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Surveying Texas' Reservoirs

High Tech Programs by TWDB, Texas Universities Produce better Insights Into Sediment Problems at Texas Lakes

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For reservoir owners and water managers, sediment is a dirty word.

Imagine that you planned and built a dam in the 1930s to store enough water to meet regional water needs for many years. For example, you may have estimated that the dam and the reservoir it created should store 50,000 acre-feet of water.

Now fast-forward to today's conditions. Unfortunately, many parts of the reservoir have probably been filled in by silt and sediment deposited by runoff caused by heavy rains. As a result, your reservoir may now be able to store just 40,000 acre-feet (AF). Maybe, if you are like many water managers, you don't know exactly how much water your reservoir can store today.

TWDB professionals take small boats like this one out on Texas lakes to gather data on lake volumes, storage capacity, and water elevations.

Sadly, stories like these are fact -- not fiction -- in many instances in Texas and the U.S. Many experts estimate that sedimentation reduces the storage capacity of reservoirs by an average rate of 0.2% annually. If that's the case, Texas could lose enough water to fill 19 reservoirs within the next 50 years. Sedimentation is a difficult problem to investigate, in part because looking at annual rates or current

conditions can be misleading. "Much of the sediment that builds up in Texas lakes is deposited by large storms that occur only once in 50 or 100 years," says Texas A&M University Civil Engineer Ralph Wurbs. "Even if less sediment is now building up in a lake than anticipated, you have to look at many years of data to see if sediment buildup rates are really accurate."

There are some notorious cases where sediments have caused major problems. White Rock Lake near Dallas experienced severe siltation problems and may now need extensive rehabilitation. In a few cases, lakes have been rendered virtually useless because so much sediment has accumulated.

Thanks to technological advances and research based developments, we are now better able to assess how much sediment is filling Texas lakes. Researchers and water managers are using such sophisticated technologies as global positioning systems (GPS), geographic information systems (GIS), and sonar to develop three-dimensional profiles of lakes. That's a long way from early survey efforts when surveyors stuck a long pole into a lake to measure water depths.

Many groups are now working to make it easier to accurately project how much water is contained in Texas lakes. State and federal agencies and universities are now using high tech methods to survey reservoirs and assess how much sediment runoff is occurring. The Texas Water Development Board (TWDB) now operates a hydrographic survey program that uses state of the art methods to assess the amount of water reservoirs are now able to store. This information helps TWDB in its efforts to forecast future water supply needs. Obviously, the agency cannot reliably project water supplies that may be available without an accurate picture of the amount of water major reservoirs can store.

The U.S. Army Corps of Engineers (USACE) also conducts hydrographic surveys of Corps' and non-Corps' reservoirs using similar high tech methods. Texas reservoirs are surveyed by professionals in the USACE Tulsa OK District.

University research is also helping to solve many of these problems. Researchers at Baylor University are developing and field testing high tech methods to simultaneously measure lake volumes and sediment thickness. At the University of Texas at Austin (UT), investigations focus on evaluating the overall accuracy of GPS-based reservoir survey techniques and methods to survey shallow and near coastal reservoirs. Texas Agricultural Experiment Station (TAES) researchers at the Blacklands Research Center at Temple are working with research and service units of the U.S. Department of Agriculture (USDA). These include the Natural Resources Conservation Service (USDA/ NRCS), formerly the USDA/ Soil Conservation Service or USDA/ SCS, and the Agricultural Research Service (USDA/ ARS). The work focuses on assessing and modeling sediment loading and runoff from rural watersheds. Texas A&M University civil engineers have investigated many aspects of reservoir management, including the impact of sedimentation on lake yields.

Still, there are major challenges. State survey efforts led by the TWDB have limited resources and typically have only been able to survey about 10 reservoirs a year. This number could grow dramatically if more lake managers approach TWDB to have surveys performed. The USACE program faces the same challenges and is also able to survey only a few reservoirs annually. At that rate, it may take 30 years to survey all of Texas' major reservoirs. Still, TWDB hopes that 95% of Texas' major lakes will be surveyed within the next 10 years.

Background Information

A fundamental fact is that waters stored in reservoirs are a critical part of Texas' overall water supplies. Anything that reduces the amount of water these reservoirs can store deserves careful scrutiny.

The LCRA uses benchmark stations like this one to properly orient the position of global positioning systems [GPS] that will be used during lake surveys. For example, these benchmarks [usually permanent positions near a lake] are located at a set of known coordinates. These benchmarks serve as reference points and help make sure that data obtained by GPS is accurate.

Texas now contains 188 major reservoirs that have storage capacities of more than 5,000 AF and three more dams are under construction. Of these, about 32 were partially funded and built by USACE in cooperation with local water suppliers. Texas' major reservoirs have the capacity to store more than 37 million AF for conservation or water supply purposes and 18 million AF for flood protection. Dependable firm yields (the average amount of water that can be withdrawn annually when extended droughts and run of the

river supplies are considered) are only roughly 11 million AF. Currently, only about 6 million AF is actually used from reservoirs each year.

Understanding the process that's used to plan for sediment buildup is also important. USACE and other agencies often allocate the storage space in a reservoir for flood control, water supplies, recreation and sedimentation. Sedimentation rates are calculated based on data about soil types, land use, rainfall, and average and peak streamflows. Using that information, they can estimate the volume of sediment expected to buildup during the reservoir's useful life.

Historically, it's been difficult, time-consuming, and expensive to survey reservoirs and determine how much water they hold. Originally, reservoir surveys were conducted with a rope strung across a lake using range lines. A crew in a small boat would stick a pole into lake waters to measure depths at key intervals along the rope line. By the 1930s, water depths in reservoirs were estimated with electronic depth sounders and sediment thickness was measured by penetrating lake bottoms with metal "spud" bars. Aircraft cables were strung across lakes, survey boats were hooked to the cables, and depths were recorded at selected intervals. This method was used by the USDA Soil Conservation Service (USDA/ SCS) for many years and worked well for small reservoirs. Because of the time and expense involved, reservoir cross-sections were spaced many miles apart, while depth measurements were made at 15- to 30-foot intervals. Cables were stretched across smaller lakes from permanent shore markers, while shore-based observations were used to estimate the bathymetry of larger lakes. Surveying larger reservoirs was more difficult because cables could not be strung across these lakes. In these cases, survey instruments were used to determine the path the boat should take. Prior to each survey, end points had to established in the field and vegetation had to be cleared so that a line of sight could be established. One surveyor monitored the path of the boat and issued commands to assure it remained on-line. Another surveyor calculated angles to estimate horizontal locations. For years, agency personnel relied on a 1939 technical bulletin (Eakin) to survey Texas lakes.

Later, electronic positioning systems were developed and implemented. A series of microwave transmitters were positioned around a lake at known coordinates and transmitted data to survey boats in the lake so they could calculate their position. A line of sight still had to be established and the boat had to be within the angles of 30deg. and 50deg. with respect to shore stations. Large reservoirs required many shore stations and crews had to move these stations around the lake. By the 1960s, acoustic fathometers replaced the sounding lines.

By the 1990s, differential GPS methods that rely on satellite navigation replaced shore-based methods. GPS technology uses a network of satellites maintained in precise orbits around the earth to determine locations on the earth's surface. Today, the combined use of precision fathometers and GPS navigation lets professionals continuously sample reservoirs. Aerial photographs have been utilized to measure surface areas and estimate reservoir volumes. These photos can be used to generate elevation contours of areas that

are not flooded and fairly accurate results can be obtained. This method is costly and is used infrequently.

Even if little sedimentation is observed, it does not mean that water agencies now have the rights to use water that was originally reserved for sediment accumulation. Water users must still apply to the Texas Natural Resource Conservation Commission (TNRCC) to obtain water rights for any of this "newly available" water before it can be legally used.

Hydrographic Survey Programs

In Texas, two publicly funded groups are involved in major efforts to surveys reservoirs. TWDB offers a program to survey virtually any reservoir in Texas, while USACE carries out surveys of Corps' and non-Corps' lakes. Private engineering and consulting firms also do this type of work.

In 1991, the Texas Legislature authorized TWDB to develop a non-profit, self-supporting hydrographic survey program. So far, TWDB has surveyed roughly 25 reservoirs. Typically, it costs about $10,000 for TWDB to survey a small lake and roughly $50,000 to survey a larger one. Detailed pricing information can be obtained from TWDB. The goal of this program is to use state-of-the-art equipment to conduct detailed hydrographic surveys. TWDB surveys generate information on lake elevations, area, and storage capacity and produce maps of underwater topography and cross sections.

TWDB measures the depth of lakes using specialized sonar equipment positioned on a specially outfitted survey boat. Digital GPS methods are used to verify the precise latitudes and longitudes of the survey boat and data is collected every second no matter where the boat is located.

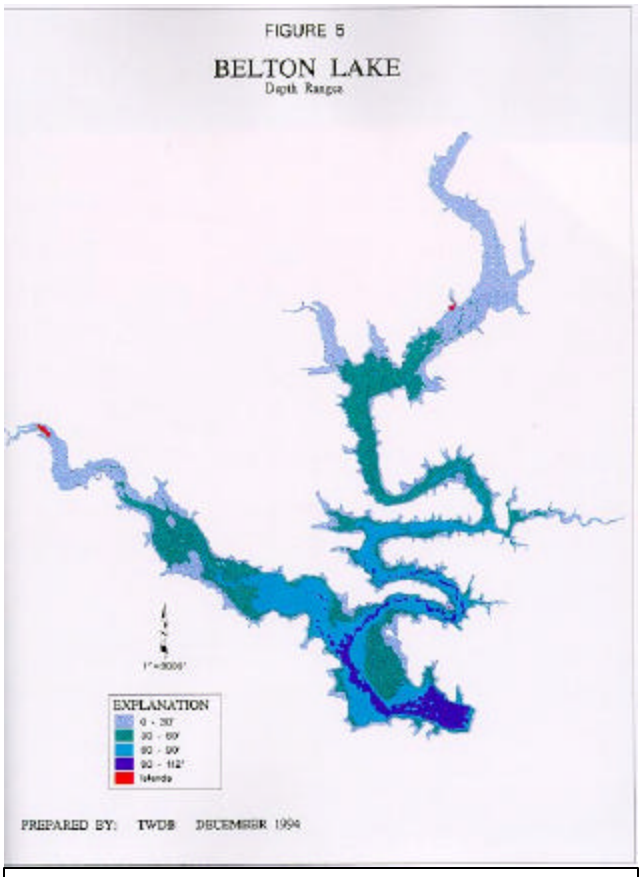
TWDB follows these steps when performing a reservoir survey. First, a lake owner requests that TWDB perform a survey, enters into a contract with the Board, and schedules the survey. TWDB then digitizes the lake boundary from the most current USGS topographical maps (usually at a 1:24,000 scale) using AutoCAD software. Later, a survey grid of 500-foot cross sections is created over the digitized lake boundary file using HyPack software. This electronic file can be taken into the field for actual use during the survey and afterwards when results are analyzed. A reference point for the GPS system is needed at the lake. TWDB looks for known benchmarks and works with lake owners to determine which control points will be used. Once TWDB arrives at a lake to conduct the survey, they establish a control point by performing a static survey between known benchmarks and convenient sites near the lake. The newly established point will be used during the survey as the basis point for digital GPS positioning.

Results of TWDB Hydrographic Survey Program (1993-1996)

Lake Name	Year Completed	Original Capacity(AF)	Year Surveyed	Revised Storage Capacity	Change in Storage Capacity(%)
Aquilla Lake	1983	52,400	1995	45,962	-12.3
Belton Lake	1954	457,000	1994	434,500	-5
Cedar Creek Lake	1966	679,200	1995	637,180	-6.2
Choke Canyon Lake	na	691,130	1993	695,271	+0.6
Fort Phantom Hill Lake	na	73,715	1993	70,030	-5.3
Granger Lake	na	65,397	1995	54,280	-17.1
Lake Georgetown	1980	37,080	1995	37,010	-0.2
Lake Granbury	na	152,452	1993	135,683	-11
Lake Arlington	na	39,984	1994	38,785	-2.9
Lake Houston	na	156,600	1994	133,990	-8.3
Lake Limestone	na	225,400	1993	215,748	-4.3
Lake Meredith	1965	864,400	1995	817,970	-5.4
Lake Nacogdoches	1976	42,497	1994	39,523	-6.6
Lake Nasworthy	na	12,390	1993	10,108	-18
Miller's Creek Lake	na	29,413	1993	27,888	-5
Possum Kingdom Lake	1941	754,716	1994	556,220	-17
Proctor Lake	na	59,398	1993	55,588	-6.9
Richland-Chambers Lake	1985	1,181,885	1994	1,136,600	-3.1
Stillhouse Hollow Lake	1968	235,700	1995	226,063	-4.1
Waco Lake	1965	152,500	1995	144,830	-5.1
White River Lake	1963	44,987	1994	31,846	-29
White Rock Lake	na	10,719	1993	9,004	-16

During the field survey, the computerized survey file is loaded and displayed for the field crew. Each survey line is run, and the boat's position is shown on the screen to the pilot, along with information about how far off course the boat is from the pre-planned survey line. The computer automatically stores latitude and longitude positions every second as the pilot runs the survey lines. Depth values are the average of 10 readings of the bottom taken every second by the depth sounder. The depth sounder is calibrated daily by the use of a velocity profiler that measures the speed of sound across the depth range of the water that will be surveyed. The overall accuracy of each depth value varies depending on the physical and chemical characteristics of the water, the density of the bottom, surface waves on the lake, and the movement of the boat. The results are generally accurate to within 6 inches. This data is then used by a GIS program to build a lake model.

Each survey typically takes about one or two weeks followed by two months of data analysis. Results TWDB provides include reports that meet TNRCC permit requirements and maps that depict water depths and water elevations. Private companies have used TWDB data to update navigation and recreational maps.

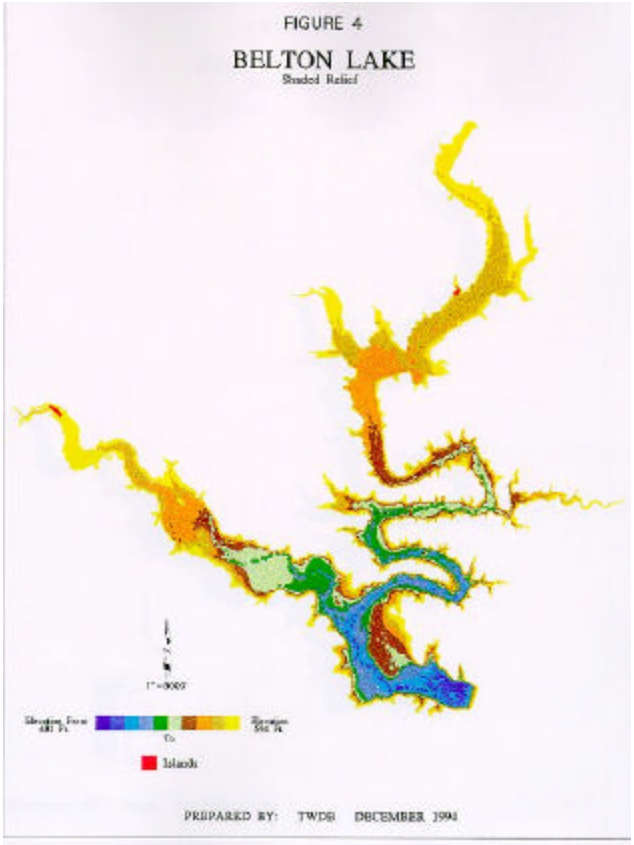


This map of Lake Belton was developed by TWDB after they conducted a comprehensive hydrographic survey of the lake. This map displays water depths in different sections of the lake. Deeper parts show up as darker areas. Maps like these can help water managers assess how sedimentation affects lake volumes and can also be useful for navigation and recreation.

TWDB's 1994 survey of Possum Kingdom Lake is an example of how the agency conducts hydrographic surveys. Possum Kingdom covers an area of 17,700 surface acres, stretches over 50 miles, and is the 23rd largest reservoir in Texas. When the reservoir was built in 1941, the reported storage capacity was 724,739 AF, but a 1974 survey by a private firm showed that the storage volume had shrunk to 570,243 AF (79% of its original volume). First, TWDB digitized the lake boundary and developed a contour map. Survey transect lines were superimposed on this map at 500-foot intervals and were computerized to guide the survey boat. Benchmarks were selected at key reference points and GPS coordinates were established using satellite data. For two weeks in June, the hydrographic survey team continuously collected data along 700 transect lines covering over 250 miles of the lake. Bathymetric data were measured with a depth sounder and stored electronically on the boat's computer. Later, a three-dimensional

digital terrain model was created of the reservoir's bottom surface using a triangular irregular network (TIN). Results showed that the lake's surface area is now 17,624 surface acres and the storage capacity is now 556,220 AF (2.5% less than the 1974 survey).

TWDB is working with USACE to survey its lakes. TWDB applied for federal funds that may be used to survey Corps' lakes, if local matching funds are provided. USACE operates a hydrographic survey program out of its Tulsa District and is also able to survey Corps' and non-Corps' lakes. Generally, USACE now employs the same high tech methods as TWDB and produces similar products. Reservoirs surveyed recently by USACE include Lake Somerville, Lake O' the Pines, Caddo Lake, Bardwell Lake, and Stillhouse Hollow Lake. For example, the Corps' surveyed Lake Somerville in 1992, collected sediment samples, and surveyed underwater portions of the lake using modern methods. Results show that sediments reduced the lake's storage capacity by 1.5% since it was built.



This map of Lake Belton shows surface water elevations. For example, lighter areas that show up as yellow and brown are higher. Sites that are darker show up as dark blue. This information is useful for water managers because it can help them determine how water is distributed within a lake and how much water they have.

Research at Texas Universities

Scientists and engineers at Texas universities are developing improved reservoir survey methods and are investigating factors that may reduce the accuracy of lake surveys.

Bob Morton of the UT Bureau of Economic Geology is leading efforts to develop a system that can be used to survey reservoirs, bays, and coastal waters. UT co-workers on the project include Bob Schultz of the Aerospace Engineering Department, James Gilbeaut of BEG, and Roberto Gutierrez of the Geology Department. The goal of the research is to create an integrated, high accuracy, high resolution, kinematic, global positioning system that can be used for bathymetric surveys. This technology combines a GPS system with electronic motion sensors, narrow-beam digital fathometers, digital compasses, portable computers, a heave compensator, and custom software. Morton hopes the research will be a way for users to continuously obtain "real-time" bathymetric data without the need for established benchmarks. This technology is appropriate for

shallow waters (less than 30 feet deep) and is expected to be accurate to within 1 inch. BEG researchers have conducted field studies on Lake Travis and compared the use of new and traditional methods. This technology could be used to monitor seasonal sediment fluxes and erosion along beaches and tidal inlets, and to determine sedimentation patterns near river mouths and in river channels. Ed Holley and Warren Payne of the Civil Engineering Department are now working with the Brazos River Authority (BRA) to evaluate the overall accuracy of high tech survey methods that use GPS to measure lake volumes and sediment buildup. Factors that can influence the results of hydrographic surveys include movement of the survey boat, boat speed, the number of satellites the GPS unit can "see" to make its measurements, the speed sound moves through waters and sediments, wind direction and speed. The research will investigate how temperature, pressure, and wind speeds influence the accuracy of sonar readings.

At Baylor University, John Dunbar and Peter Allen of the Geology Department are developing new equipment and methods to survey reservoirs. Some of the work is funded by the Texas Higher Education Coordinating Board's Advanced Research Program. The goal is to inexpensively measure water depth and sediment thickness with a suite of integrated technologies. Dunbar and Allen hope to develop a multichannel surveying system that will combine the use of satellite navigation for accurate positioning, a fathometer to measure the depth of water (bathymetry), and a sub-bottom profiler to measure sediment thickness. These elements will be combined into a portable system (the size of a suitcase) that can be mounted and deployed on small and large boats. Data will be gathered in the field from Lake Waco, Lake Belton, Aquilla Lake, and other Central Texas lakes. New methods for data collection and analysis will be developed. Sediment cores will be collected and compared to acoustically obtained sediment thickness profiles. Dunbar hopes the finished system will cost only about 25% of comparable technologies built from separate components. He believes that these studies should provide new insights into the optimal spacing between survey transects to obtain accurate results and if transects should be concentrated in sections of lakes known to have siltation problems.

At Texas A&M University, Ralph Wurbs has conducted many studies on reservoir management. His reservoir system analyses and computer modeling studies include preliminary assessments of how sediment levels influence firm yields and conservation storage capacities (Wurbs and others, 1988). Simulation models run by Wurbs suggest that anticipated sedimentation rates for Lake Belton could reduce conservation storage capacity by 13% and reservoir yields by 7% by the year 2010.

Work by Government Agencies

Governmental research units and regulatory agencies are also studying sedimentation rates in reservoirs and working to prevent sediment buildup.

A major player is USACE, which has built 32 major reservoirs in Texas. When a new reservoir is built, the Corps estimates the volume of sediments expected to accumulate within 50 or 100 years. USACE operates a hydrographic survey program for its lakes.

Engineers in the Corps' hydraulics section study sedimentation rates and trends as part of overall lake management efforts.

Recently, the BRA has been working with TWDB to survey many reservoirs in its system. In 1991, the BRA budgeted funds to survey Lake Limestone, Lake Granbury and Possum Kingdom Lake using traditional methods. In 1993, BRA determined it could save money by using the TWDB hydrographic survey program. Since that time, TWDB surveyed lakes Limestone, Granbury, Proctor, Possum Kingdom, and Belton. "We surveyed 11 lakes in the basin with new GPS technology for less money than we thought it would cost to survey three reservoirs with older methods," says BRA water resources division manager Sheryl Franklin. Results have been encouraging, according to BRA water operations manager Wayne Hughes. "We've discovered much less sedimentation is occurring than was predicted in most of our reservoirs," Hughes said. "If we projected the revised sediment rates of all BRA reservoirs to the year 2020, we expect to have more than 230,000 AF more water in our reservoirs than we originally estimated. The combined effect of the reduced sedimentation is an increase in yield equal to adding another new reservoir the size of Lake Somerville to our system." Lakes Limestone and Aquilla are the only BRA lakes that TWDB surveyed where sediments have built up at rates higher than predicted when the lakes were built.

The Lower Colorado River Authority (LCRA) has been surveying and monitoring sediment at several of its lakes since the 1990s. "The problem areas are grazing lands above Lake Buchanan, and areas where Sandy Creek and Llano River enter Lake LBJ," says LCRA's Wes Birdwell, "We estimate that Lake Buchanan may have lost 11% of its original capacity because of sediment buildup." Deltas created by sediments adversely affect navigation and lakefront property at the upper end of Lake Buchanan, especially when water levels are low. After severe storms, LCRA monitors sediments at key points where problems are likely to occur. LCRA efforts emphasize preventing soil erosion, controlling runoff from new construction, and limited dredging to improve navigation and recreation.

At Temple, work in sedimentation research is a team effort. Lead researchers include Jeff Arnold of USDA/ ARS, Charlie Baird of USDA/ NRCS, and Raghavan Srinivasan and Wesley Rosenthal at the TAES Blacklands Research Center. Many efforts involve developing, testing and refining computer models that predict the impact of management practices on sediment and agricultural chemical losses into reservoirs. The Soil Water Assessment Tool (SWAT) model is used to project the impact of changes in land use and farming practices on rural watersheds.

Reducing sediment loads is a goal of USDA efforts. USDA/ ARS began building soil conservation storage reservoirs in the 1950s in much of Texas. They built more than 300 small flood retarding dams in the Brazos River basin and 200 along the LCRA's Highland Lakes system. USDA estimates these structures have trapped roughly 90% of the sediments that would have flowed to reservoirs were these dams not built. The USDA/ SCS Cropland Reserve Program (CRP) encourages farmers to convert row crops to grazing pastures and rangeland on highly erodible lands. Nationally, 46 million acres of

row crops were converted as a result of the CRP. USDA/ NRCS directs efforts of the Water Resources Assessment Team (WRAT), which is headquartered at Temple. The goal is to identify critical areas in agricultural watersheds that contribute significant sediment loads and other water quality problems that can be addressed through the use of (BMPs). WRAT is working with the Tarrant County Water Control and Improvement District (TCWCID), BRA, LCRA, and the Corpus Christi Bay National Estuary Program to assess potential sediment runoff problems. According to TCWCID environmental services manager Woody Frossard, utilizing these simulation models saves time and money and lessen the need for field studies.

WRAT staff are carrying out projects with TAES and USDA scientists. The work uses computer models like SWAT, the Hydrologic Unit Model of the United States (HUMUS) and GIS to identify sites that may cause sedimentation problems and to predict how runoff transports sediment to lakes. Srinivasan and Rosenthal are working to link GIS and simulation models to assess sediment loads and water quality, to apply the SWAT model to the Richland-Chambers and Bosque River watersheds, and to develop detailed GIS products that examine specific pollution problems. Arnold has developed a continuous water and sediment routing model for large watersheds.

Summary

What's the bottom line? We now have better and more accurate ways to survey reservoirs than before. Excellent programs, notably those by TWDB and USACE, are in place to conduct these surveys. Although the need for these efforts now greatly outweighs resources available to conduct them, TWDB officials hope that the program may eventually become fully funded by the State so that it will be possible to survey more lakes in need of these studies. They also want lake owners to contact them TWDB to determine if more of these surveys can be performed.

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Contact TWRI for More Information

TWRI publishes many newsletters and technical reports. New TWRI technical reports include *Gypsum and Polyacrylamide Soil Amendments Used with High Sodium Wastewater* (TR-174) by Duane Gardiner, *The Use of Remotely Sensed Bioelectric Action Potentials to Evaluate Episodic Toxicity Events and Ambient Toxicity* (TR-172) by Tom Waller, Miguel Acevedo, H.J. Allen and F.U. Schwalm, *Volume-Duration-Frequencies for Ungaged Catchments in Texas* (TR-173, Volume I and TR-173, Volume II) by Ravi Devulapalli and Juan Valdes, *Water Supply Planning Using an Expert Geographic Information System* (TR-162) by Daene McKinney, John Burgin, and David Maidment, and *Flow, Salts, and Trace Elements in the Rio Grande* (TR-169) by Seiichi Miyamoto, Lloyd Fenn and Dariusz Swietlik.

Learn More About the TWDB Program

Information about the TWDB hydrographic survey program can be obtained by contacting the Board at (512) 445-1473. Details about this program can be found through the Internet by visiting the TWDB WWW site at http://www.twdb.state.tx.us/www/twdb/hydro/hydro_hp02.html. This WWW site contains a description of the TWDB hydrographic survey program, examples of contour maps developed by the program, and a list of reservoirs that have been surveyed by TWDB. The WWW site contains downloadable files with data on contours, lake boundaries, and TINs that can be downloaded and used in GIS applications.