii, and Alaska. The data span the period 1755–1997, with 95 percent of the surveys performed from 1930–1990. Only 11 surveys appear in the database after 1992 (figure 2). The reservoir surface areas range from sub-hectare-scale farm ponds to 658-square-kilometer Lake Powell in Arizona and Utah.

The average percent of total capacity loss for the 1,365 RESSED reservoirs that contain multiple surveys ranges from near zero to 97 percent (figure 3). However, recent satellite imagery reveals that some RESSED reservoirs have lost all storage capacity; i.e., they are filled with sediment.

Figure 4 shows RESSED reservoir ages and associated percentage of total capacity lost. The large majority of RESSED reservoirs retain more than half their original capacities on the date of the last survey for each reservoir. However, absent active means for managing reservoir sediments by dredging or sluicing, all reservoirs inevitably fill with sediment, given enough time. Given the above information, John Remus (U.S. Army Corps of Engineers, written commun., 2010) observed that, “there is time to be proactive [e.g., efficient and effective]” in dealing with the reservoir-sedimentation problem.

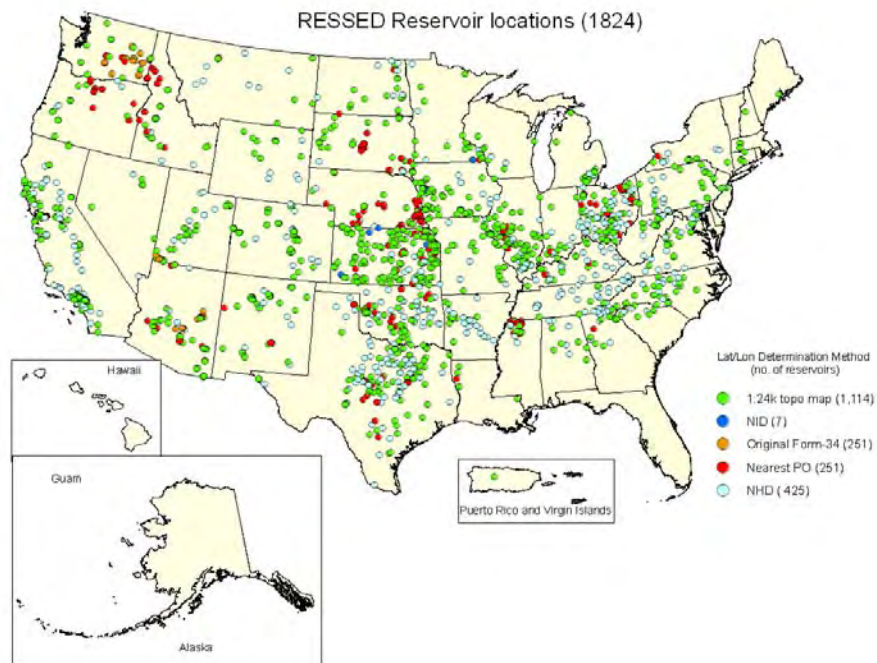


Figure 1 Map showing RESSED reservoir locations (March 2010). The RESSED database contains no reservoirs for Florida, Vermont, Rhode Island, Delaware, Hawaii, and Alaska.

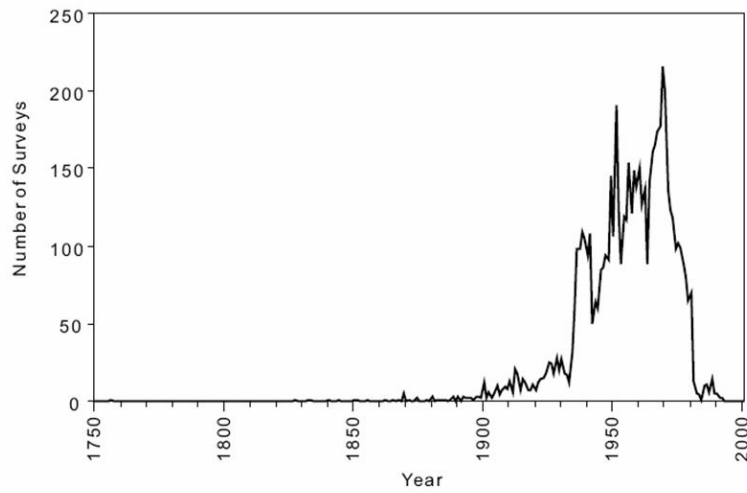


Figure 2 Number of RESSED surveys conducted annually from 1755–1997.

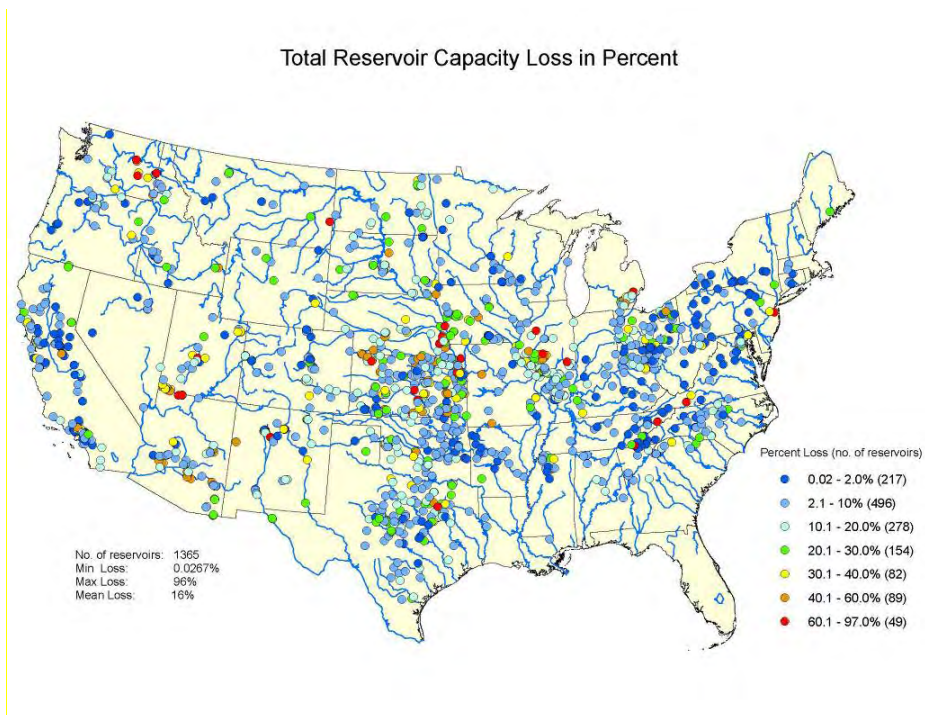


Figure 3 Map showing locations of 1,365 RESSED reservoirs with two or more surveys, showing the total average loss in capacity for the period of data for each reservoir.

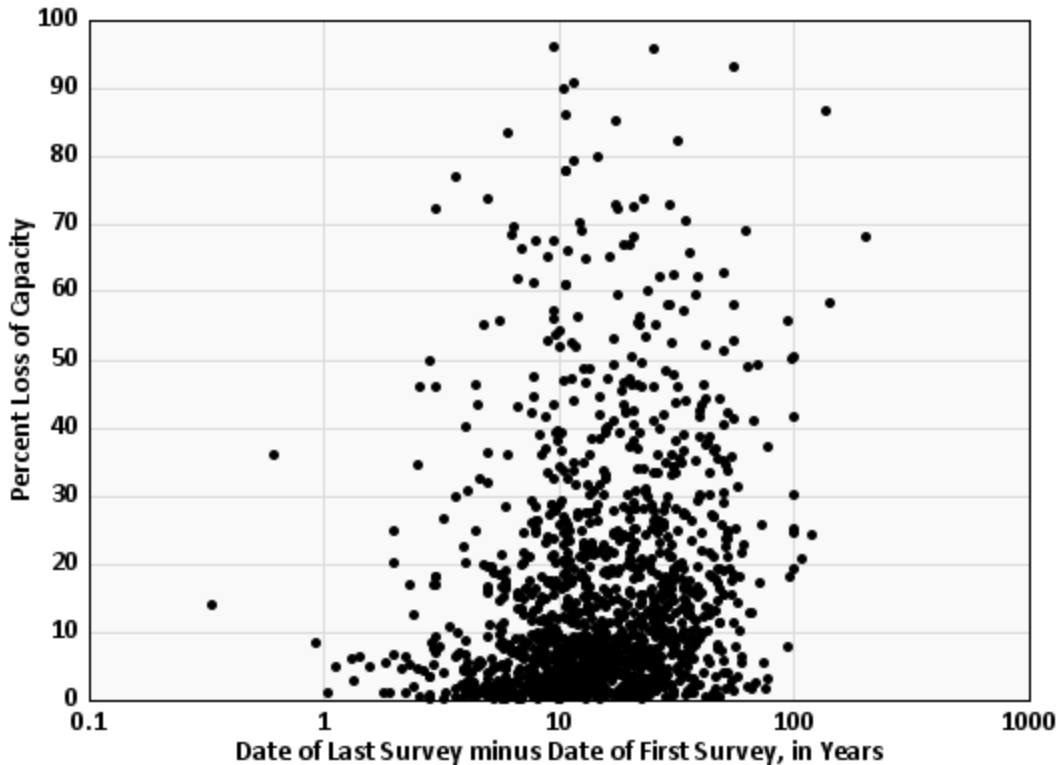


Figure 4 Graph showing percent capacity loss of 1,365 RESSED reservoirs based on the length of time between the first and last surveys for each reservoir.

**History that Led to Development of the RESSED Database and Website** Efforts to develop a reservoir-sedimentation database for the United States began around 1951 with the production of 2-page Soil Conservation Service (SCS) Form SCS-34. Form SCS-34 was designed to contain all salient information related to the survey of sediment deposits in reservoirs, while minimizing the paper required to capture this information. It was originally designed as a paper copy to house survey data for dissemination in hard copy format either as raw data sheets and (or) as compilations (e.g., Dendy and Champion, 1978; SOS, 1953). Instructions for completing the reservoir-sediment data forms were issued by the SOS (1978), including explanations for the information required in each block or data field.

On behalf of the SOS, the SCS (after Oct. 20, 1994, the Natural Resources Conservation Service) coordinated the collection of reservoir sedimentation-survey data and disseminated survey data sheets to its members beginning in 1953 (SOS, 1953). Additionally, the SOS published 5-year summaries of reservoir-sedimentation rates in U.S. Department of Agriculture Miscellaneous Publication No. 1362 (Dendy and Champion, 1978). Form SCS-34 data sheets were collected through the SOS through the mid-1980s, and additional Form SCS-34 data sheets have been collected independently since then in anticipation of their inclusion with other such data in a centralized reservoir-sedimentation database.

In the 1980s, the SCS attempted to develop an electronic database for analysis of the survey data. Dennis Erinakes (SCS) supervised the key-punching of all of the data on the available, completed Form-34 survey sheets. Attempts to analyze the data using a database-management

system (DBMS) at the time were unsuccessful and were abandoned, primarily due to the inadequacy of the database management software then available.

Thereafter and until 1993, no evidence is available to the authors indicating that any effort was directed toward an electronic national reservoir-sedimentation database. In 1993, the SCS found in a cardboard box an unmarked magnetic tape containing what is presumed to be the results of the aforementioned SCS electronic database-development effort. In 1994, Jay Atwood (NRCS) obtained the digital data through Jerry Bernard (NRCS), created a relational database using the MS-Prelude® and MS-Informix® DBMSs, and performed queries and analyses on reservoir-sedimentation characteristics. These results were provided to Jerry Bernard, who was leading an analysis of the status and trends related to requirements of the Third Resource Conservation Act (RCAIII). Lyle Steffen (NRCS) assisted Jay Atwood with the technical definitions and information in the database during the conversion and subsequent analyses. This version of the database was called RSED at the time but quickly became known as the Reservoir Sedimentation Information System, RESIS.

After the completion of the reports for the aforementioned RCAIII effort, the database was offered to the SOS for dissemination. Lyle Steffen worked with the Information Technology staff at the NRCS National Soil Survey Center to maintain a working copy of the RESIS database, and provided an electronic copy of the database to the USGS Earth Resources and Observation Science (EROS) Data Center.

Subsequently, the USGS (Stallard and others, 2001) obtained the EROS Data Center's copy of the RESIS database and utilized it as part of an evaluation of sediment and carbon storage within the Mississippi River Basin. Stallard and others (2001) transferred RESIS to a desktop computer environment using the database management programs MS-Paradox® and MS-Access®. In addition to using the original version of the RESIS data as the core of the new database, referred to as RESIS-II, links were made to:

- the National Inventory of Dams (*NID*) (U.S. Army Corps of Engineers, 2010),
- scanned versions of the original primary datasheets, and
- GIS polygon coverage of selected (580) reservoir watershed boundaries, derived from Digital Elevation Model (DEM) datasets (Mixon, 1998).

Katherine V. Ackerman and Eric T. Sundquist, USGS, subsequently obtained RESIS-II from Stallard and Mixon with the primary intent to estimate rates and amounts of carbon storage in United States reservoirs. In concert with David W. Stewart and Gregory E. Schwarz (USGS), Ackerman and others (2009) improved georeferencing for 1,506 reservoirs, performed other upgrades, and documented the RESIS-II database. It is this version of the RESIS-II Microsoft Access® database that was updated with new reservoir-survey information and named RESSED. In late 2009, the information in the RESSED Microsoft Access® database was ported to an Oracle® database, maintained by the U.S. Army Corps of Engineers (USACE), as part of the national reservoir-sedimentation development effort.

**RESSED Website Description** The RESSED (2010) website (<http://ida.water.usgs.gov/ressed/>) was developed with four primary purposes:

- Make the RESSED Microsoft Access® database publically available as a complete download.
- Provide interactive maps for viewing reservoir locations and ancillary information.
- Provide background information and historical documents to aid those using the RESSED database.
- Provide interim instructions and capability to solicit updated or additional reservoir-survey data to alert SOS to the availability of the information, so that the SOS could seek this information at such time that these data could be added to the extant reservoir-survey database.

The March 2010 version of the RESSED website home page (2010) has the following clickable categories:

- Welcome
- Purpose and Scope
- Background
- Data Sources and Data Quality,
- Database Download and Documentation
- Interactive Map
- List of Reservoirs
- Enhancement and Expansion
- Updating RESSED – Interim Guidelines
- Acknowledgements
- Selected References

In addition to retrieval of the entire RESSED Microsoft Access® database, the user can identify reservoirs of interest on a map or in a list, and retrieve electronic scans of the original Form SCS-34s used to populate the Microsoft Access® database.

A web-based form to capture key metadata associated with reservoir-survey information not included in the RESSED database, or corrections to the database, can be found under the category, “Updating RESSED – Interim Guidelines.” This information is being compiled in anticipation of enhancing the RESSED database to include data-input capability. This category will be removed when the RESSED database is enhanced to include online data entry by any user.

Those interested in learning more about the SOS’s RESSED database are encouraged to access and navigate the RESSED website at <http://ida.water.usgs.gov/ressed/> .

**RESSED Database and Website Deficiencies** The multiple incarnations of the reservoir-sedimentation information in the RESSED database—from Form SCS-34 through several database management systems (DBMSs)—are at least partly responsible for a number of deficiencies in the database and website. Neither the RESIS, RESIS-II, nor RESSED databases was populated with data directly from Form SCS-34; instead, the data were keypunched from Form SCS-34 and then successively converted to at least 3 DBMSs (as previously inferred, pre-

DBMS-era Form SCS-34 was designed for use and dissemination as hard copy). Although "spot-checks" of values in the 47 fields of the original Form SCS-34 data and the data for the same survey(s) in the current database indicate that the migration was successful and accurate, the origins and definitions of all 325 fields in the Microsoft Access® database have yet (March 2010) to be resolved. Other issues that have combined to complicate enhancement of RESSED to a dynamic, national reservoir-sedimentation database include:

- The structure of the RESSED database, indirectly tied to the 1950s-era Form SCS-34, is not designed to accommodate 21<sup>st</sup>-century data or all "modern" reservoir-survey data deemed worthy of storage, such as the "raw" data produced by electronic means, and their associated quality-control metadata.
- Inconsistencies in derivation of values in some fields have been detected on rare occasions, most likely because the field definitions were not consistently used in all 6,618 surveys.
- RESSED database footnote and comment fields often contain valuable information; however, this information is not stored in an efficient, digitally searchable and quantitatively useful manner. A single comment can be stored in multiple lines, creating multiple records in the database that lack the requisite DBMS data relationships.
- In spite of considerable efforts to improve geolocation information, as of March 2010, the locations of 251 reservoirs remain identified by the coordinates of the nearest post office because only the city/state location information was populated in the respective Form SCS-34 data sheets. Another 27 RESSED reservoirs retain the original Form SCS-34 data sheet coordinates, the accuracy for which have yet to be resolved.
- A review of changes in capacities of RESSED reservoirs has revealed that some reservoirs have gained storage capacity. Although reservoirs indeed can gain capacity—for example, by increasing the dam spillway elevation, and/or by dredging, which may or may not be noted as a comment on the data sheet—the ostensible increase in capacity of at least one RESSED reservoir was due to a typographical error in the capacity field.
- Some RESSED reservoirs have completely filled in and now appear on current satellite images as stream segments.
- Programmatic funding to develop and maintain a national reservoir-sedimentation database has yet to be secured, even if some short-term funds have been obtained and services-in-kind have been utilized for maintaining and enhancing the RESSED database.

## **TOWARD A NATIONAL, DYNAMIC RESERVOIR-SEDIMENTATION DATABASE**

The importance of water supply to society is self-evident. Additionally, the U.S. Department of Agriculture, Agricultural Research Service (ARS), and USGS estimate that the costs associated with sediment damage and remediation on reservoir-storage facilities total about \$3 billion annually in 2008 dollars (Osterkamp and others, 1998). A truly national, dynamic, modern reservoir-sedimentation database would provide critical information on the long-term viability of water supplies, and enable managers to more wisely allocate resources to reduce damages and enhance reservoir-storage facility maintenance and remediation.



Development of a dynamic national reservoir-sedimentation database is also important because the RESSED database contains data from but a miniscule percentage of the lentic water bodies (reservoirs, lakes and ponds) in the conterminous United States. For example,

- The National Inventory of Dams (U.S. Army Corps of Engineers, 2010) contains information for about 81,000 dams, or about 44 times the number of RESSED reservoirs (not all RESSED reservoirs are associated with dams in the National Inventory of Dams).
- The USGS National Hydrography Dataset (U.S. Geological Survey, 2010) contains at least 6.3-million lentic water bodies in the United States, which include reservoirs, lakes, and ponds of any size in arid areas, and those with a width of at least 30 meters in non-arid areas (Simley, 2007).
- Renwick and others (2006) identified the presence of between 2.6 and 9 million artificial ponds in the conterminous United States.

Additionally, many reservoir-sedimentation surveys have been conducted in the past two decades by Federal, state, and local agencies; however, none of these data have been entered into the RESSED database because a publically available reservoir-sedimentation database did not exist until RESIS-II was published (Ackerman and others, 2009). The new survey data exist in a variety of formats, both electronically and on paper. The Bureau of Reclamation, for example, has about 100 surveys in Microsoft Excel® format, which are intended to be entered into the RESSED database when that capability is enabled. One state agency has used the “Interim Guidelines” web-link available via the RESSED website to inform the SOS of the availability of recent publications of several reservoir-survey updates in that State.

Once an easy and robust mechanism is available for entry of reservoir-survey data into the RESSED database, the number of RESSED reservoirs and surveys are expected to increase substantially, thus increasing the utility of the database for further analysis.

**Progress toward Development of a National Reservoir-Sedimentation Database** Although the SOS has made the static RESSED Microsoft Access® database and website publically available, no programmatic funding has been or currently (March 2010) is available to continue to maintain, develop, and enhance the database. Without consistent and adequate funding, the potential for developing a fully populated and publically useful national RESSED database is sorely limited. To this end, the SOS plans to work with its parent organization, the ACWI, to develop a programmatically funded national RESSED program.

In the meantime, the USACE and USGS have initiated a RESSED enhancement project with four objectives:

1. Design a new, modern database schema that will be used as the foundation for future enhancements.
2. Integrate information on sedimentation in USACE reservoirs into the RESSED database.
3. Develop a data-input mechanism to the RESSED database to include data from reservoirs not currently represented in the database, and additional data from reservoirs already represented in RESSED database.
4. Enable retrieval of reports from the database describing selected attributes of RESSED reservoirs.

The RESSED enhancement project was funded by the USACE in 2009–2010 with the USGS leading the programming effort. A new web-based user-interface to a new database is enhanced by the development of a new, logical schema, featuring a flexible design that removes many limits in the original RESSED database schema. For example, the original schema only allowed the entry of 15 sampling points and characteristics for 15 reaches; these are unlimited in the new schema. The new schema provides the ability to dynamically accommodate the incorporation of future statistical and characterization fields without having to modify the underlying structure. The new schema also substantially improves the self-documenting nature of the database by incorporating look-up tables showing the correlation between the coded values and their definitions, eliminating the need to synchronize separate documentation, and permitting the automatic use of more meaningful labels on generated output reports without additional programming. The user-interface is being developed using the Filemaker Pro® software, and the new database will be in the Oracle® DBMS. The SOS intends to provide web-based access to the RESSED database through the website (<http://ida.water.usgs.gov/ressed/>) by fall 2010 for:

- adding survey data for RESSED reservoirs.
- adding sedimentation-survey and related data for other reservoirs to the database.
- refining coordinates for reservoirs lacking reliable location information in the database.
- correcting or improving other information in the database.

The online system will allow information to be user-entered and stored in a non-public “holding bin” database until these data can be vetted/quality-assured by the SOS before being merged with the publically accessible database.

Finally, toward development of a national RESSED database, three ad hoc committees under the SOS RESSED workgroup were formed in September 2009 (Subcommittee on Sedimentation, 2009). The foci of these three committees are:

- Reservoir-sedimentation-survey data types and data uses (to provide critical data on data-input fields and output options for the national RESSED database),
- Database architecture (to ensure that the database can handle existing data types and is sufficiently flexible to accommodate other appropriate data types over time), and
- Data-collection protocols (to provide guidance to data collectors to acquire the most complete datasets that are compatible with the national RESSED database).

Information from the data types and uses committee (above) may be relevant to, and included in the 2009-2010 USACE-USGS RESSED database enhancement project.

## **SUMMARY**

The Nation would benefit immensely from a national, dynamic reservoir-sedimentation database, by allowing managers and decision makers to be proactive in addressing reservoir-sedimentation issues that will ultimately lead to more effective and efficient solutions. The SOS’s RESSED database and website is the first such effort toward achieving this end.

The RESSED database contains 6,616 surveys for 1,823 reservoirs in the conterminous United States, and two surveys for one Puerto Rico reservoir. Although this is the largest such reservoir-sedimentation database for the United States, these reservoirs represent a miniscule fraction of the total number of impoundments in the United States. Additionally, the RESSED database is considered inadequate for the Nation's long-term reservoir-sedimentation data needs. A dynamic reservoir-sedimentation database with a well-designed, flexible architecture supported by recommended data-collection protocols will facilitate entry of the broadest and most relevant data on changes in reservoir capacities and associated ancillary data.

A national programmatically funded RESSED database is envisioned that will provide an expanded dataset with corrections for current database errors, and input and quality-assurance capabilities. As a prelude to development of a national RESSED database, the USACE and USGS in 2009-2010 are developing an input mechanism that will enable users to add reservoir-sedimentation and related information not currently in the RESSED database, and provide reports on selected reservoir-database characteristics. The SOS has formed ad hoc committees to plan for development of a national RESSED database if programmatic funding can be acquired.

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