# METHODS, BATHYMETRY, AND SEDIMENT-STORAGE CAPACITY CHANGE IN A SYSTEM OF RESERVOIRS ON THE LOWER SUSQUEHANNA RIVER AND BATHYMETRY OF THREE STATE PARK LAKES, 2007-2009

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**Abstract** Throughout Pennsylvania, there is a need to collect accurate geo-referenced bathymetric data of lakes and reservoirs. Until recently, the use of conventional surveying and fathometer methods made conducting accurate bathymetric surveys of lakes and reservoirs time consuming. Technological advances in data-collection equipment, data-collection, computer software, and differential global positioning systems (DGPS) make it possible to produce accurate digital products of bottom-surface elevations more efficiently than in the past.

Since 1990, the U.S. Geological Survey Pennsylvania Water Science Center (PaWSC), in cooperation with the Pennsylvania Department of Environmental Protection and the Pennsylvania Department of Conservation and Natural Resources, has completed bathymetric surveys on a system of three reservoirs on the lower Susquehanna River and more recently in three state park lakes. The systems of reservoirs on the lower Susquehanna are located behind 3 hydroelectric dams. Since 2007, the U.S. Geological Survey, in cooperation with the Pennsylvania Department of Conservation and Natural Resources has completed bathymetric surveys on three state park lakes. The state park lakes are Raccoon Lake, Lake Arthur, and Pymatuning Reservoir. Raccoon Lake was used to develop and refine the approach and methods for the study, while Lake Arthur and Pymatuning Reservoir represent two of the three largest lakes in the Pennsylvania State Park system.

Identical methods were used to collect bathymetry data in the four studies. A differential global positioning system (DGPS) instrument was used to provide the horizontal coordinate position. Bathymetry data were collected using a single beam 210 kHz (kilohertz) echo sounder at pre-defined transects. Final horizontal geographic positions (X and Y) and vertical depth to bottom (Z) were used to create bathymetric (lake-bed elevation) maps.

Bathymetric maps showing current lake-bed elevations were produced for two of the state park lakes. For the lower Susquehanna River system of reservoirs, the current bathymetry data were used in conjunction with historical data to provide an estimate of the remaining sediment-storage capacity. The system of reservoirs has been steadily losing the capacity to store sediment since construction began in the early 1900's. Of concern is that once the reservoirs reach their sediment-storage capacity, sediment and phosphorus loads entering the Chesapeake Bay will increase. Approximately 20,000 acre-feet or 30,000,000 tons of remaining storage capacity is available in Conowingo Reservoir. At current transport (3,000,000 tons per year) and deposition (2,000,000 tons per year) rates and with no occurrence of major scour events due to floods, the remaining capacity may be filled in 15 to 20 years. In a scenario where future changes from expected scour events and continued progress in reducing in-coming sediments to the reservoirs are considered, the remaining capacity could be extended an additional 10 years.

## INTRODUCTION

Throughout Pennsylvania, there is an existing need to collect accurate geo-referenced bathymetric data of lakes and reservoirs. These bathymetric data can be combined with Light Detection and Ranging (LIDAR) land-surface-elevation data to produce seamless elevation maps of lakes and reservoirs and the surrounding area. Until recently, the use of conventional surveying and fathometer methods made conducting highly accurate bathymetric surveys of lakes and reservoirs time consuming. Recent advancements in equipment and techniques, computer software, and differential global positioning systems (DGPS) make it possible to produce accurate digital products of bottom-surface elevations within a shorter time frame. This paper discusses the use of these techniques in two different studies discussed as reservoirs in the Susquehanna River Basin and lakes in the Ohio River Basin.

The PaWSC in cooperation with the Pennsylvania Department of Environmental Protection (PaDEP) began collecting bathymetry data in three reservoirs located behind three hydroelectric dams on the Lower Susquehanna River in 1990 (figure 1). Follow-up bathymetry studies were completed in 1993, 1996, and 2008. The purpose of the reservoir studies was to document change in the bottom-surface profiles between studies and estimate the remaining sediment-storage capacity. The previous bathymetric surveys indicate the system of three reservoirs (Lake Clarke, Lake Aldred, and Conowingo Reservoir) has been steadily losing capacity to store sediment since construction in the early 1900's.

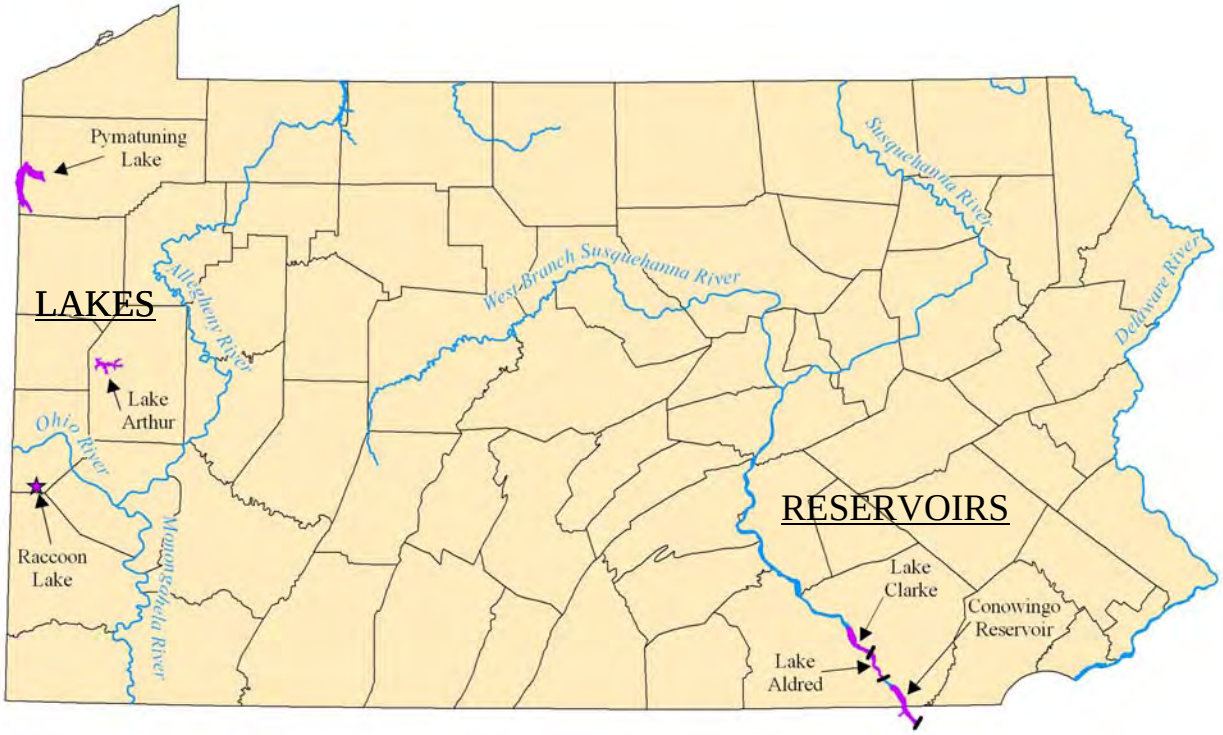


Figure 1 Map showing locations of Lakes and Reservoirs in Pennsylvania studied and described in this report.

In the mid-1980s, the Chesapeake Bay Program, a partnership between the Commonwealths of Pennsylvania and Virginia, the State of Maryland, the District of Columbia, the Federal Government, and the Chesapeake Bay Commission, began efforts to reduce nutrients and sediments in the bay. Improvement in water-quality conditions in the bay has been slow and the bay was listed as an "impaired" water body under the regulatory statutes related to the Clean Water Act. The CBP developed water-quality criteria for the bay (U.S. Environmental Protection Agency, 2003) and is working with the states to establish “allocation goals” and help implement measures to reduce sediments and nutrients entering the bay in an attempt to meet these criteria by 2010.

The Susquehanna River empties into the Chesapeake Bay and delivers 50 percent of the total freshwater, approximately 60 percent of the nitrogen and approximately 40 percent of the nitrogen load from the non-tidal areas of the Chesapeake Bay Watershed on an annual basis. Of concern is that as the reservoirs continue to fill, Pennsylvania’s sediment and nutrient allocations will not be met and actual loads may increase as a result of the loss of reservoir capacity.

In 2007, the PaWSC and the Pennsylvania Department of Conservation and Natural Resources (PaDCNR), Bureau of Topographic and Geologic Survey (T&GS), began a cooperative effort to collect lake-bed elevation (bathymetric) data within water bodies in the Commonwealth of Pennsylvania. Of primary interest are the lakes within the system of Pennsylvania State Parks. The initial area of data collection (Raccoon Lake, fig. 1), was selected to develop standard and efficient data-collection and manipulation methods for future bathymetric studies. These methods were used in Lake Arthur and Lake Pymutuming (fig. 1); two of the three largest lakes in the Pennsylvania State Park System. The objectives of the data-collection effort were to acquire accurate geo-referenced bathymetry data, quality assure the collected data points, and deliver a digital lake-bed-elevation product of geo-referenced X, Y, Z points.

## METHODS AND APPROACH

To successfully accomplish each project objective of the recent studies, four primary tasks were performed: (1) office preparation, (2) data collection, (3) data processing and analysis, and (4) quality assurance. The tasks for two of the most recent studies are described in more detail in Hittle and others (2008) and Langland (2009).

Office preparation activities included such tasks as obtaining geo-referenced aerial photographs of the study areas, obtaining available transect data from previous surveys, and assembling field equipment such as an echosounder with transducer and thermal paper, DGPS data-processing software, two laptops, and a laser range finder with compass. In addition, transects were established beforehand for each of the three reservoirs and three lakes discussed in this report. An example of planned transects is shown in Figure 2.

Data collection for each bathymetric survey involved two people, one to operate the boat and maintain position along the transect, the other to operate the equipment. The transducer was positioned on the port (left) side with the DGPS antenna mounted directly above. Each day, an offset was measured to correct for the water depth of the transducer. The procedure for each of the surveyed transects was as follows: (1) the boat was held stationary at one end of the transect

near the shore while the laser range finder was used to measure the distance and azimuth (bearing) reading to the shoreline, (2) the echo sounder (depth sensor) and DGPS (position sensor) were started and simultaneously recorded within HYPACK™ software, (3) the boat proceeded to the opposite end of the transect and was stopped near the shore where distance and bearing readings were again recorded, (4) the recording was stopped and the boat proceeded to the next transect to repeat the process. After each transect data-collection phase, if any gaps or problems in the data were identified, the transect was rerun.

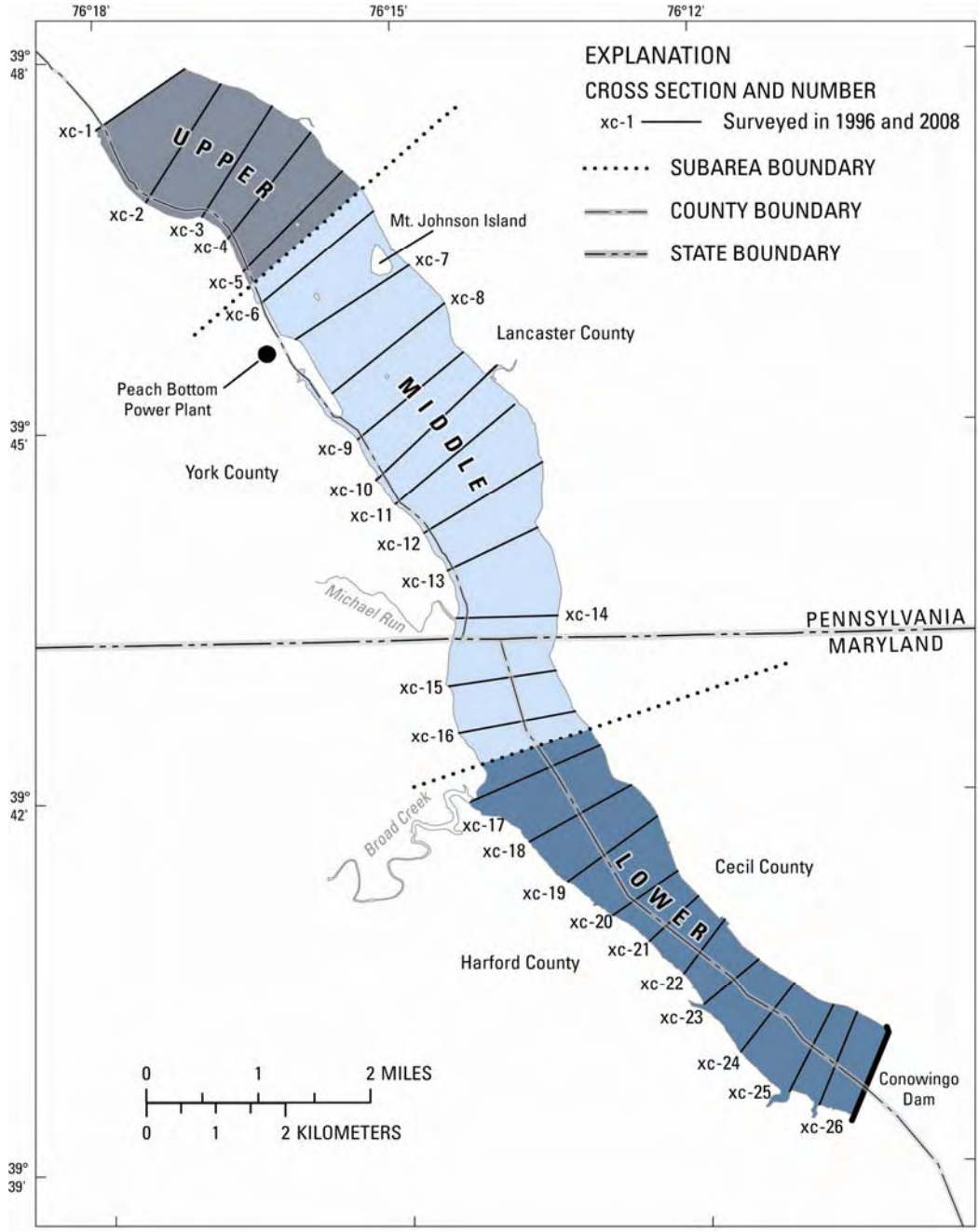


Figure 2 Map showing Conowingo Reservoir with 26 planned bathymetry transects.

Raw bathymetry data were processed and analyzed with HYPACK™ software to filter: (a) multiple-return acoustic signals in shallow water, (b) corrupt acoustic signals in deeper water, (c) corrupt GPS signals, and (d) redundant areas along the banks caused by equipment limitations. The raw data were viewed (fig. 3) corrections made if necessary, and saved as edited files (fig. 4).

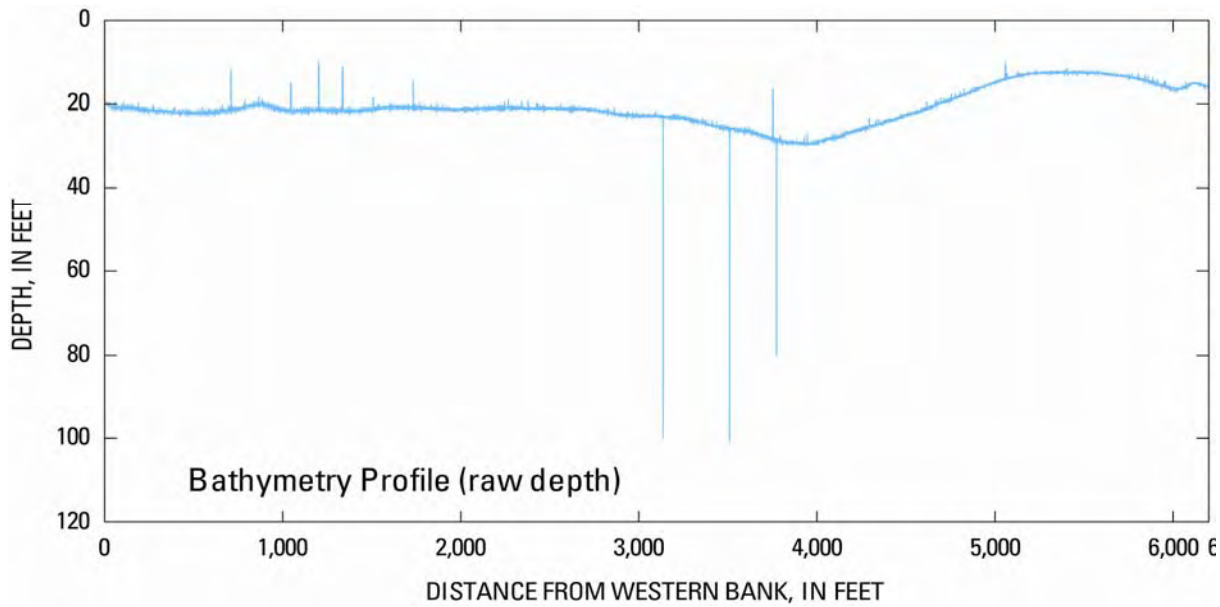


Figure 3 Raw bathymetry data collected from transect 7 in the Conowingo Reservoir.

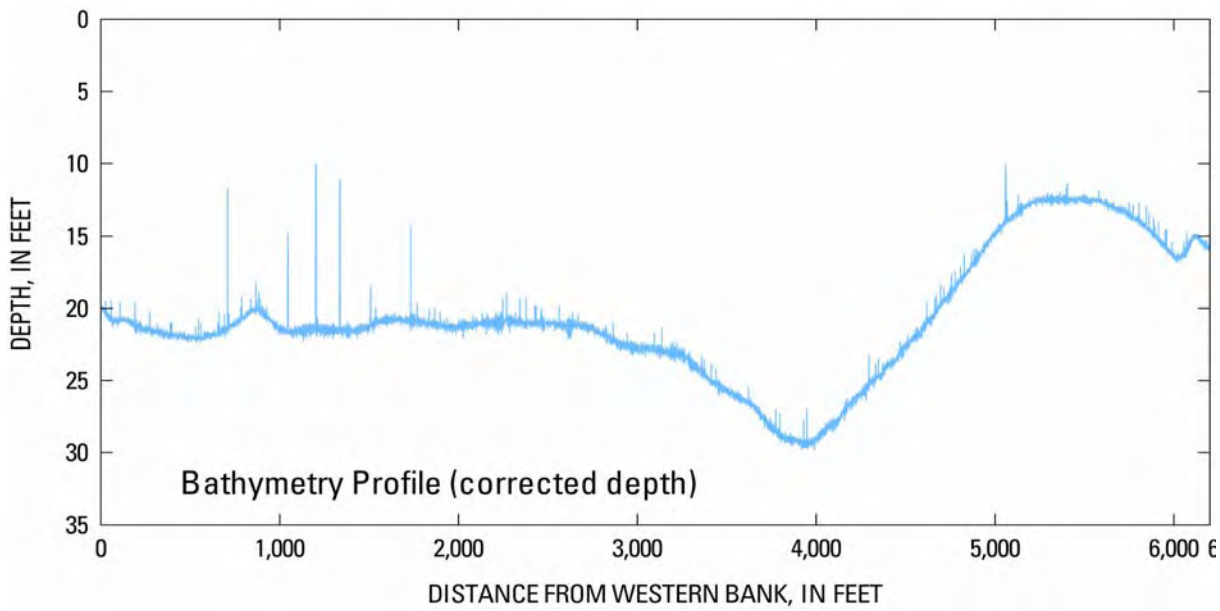


Figure 4 Edited bathymetry data collected from transect 7 in the Conowingo Reservoir. (Note the change in the depth scale, the Y-axis).

Data were then exported into a Geographic Information System (GIS) for further analysis. For the studies, X and Y data (horizontal position) were converted to latitude and longitude in degrees, minutes, seconds and Z (water-surface to bottom) data were converted to feet.

Every effort was employed to minimize error and develop quality assurance data. These efforts included, running diagonal transects to have depths and position data for the same point from a different path, daily check bar measurements to verify the fathometer readings, thermal-paper depth recordings as backup to the digital depth readings, and using two DGPS units to verify geographic position. Additional descriptions of these quality-assurance techniques are described in Hittle and others (2008) and Langland (2009).

## RESULTS

**Bathymetry** Following the collection of bathymetric data, the X, Y, and Z data were exported from HYPACK ™ and into a GIS. Two different approaches were used to develop the bathymetric maps for the two state park lakes and the three lower Susquehanna Reservoirs. For Raccoon Creek Lake and Lake Arthur, cross section data were brought into the Multi-Dimensional Surface Water Modeling System (MD-SWMS) (McDonald and others 2005). The cross-section data were combined into a single point dataset. Centerlines were defined for the main section of each lake, as well as, each arm of the lakes. A curvilinear orthogonal grid was generated with a user-defined set of points that provided adequate coverage of all the bathymetric soundings. The grid interprets the bathymetric data between cross sections to provide a smooth transition in elevation. In areas where automated interpolation between cross sections was insufficient, manual interpolation was used. Contour lines of the bottom surface were generated from the resulting profiles (fig 5). Identical methods were used to collect the data at the third state park lake (Lake Pymatuning), however a reduced scope for this study did not call for the generation of a final bathymetric map.

Figure 5 Map of Raccoon Lake showing detailed bottom surface profiling using the Multi-Dimensional Surface Water Modeling System.

In the lower Susquehanna reservoirs, the distance between cross sections was too great to enable the effective use of MD-SWMS. Cross-sectional profile data were collected in the reservoirs on

at least nine occasions from 1939 to 1996. The methods for the analysis of the previous reservoir bathymetry data are documented in Langland and Hainly (1997). The most recent surveys (1990, 1993, and 1996) and new profile data collected in 2008 were used to produce bathymetry (depth to bottom) contour maps, one for each reservoir, and provide a new estimate of remaining reservoir capacity to store sediment. The majority of the cross sections profiled in 1993 and 1996 were re-profiled in 2008 to document bed elevation change. Bathymetry maps of ten foot isopleths were produced for each of the three surveyed reservoirs in the Lower Susquehanna River basin (fig 6).

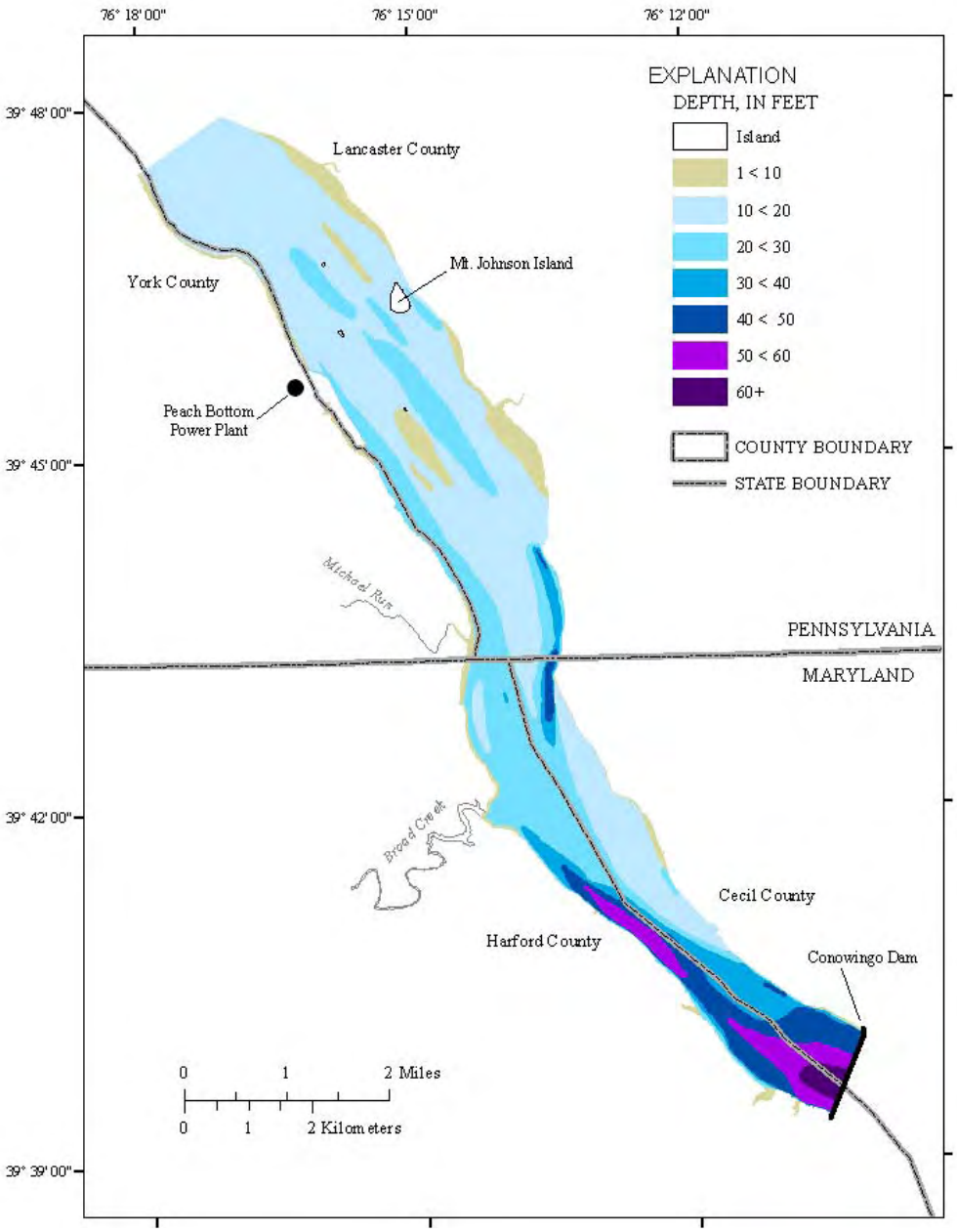


Figure 6 Map of Conowingo Reservoir showing depth to bottom contours.

**Reservoir Capacity Change** Changes in water and sediment storage capacity were estimated in each of the three reservoirs by computing the change in water volume in relation to the original bed elevation and capacity of the reservoirs (Langland and Hainly, 1997). Multiplying the cross-sectional length by the width between adjacent cross sections by the average depth of the cross section produced an estimate of the volume of water between the cross sections. As a result of using the same transects as in previous studies, the cross sectional area remained constant. With area being held constant, changes in each cross-section's average depth from the 1996 and 2008 surveys indicated the change in bottom surface elevation, water volume, and sediment storage. Using a normalized density of dry sediment of 67.8 lb/ft$^3$, as suggested by Reed and Hoffman (1997), a change in sediment mass for a cross section was estimated. The sum of the cross-section changes provided a sediment-volume change for each reservoir. The relative change in sediment volume among each cross-section also provided spatial information to determine scour and deposition areas during the 12-year period between surveys.

The 2008 survey of the three Lower Susquehanna River reservoirs confirmed the findings of previous studies that the two upstream reservoirs (Lake Clarke and Lake Aldred, fig 1) no longer trap large quantities of sediment and are in "equilibrium" or a steady-state in terms of incoming and outgoing sediment. Only the most downstream reservoir, Conowingo, maintains the capacity to trap significant quantities of sediment and the capacity to store sediments is being steadily reduced. When built in 1929, the original sediment-storage capacity (SSC) was approximately 150,000 acre feet or 200 million tons of sediment (Langland, 2008). As successive surveys indicate, the capacity to store sediment has been reduced (fig 7). The 2008 survey indicated that approximately 162 million tons of sediment are deposited in Conowingo Reservoir and that the reservoir has lost 80 percent of its capacity to store sediment. Current estimates indicate Conowingo Reservoir may reach SSC in 10-20 years. However, considering future best-management-practice scenarios where statistically expected sediment removal scour and reduction in riverine sediment transport are considered, an additional 10 years could be added to the time before reaching the SSC.

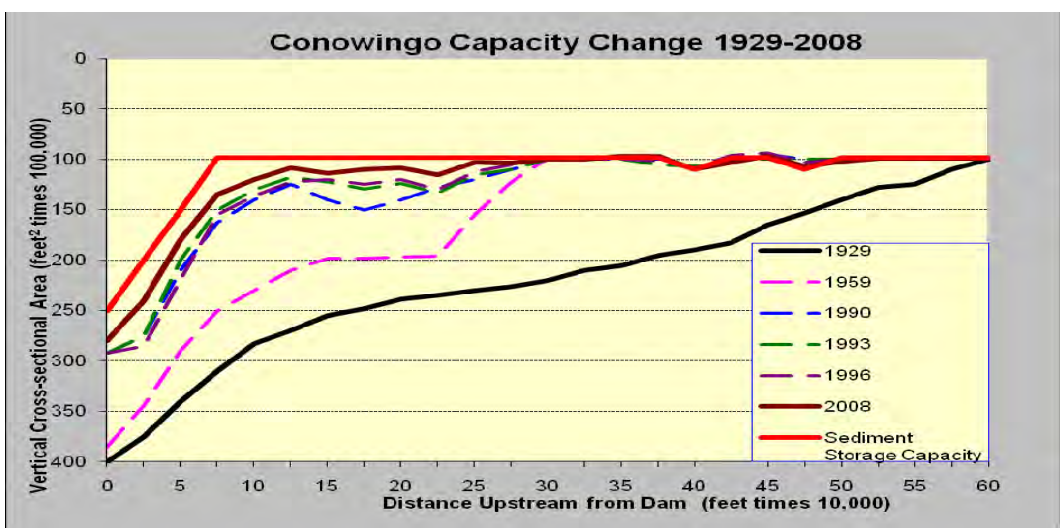


Figure 7 Loss of sediment-storage capacity in Conowingo Reservoir.

## REFERENCES

Hainly, R.A., Reed, L.A., Flippo, H.N., and Barton, G.J., 1995, Deposition and simulation of sediment transport in the Lower Susquehanna River Reservoir System: U.S. Geological Survey Water-Resources Investigations Report 95-4122, 39 p.

Hittle, C.D., and Ruby, A.T., III, 2008, Bathymetric surveys of Lake Arthur and Raccoon Lake, Pennsylvania, June 2007: U.S. Geological Survey Data Series 357, 10 p.

Langland, M.J., and Hainly, R.A., 1997, Changes in bottom-surface elevations in three reservoirs in the lower Susquehanna River, Pennsylvania and Maryland, following the January 1996 flood – Implications for nutrient and sediment loads to Chesapeake Bay: U.S. Geological Survey Water-Resources Investigations 97-4138, 34 p. and 3 plates.

Langland, M. J., 2009, Bathymetry and sediment-storage capacity change in three reservoirs on the Lower Susquehanna River, 1996–2008: U.S. Geological Survey Scientific Investigations Report 2009-5110, 21 p.

Reed, L.A., and Hoffman, S.A., 1997, Sediment deposition in Lake Clarke, Lake Aldred, and Conowingo Reservoir, Pennsylvania and Maryland, 1910-93: U.S. Geological Survey Water-Resources Investigations Report 96-4048, 14 p., 3 pls.

U.S. Environmental Protection Agency, 2003, Ambient water quality criteria for dissolved oxygen, water clarity, and chlorophyll a for the Chesapeake Bay and its tidal tributaries: 903-R-03-002, 231 p.