USGS Reservoir & Lake Gages:
Elevation & Volumetric Contents Data, & Their Uses

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Water Level Gage Basics

In December of 2013, the U.S. Geological Survey (USGS) marked the 125th anniversary of the installation of its first official water level and streamflow gage, on the Rio Grande at Embudo, New Mexico. The gage was installed because it was recognized that water data were important to expanding irrigation needs. The USGS is a federal agency that provides nationally consistent and unbiased surface-water elevation and streamflow data at more than 10,000 gaging locations in the United States, about 330 of which are lakes and reservoirs (referred to hereafter as lakes) (Figure 1). The job of quantifying water resources, whether lakes, streams, or aquifers, is fundamental to proper water management and conservation of resources.

The purpose of lake monitoring stations generally is to obtain a real-time record of water-surface elevation. Water-surface elevation, known as stage, is either referenced to an established datum or an arbitrary datum (a datum being a point against which measurements are made, and stage being the height of the water above that given point or datum) (Sauer and Turnipseed 2010). In its most basic design, a real-time lake gaging station consists of a few simple components: an automatic water level sensor, a data recorder, a telemetry system, a power supply system, and a non-recording reference gage that is independent from the rest of the gaging station equipment. The gaging stations are inspected periodically to ensure proper calibration and function of the equipment deployed.

At lakes, the stage is often used as an index to determine the approximate contents (current water volume) of the lake (usually in acre-feet in the United States). The relation between stage, lake surface area, and capacity is defined in area-capacity tables, which are derived from water-body-specific bathymetric and land surveys. Lake capacity refers to the amount of water that the surveyed area can theoretically contain, whereas contents refers to the volume of water present at a given water surface elevation or point in time. The real-time water-surface elevation data and corresponding reservoir contents, along with inflow and outflow, are essential tools for the management of water releases from the lake. Lake managers control water releases for several reasons, including: to mitigate flood damage for communities upstream and downstream from the lake; to maintain navigable water depths in streams; to maintain and deliver a water supply for agricultural, municipal, and industrial users; to preserve aquatic ecosystems and lessen bank erosion; and to ensure public health and safety in recreation.

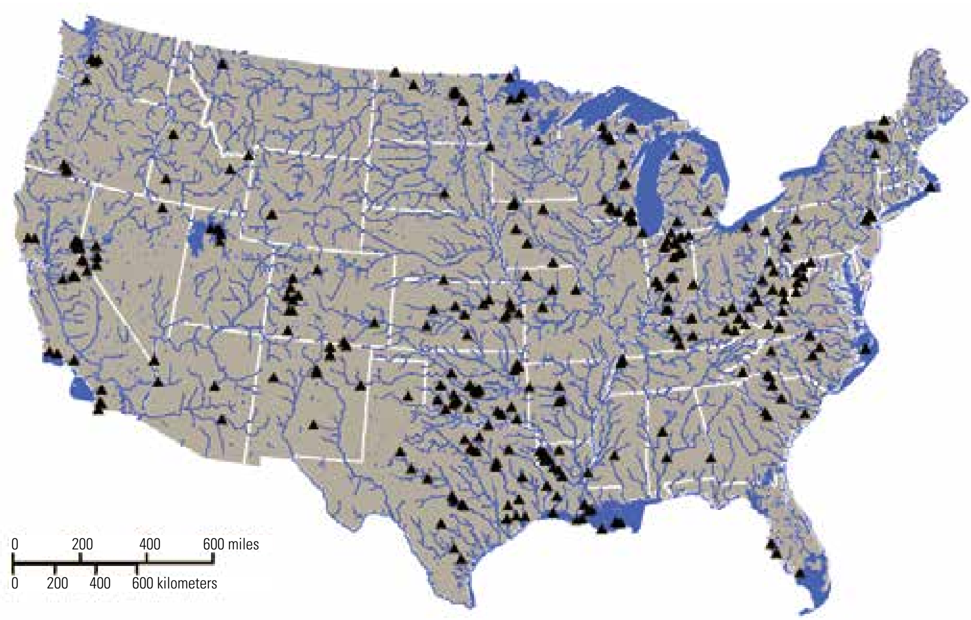


Figure 1. USGS lake and reservoir real-time monitoring stations in the continental U.S. as of 2013 (base map from the National Atlas of the United States, 2012, sites current as of Dec. 19, 2013).

How Water-Surface Elevation is Measured

There are several common systems that currently are employed to electronically measure and transmit lake stage (water-surface elevation). Some of these systems are located inside stilling wells, which are basically small tanks of water connected to the lake with pipes (Figure 2), while other systems have sensors placed directly in the lake itself to measure the elevation of the water surface (Figure 3). Each electronic system is set to the stage reading of a non-recording reference gage that is physically independent from the recording system.

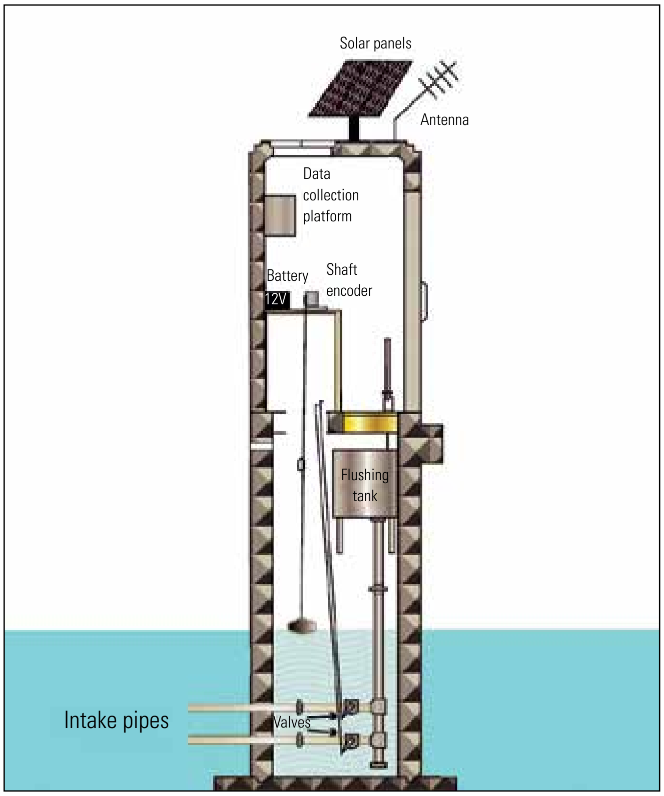


Figure 2. Diagram of a common equipment configuration inside a stilling well (modified from Sauer and Turnipseed 2010).

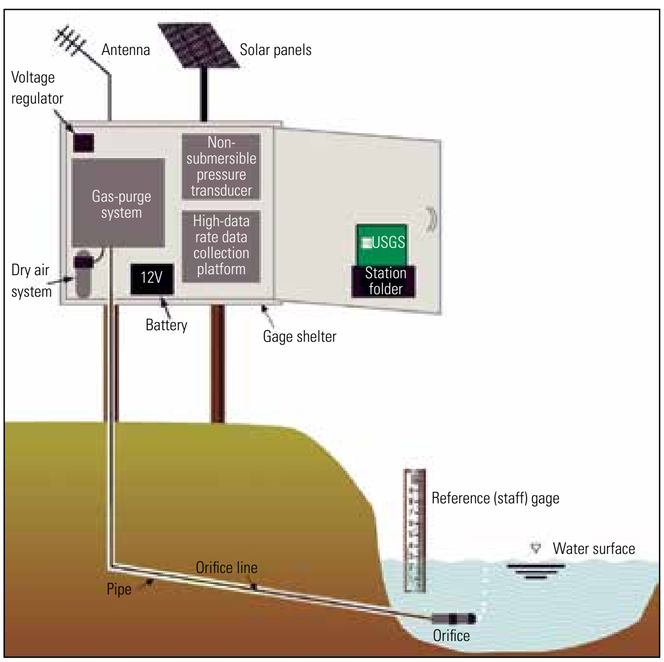


Figure 3. Diagram of a common equipment configuration on the shore of a lake (modified from Sauer and Turnipseed 2010).

A stilling well is often made of concrete, metal, or polyvinyl chloride (PVC), with intake pipes that equilibrate the water-surface elevation inside the well with the lake's water surface outside of the well. The well dampens the effects of wind and wave action on the water surface, thereby increasing accuracy of stage readings measured by the stage sensor placed inside of the well.

Recording Stage Sensors

There are three common types of recording stage sensors used at lakes: shaft encoders, non-submersible pressure transducers, and submersible pressure transducers (Figure 4). Electronic sensor readings are generally relayed to a data logger (or data collection platform) in the gage shelter (Figure 3), which collects and transmits the data so that lake managers and others have access to the real-time (current) lake elevation data on the Internet.

Shaft encoders are sensors that work on a float-pulley system inside a stilling well, where a graduated metal tape on a spindle is weighted on one end and attached to a float on the other end. As the water rises, the float rises, turning the spindle, which then registers an increase in stage and similarly, when the water surface drops, the shaft encoder indicates a decreasing stage (Figure 2).

A non-submersible pressure transducer, commonly called a bubbler system, is a system based on pressure variance where a gas is forced through tubing to a fixed orifice mounted below the water surface. The pressure transducer housed in the gage shelter measures pressure exerted on the gas in the tubing. This back pressure varies with changes in stage and can be converted from units of pressure to water head (feet of water above the end of the orifice) (Figure 3). A submersible pressure transducer is similar to the non-submersible transducer except that the sensor itself is in the water, and pressure above the unit is measured directly. This type of sensor is also generally installed in a pipe that runs from the gage shelter into the water.

Non-Recording Reference Gages

Recording stage sensors are generally very accurate, but they do need to be checked occasionally against and set to an independent reading of water-surface elevation. Non-recording "reference" gages are used for these readings and are considered to be the most accurate. Both the reference gage and the recording stage sensor are tied to the same gage datum, which can be arbitrary and gage-specific, or tied to a recognized datum such as North American Vertical Datum of 1988 (NAVD 88). For gages with stilling wells, the reference gage usually indicates the elevation of the water surface inside of the stilling well. At gages without stilling wells, the reference gage directly indicates the elevation of the lake water surface.

The four most common non-recording gages used are staff gages, wire-weight gages, tape-down reference points, and electronic tape gages (Figure 5). To ensure that these reference gages are accurate, they are periodically surveyed and checked against the elevation of nearby stable benchmarks of known elevation with a levelling instrument (usually every one to three years).

Staff gages are commonly seen near boat ramps, on the side of a lake control tower structure, inclined on a sloping bank, or installed directly in the water itself. Occasionally, staff gages are found on the inside of stilling well structures. Staff gages are essentially a long ruler attached to a fixed object in the water to determine the water elevation.

A wire-weight gage consists of a weighted steel wire that is wrapped around a drum, with a dial that rotates with each turn of the cylinder. The weighted steel wire is lowered until it just

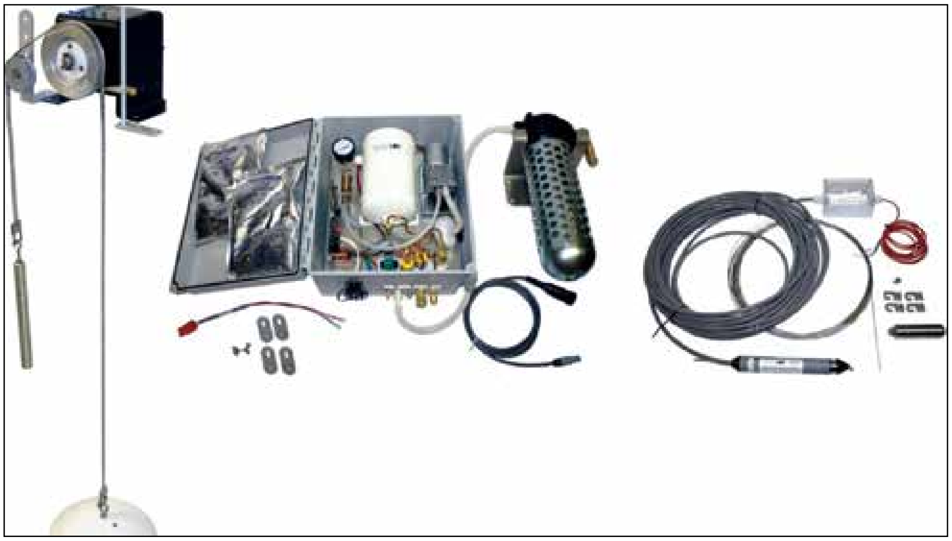


Figure 4. Example of stage sensors from left to right: shaft encoder, non-submersible pressure transducer, and submersible pressure transducer (Sauer and Turnipseed 2010).

Figure 5. Examples of non-recording reference gages: staff gage (upper left), wire-weight gage (upper right), tape-down reference point (in orange) on a stilling well (lower left), electronic tape gage (lower right, Sauer and Turnipseed 2010).

touches the water surface, and then the dials are read. A wire-weight gage is an auxiliary reference gage used to determine that the intake pipes in a stilling well are clear, and that the water level inside the well is representative of that outside the well. A measurement of stage inside a stilling well is more accurate than a wire weight reading due to the dampening of waves by the well.

A tape-down from a reference point in a stilling well is a similar process, where a chalked steel measuring tape is lowered into the water, suspended from a reference point. It is then pulled up, the wetted mark is read, and then the reading is subtracted from the point on the measuring tape that was held at the reference point. This calculation gives a distance from the measuring point to the water surface. This distance is then subtracted from the known elevation of the reference point to get the water surface elevation. Taping down from a reference point can also be done outside of stilling wells using a wetted chalk line on the tape, or simply by directly reading the distance on the tape itself to measure a reference elevation of the lake's water surface.

Electronic tape gages (ETGs) and manual tape downs from a reference point of known elevation are very similar methods and fairly accurate when used inside a stilling well. These are usually the type of reference gages used with a stilling well type gage. An ETG is a weighted, graduated metal tape on a reel that is mounted inside a stilling well and connected to a voltmeter and power source. When the bottom of the tape touches the water surface, the circuit is completed (activating an indicator) and a technician reads a depth (the length of the unspooled tape) and subtracts that value from the reference point to get the lake elevation.

Lake Capacity and Contents

The capacity of a lake is determined by surveying the elevations of the land surface in the lake basin, both above and below the water line, up to the highest elevation the lake could potentially reach, and then using special software that converts that topographic data into volumes. The details of this process involve conducting a bathymetric survey, where technicians make many transects across the lake in a boat with survey-grade depth sounders and GPS instrumentation (Figure 6). The transects are spaced apart at approximately 1% or less of the longitudinal length of the lake. Depths are referenced to the known water surface elevation at the time of the survey. These data are then compiled and modeled in GIS software along with the best available topographic elevation data for the land in the basin above the water line, usually determined from Light Detection and Ranging (LIDAR) imaging. A contour map is produced and refined and a capacity table is computed from this model (Figure 7, Wilson and Richards 2006). The capacity and surface area tables, with values of acre-feet (volume) and square feet (area) in the United States and indexed by stage in hundredths of feet, act as tools for making informed management decisions and conducting scientific studies.

This nationally consistent and unbiased real-time lake elevation and contents data can be accessed from the main USGS water website at http://water.usgs.gov. From there, real-time streamflow, groundwater, and water quality data are available, as well as an abundance of information on work done by USGS Water Science Centers. Real-time water data can be found more directly by visiting http://waterdata.usgs.gov and searching by name, region, or category.

Uses of the Data:
Water Management and Recreation

One important use of accurate lake elevation and associated capacity (Figure 8) is flood mitigation and drought alleviation. In flood conditions, outflow from the lake is controlled to reduce flood damage, while still meeting other primary uses, such as drinking water supply or irrigation allotments. In times of drought, knowing lake elevation and capacity in real-time helps managers maintain minimum water releases, wherein the water for ecosystem health, recreational use, and existing water rights are not adversely affected downstream of the lake.

Lake elevation and capacity are also vital to understanding the effects of sedimentation and the long-term capability of the lake to store water. As most lakes age, sediment deposition increases, causing reductions in capacity, depth, and surface area, which can lead to water shortages and loss of biodiversity (Miranda and Krogman 2013). Real-time turbidity data, sediment core sampling, bathymetric surveys, calculated residence time, and comparisons of historic area-capacity tables can give accurate assessments of the loss in capacity of the lake over time. For example, John Redmond Reservoir, near Burlington, Kansas, has experienced a great loss in capacity. From its completion in 1964 to 2010, 42% of the conservation pool capacity has been lost due to sedimentation, a deposition rate which is nearly double the rate predicted at the

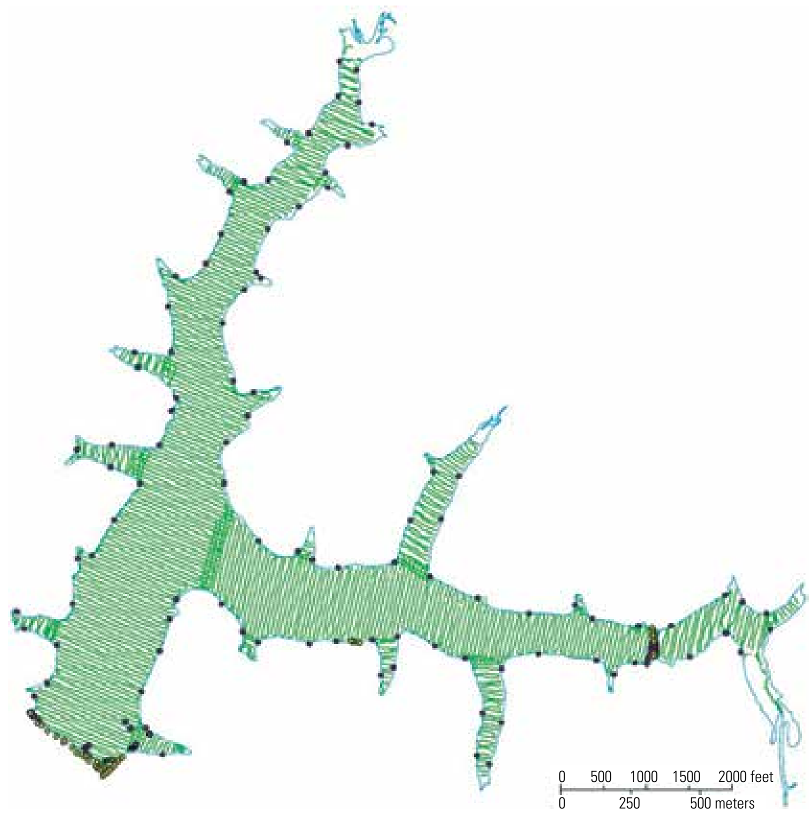
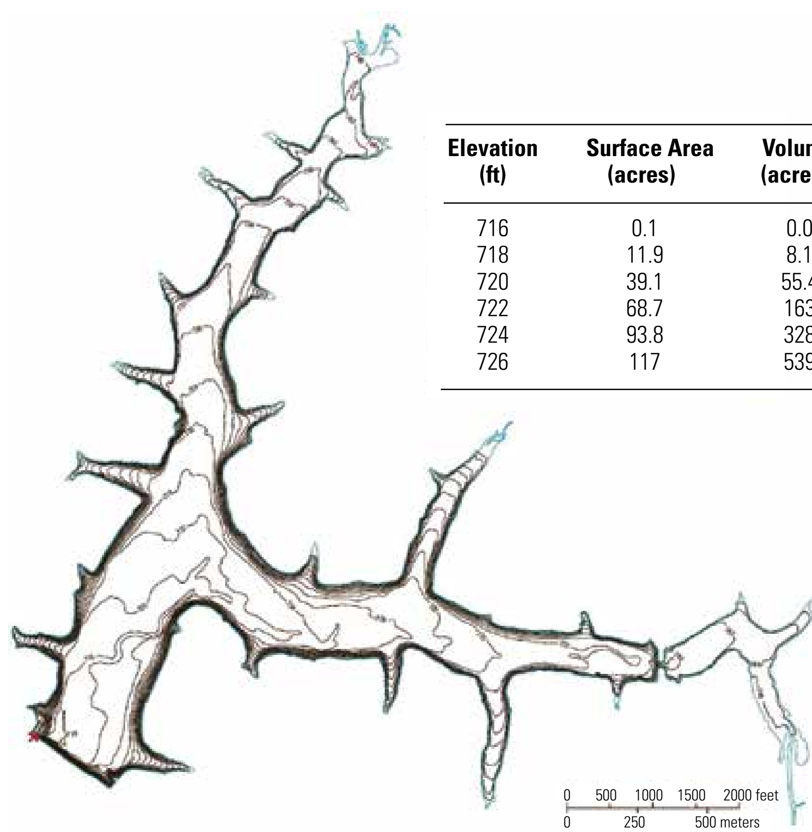


Figure 6. Layout of a bathymetric study, depicting echo-sounder, target-point, and land-survey data at Sugar Creek Lake near Moberly, Missouri (Wilson and Richards 2006).



Elevation (ft)	Surface Area (acres)	Volume (acre-ft)
716	0.1	0.0
718	11.9	8.1
720	39.1	55.4
722	68.7	163
724	93.8	328
726	117	539

Figure 7. Bathymetric contour map computed from survey data at Sugar Creek Lake near Moberly, Missouri, and a portion of the corresponding area and capacity table (Wilson and Richards 2006).

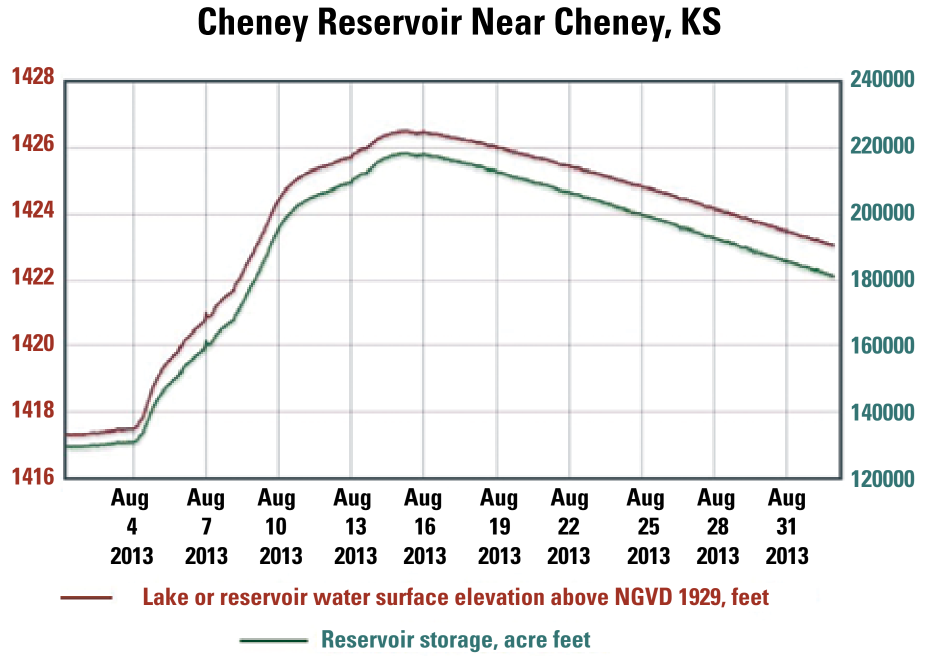


Figure 8. Example of real-time lake elevation and contents data (referenced to NGVD 1929, or National Geodetic Vertical Datum of 1929) at USGS gaging station 07144790, Cheney Reservoir near Cheney, Kansas, available at http://waterdata.usgs.gov.

reservoir's inception (Lee and Foster 2012). This study described an altered management scenario to assist lake managers in reducing sedimentation effects, including larger, rapid releases after large inflow events.

Another significant use of lake capacity data is the determination of water residence time, which, according to Kalff (2002), is the average length of time required to refill a basin with water if it were to be emptied. Water residence time is a calculated variable that affects general limnological processes such as nutrient dynamics and biological community structure. More specific applications include predictions of harmful algal bloom (HAB) formation, models for the occurrence of the taste- and-odor compounds geosmin and 2-methylisoborneol (MIB) (important to drinking water quality), and sedimentation rates (Journey et al. 2013, Lee and Foster 2012). For example, the taste-and-odor compounds geosmin and 2-methylisoborneol (MIB) are most commonly produced by cyanobacteria and actinomycetes bacteria. Generally, cyanobacteria cause these compounds to occur during HABs when residence time is longer, where inflow amounts are low. Conversely, actinomycetes bacteria can generally cause the taste-and-odor compounds to occur after inflow events, when actinomycetes bacteria are abundant and water residence time is short (Beussink and Graham 2011).

Outside the realm of scientific studies and water management decisions, lake elevation and capacity play a significant role in recreation. Bathymetric contour maps, coupled with stage, can act as a guide for safe navigation and possibly indicate which parts of the lake would be good for fishing.

USGS Water Data

Real-time lake elevation and contents data will continue to serve an essential function as water becomes a more regulated and scarce resource. For 125 years, the USGS has provided these impartial water data to meet a variety of water quantity and quality needs facing our nation and our communities. These data, collected at nearly 1.5 million sites in the United States, Puerto Rico, Virgin Islands, Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands, are available to the public online in the form of real-time or historical graphs, tables, samples, maps, and articles, from the main portal at http://water.usgs.gov.

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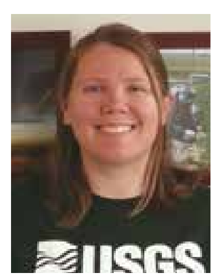

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