Reprinted from Eos, Vol. 85, No. 20, 18 May 2004

EOS
EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

VOLUME 85 NUMBER 21

18 MAY 2004

U.S. Stream Flow Measurement and Data Dissemination Improve

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Stream flow information is essential for many important uses across a broad range of scales, including global water balances, engineering design, flood forecasting, reservoir operations, navigation, water supply, recreation, and environmental management. Growing populations and competing priorities for water, including preservation and restoration of aquatic habitat, are spurring demand for more accurate, timely, and accessible water data. To be most useful, stream flow information must be collected in a standardized manner, with a known accuracy, and for a long and continuous time period.

The U.S. Geological Survey (USGS) operates over 7000 stream gauges nationwide, which constitute over 90% of the nation's stream gauges that provide daily stream flow records, and that are accessible to the public. Most stream flow records are not based on direct measurement of river discharge, but are derived from continuous measurements of river elevations or stage. These stage data, recorded to 3-mm accuracy, are then converted into discharge by use of a stage/discharge relation (rating) that is unique for each stream gauging location. Because stream beds and banks are not static, neither is the stage discharge rating. Much of the effort and cost associated with stream gauging lies in establishing and updating this relation. Ten years ago, USGS personnel would visit stream gauging stations 8 to 10 times a year to make direct measurements of river depth, width, and velocity using mechanical instruments: a sounding rod or cable, a tagline, and a current meter. From these data, flow rates were computed. The range of measured flow and concurrent river stages were then used to build the rating curve for each site and to track changes to the rating curve.

Once the correct rating was applied to the continuous stage records, the resulting stream flow data, typically accurate to within 5–10% of actual flows, would be published in reports 6–18 months later. Unfortunately, there are some conditions under which direct measurement of discharge by mechanical current meter is unreliable, unsafe, or impossible, such as during large floods or when flows are changing rapidly. In this situation, discharge is determined indirectly by surveying high-water marks left by the flow and by using hydraulic formulas to calculate discharge for the peak stage. Accuracy associated with these methods can be far less than with direct measurements.

Here and Now

Today, the rating curve continues as a dominant component of stream gauging, but much has changed in terms of how the measurements are obtained and how the data are distributed. The most important development in stream flow measurement in the last 10 years has been the deployment of acoustic Doppler current profilers (ADCPs) [*Simpson*, 2001].

An ADCP uses acoustic energy, typically in the range 300–3000 kHz, to measure water velocity throughout most of the water column by measuring the shift in the frequency of the acoustic signals reflected from materials suspended in, and moving with, the water. The ADCP determines water depth by measuring the time-of-travel of signals reflected from the channel bottom and measures boat velocity by using the Doppler shift of separate acoustic pulses reflected from the riverbed. The channel width can then be computed using the instantaneous boat velocities and time between each measurement (Figure 1).

The ADCP has made three important contributions to direct stream flow measurements. First, a conventional discharge measurement using a mechanical current meter requires a minimum of 20 individual measurements across the river, and could take as long as several hours to complete. The ADCP measurement is dramatically faster, made in a matter of minutes rather than hours, and equally accurate [*Morlock*, 1996; *Mueller*, 2003]. Second, the ADCP allows measurements in environments where conventional mechanical current meters are inappropriate or unreliable, such as in tidally affected flows, highly unsteady flows, and flood flows that heretofore may not have been measurable. Third, ADCPs are used to measure continuous profiles of water velocity. The vertical velocity distribution is no longer assumed, but rather, measured for all but the near-bed and near-surface, thereby providing more accurate measurements of stream flow. An additional advantage is that the ADCP measures the flow field in the stream channel in three dimensions, which provides a far more accurate and detailed view of velocity profiles and flow structure in the river. Use of ADCP techniques in fixed deployments has also enabled opportunities for continuous

Fig.1. Hydrographers measure stream flow using an Acoustic Doppler Current Profiler (ADCP) on the Kankakee River at Dunns Bridge, Indiana.

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measurement of flows in many difficult-to-measure situations.

The ADCP has been widely introduced within the USGS through an aggressive training and field support program. Rapid developments in ADCP technology have allowed for increasing use within the USGS, while also affording many opportunities for demonstrating its utility and value in stream flow measurements.For example, during the summer of 2003, use of ADCPs permitted USGS field crews in Indiana to make 55 flood measurements, two to three times the number of measurements that would have been possible during the same time, and using the same number of personnel using conventional current meters. Some measurements obtained in Indiana during the floods using the ADCP would not have been possible using the conventional current meter method.

Now You See It

Widespread use of the Internet has encouraged innovative solutions to make stream flow data available.Today, about 93% of the USGS stream gauging network has some kind of near-real-time telemetry, either satellite, telephone, or radio.About two-thirds of the sites are equipped with automated Data Collection Platforms (DCPs) that use satellite radio transmissions to broadcast stream stage data (along with other data) as often as every 15 minutes, 24 hours a day. In 1995, the USGS began providing real-time discharge data to the public via the Internet. Many incremental improvements have been made. Today, WaterWatch is the official USGS Web site for maps and graphs showing real-time stream flow conditions as color-coded dots at about 3000 stream gauges in the United States and Puerto Rico.WaterWatch is located at http://water.usgs.gov/waterwatch/ [*Lins*, 2002] (Figure 2).

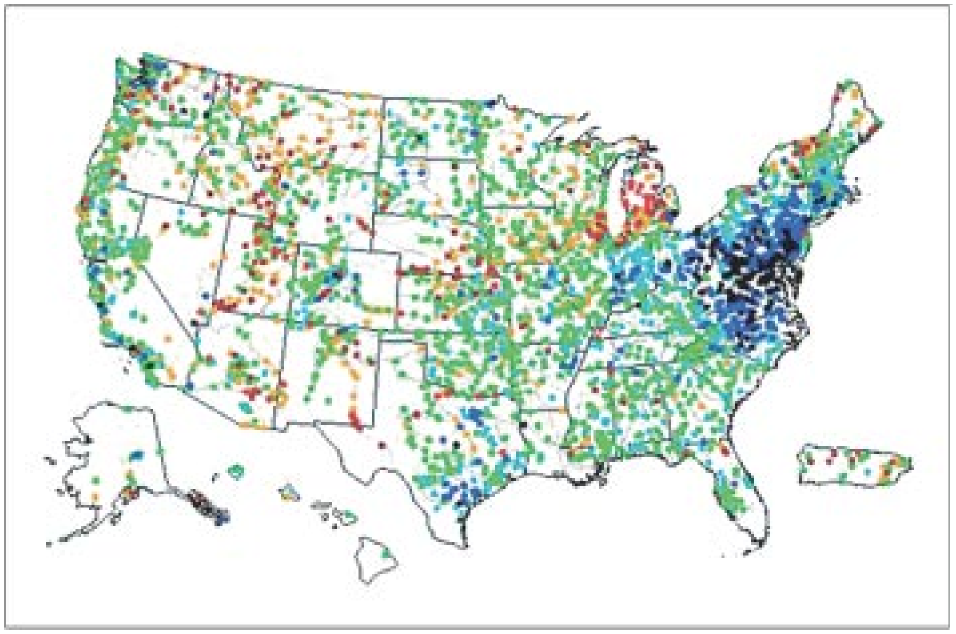

Fig. 2.This WaterWatch real-time map shows flow conditions at USGS stream gauging stations. Darker dots are gauges recording high flows.The map is for the day following the passage of Hurricane Isabel on the east coast (19 September 2003, 16:20 ET).The colors represent percentiles of stream flow that are calculated from historical observations for the current day of the year at stream gauging stations with at least 30 years of record. A major attribute of WaterWatch is a point-and-click feature that allows users to retrieve maps and graphs of real-time river stage and discharge data for individual stations. It includes pages that summarize real-time stream flow, daily stream flow, 7-day average stream flow, flood and drought flows, and graphs of recent conditions.Water-Watch also serves as a geospatial front-end to the new USGS online National Water Information System (http://water.usgs.gov/nwis), which provides open access to real-time and historical surface water, groundwater, and water quality data. NWIS-Web contains over 181 million historical daily stream flow values and makes them available in graphical or tabular form.These new data delivery systems greatly simplify the process of obtaining stream flow data from the USGS.

On the Horizon

There will always be circumstances or situations in which existing methods that require instruments to be placed in the water will be inadequate, be it a rapidly changing unstable channel or unsafe flood conditions.The value of a stage/discharge rating curve is ambiguous when the channel bottom is changing or during floods, when debris and dangerous hydraulic conditions preclude making direct measurements with a mechanical current meter or ADCP.

In recognition of these limitations, USGS researchers are engaged in a series of proof-of-concept experiments to demonstrate the use of microwave and low-frequency radars to measure discharge directly without having to place instruments in the water.To measure flow at a given cross section of a river, two pieces of information are essential: water velocity and channel cross-sectional area (depth and width). Surface velocity can be measured at various points across the river using the principal of Bragg scatter of a high-frequency (10 GHz) pulsed Doppler radar signal. Cross-sectional areas can be measured by suspending a conventional low-frequency (100 MHz) ground-penetrating radar (GPR) system over the water surface from a bridge or cableway and transiting it across the stream [*Costa et al*., 2000]. In the absence of a bridge or cableway, GPR and radar systems have been mounted on a helicopter and flown across the river, producing discharge values comparable to conventional discharge measurements [*Melcher et al*., 2002]. Continuous measurement of stream flow in this way could eliminate the need to maintain a stage discharge rating, because all the essential variables are measured directly and continuously (Figure 3).

Non-contact methods of stream gauging show great promise, but much remains to be learned. Conductivity has a significant negative effect on radar energy in water, and there are physical limits to the depth of penetration of radar energy in water.When relying on surface-velocity data, an assumption of the shape of the velocity profile is needed to convert surface to mean velocity. USGS experiments to date indicate that the assumption of a logarithmic velocity profile produces good agreement with measured velocity profiles, but this assumption may not hold in all cases.

Future Policy Issues

Hydrologists have begun to consider the possibility of measuring and monitoring surface water from space [*Alsdorf and Lettenmaier*, 2003; *Alsdorf et al*., 2003]. Many important streams and rivers worldwide have no stream gauges. The ability to measure off-channel surface water storage in wetlands, floodplains, and lakes and river discharge in virtually any location would provide new insight into the global hydrologic cycle and the role of surface water in regulating the regional and global biogeochemical cycles.

Such a space-based system might rely on radar altimetry for river stage and along-track interferometric synthetic aperture radar (SAR) measurements [*Goldstein and Zebker*, 1987] of surface velocity along an entire river reach. This requires new thinking about the spatial utility of space-based remote sensing and the present in situ or cross-sectional basis for measuring river flow. Space-based technologies are unproven as tools for measuring discharge from great distances, but with support from NASA, scientists are beginning to consider possible approaches [*Vörösmarty et al*., 1999]. Space-based instruments hold promise for measuring elevations and perhaps even flow rates of the world's largest rivers. Far smaller streams (draining less than, say, 10,000 km^2) around the world, however, including those in the United States, present significant measurement needs.These smaller streams are pervasive sources of drinking water, habitat, and flood hazards,which will challenge the resolution-cost trade-off capability of space-based sensors.

Monitoring stream flow in less-developed countries presents serious challenges.There are two possible ways to meet this need. One is to pursue space-based techniques.The other option is for nations with advanced stream gauging capabilities to work with less-advanced nations to develop the institutional capability to undertake these proven stream gauging technologies. One advantage of this latter approach is that developing the institutional capability to measure and report on stream flow may help these nations build a better infrastructure for managing these resources. Disadvantages include number, size, remoteness, and political instability of many areas outside the United States and Europe.This issue needs to be debated by a cross section of experts in hydrology and international development.

On the domestic front, the most crucial policy question remains how the stream gauging network should be supported to foster continued modernization and improved efficiency, and to assure the continuation of valuable long-term stream flow records. Since 1990, about 640 USGS stream gauges with records of more than 30 years have been discontinued. This instability comes about because the stream gauging network is heavily dependent on the funding of over 800 partner agencies. In fact, only 7% of the stream gauges are fully supported by USGS funding. Changing funding priorities of partner agencies leads directly to changes in the network and the ensuing discontinuation of critical long-term stream gauges.

A stable national stream gauging network is crucial if that network is to provide the scientific data needed to understand and manage a changing world.

Fig. 3. Pulsed Doppler radar on the bank of the San Joaquin River, California, provides surface-velocity measurements. Cable across channel is used to suspend GPR system over the water to measure channel cross section.

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