Remote Sensing of Streamflow in Alaska Rivers—New Technology to Improve Safety and Expand Coverage of USGS Streamgaging

Why Measuring River Flow in Alaska Is Important

The U.S. Geological Survey (USGS) monitors water level (water surface elevation relative to an arbitrary datum) and measures streamflow in Alaska rivers to compute and compile river flow records for use by water resource planners, engineers, and land managers to design infrastructure, manage floodplains, and protect life, property, and aquatic resources. Alaska has over 800,000 miles of rivers including the Yukon River, the third longest river in the United States. These rivers are home to rare and important ecosystems and are used for recreation, hydropower generation, commercial fishing, and transportation. River flow measurements are essential for wise and safe development and use of Alaska rivers.

Alaska River Facts

- *Alaska has more than 800,000 miles of rivers and streams*
- *The Yukon River is the third longest river in the U.S. and second largest by flow volume*
- *Alaska rivers are usually frozen from December to April*
- *Alaska rivers drain to the Arctic Ocean, Bering Sea, and Pacific Ocean*

USGS Flow Measurements in Alaska

- *USGS has partnered with NASA and is using data from NASA satellites.*
- *Alaska has one streamgage per 6,500 mi^2, compared to one streamgage per 400 mi^2 in the lower 48 States*
- *Hydrologic technicians visit streamgages six to ten times annually for maintenance and data collection*
- *On frozen rivers, USGS hydrologic technicians drill holes through the ice to take streamflow measurements*
- *Streamflow measurements at remote sites can take up to 3 days, including travel time, and some locations are only accessible by airplane or helicopter because of difficult terrain*

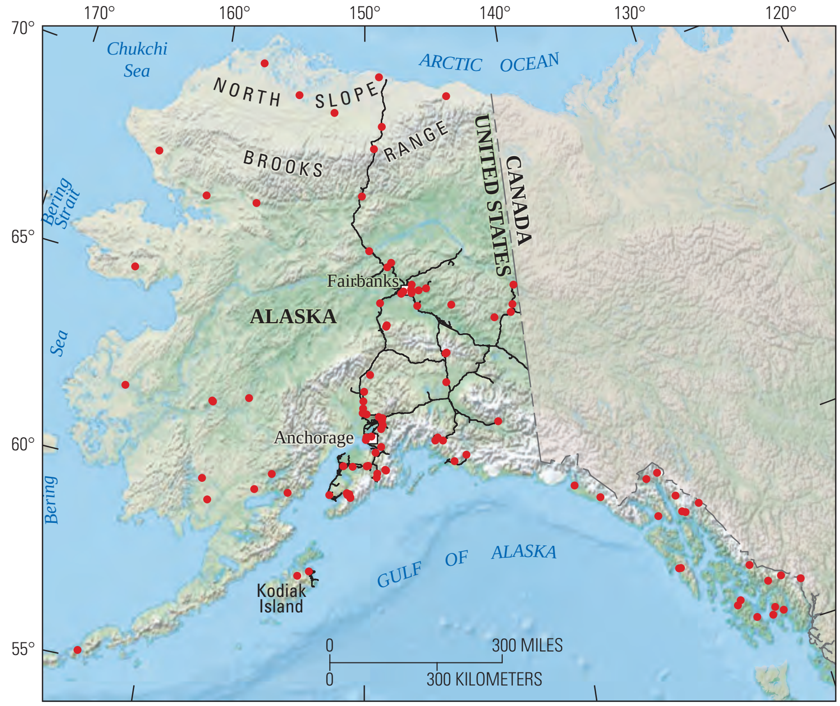

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Figure 1. Dots show U.S. Geological Survey continuous river monitoring stations in Alaska as of 2018.

How Streamflow Is Measured Today

The USGS monitors water levels at more than 100 streamgages in Alaska (fig. 1). Converting the streamgage water-level data into flow (or discharge) data requires hydrologic technicians to travel to river monitoring sites to collect direct flow measurements several times each year, including when rivers are flooded or covered with ice.

Hydrologic technicians regularly visit streamgages to measure river flow with handheld mechanical-impeller and hydroacoustic velocity meters with depth-sounding rods, or with an Acoustic Doppler Current Profiler (ADCP) that simultaneously measures water velocity and channel depth across the channel as it is pulled across the river surface by boat or cable (fig. 2). Many streamgage stations are remote and are only accessible by airplane or helicopter, requiring multiple days per visit. When rivers are covered with ice, typically from December through April, technicians drill holes through the ice to access the flowing water. River conditions are particularly hazardous during periods of ice breakup, when shore ice becomes unstable and ice floes move downstream.

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Figure 2. U.S. Geological Survey hydrologic technicians collecting flow measurement data using in-water methods: (*A*) technician measuring flow depth and velocity at Evaingiknuk Creek near Noatak, Alaska; (*B*) technician augering ice to measure flow depth and velocity beneath the ice at Copper River near Cordova, Alaska; and (*C*) technician ferrying hydroacoustic equipment across Ikalukrok Creek near Kivalina, Alaska.

How Remote Sensing Can Improve Flow Measurement

Measuring river flow with remote sensing from satellites or aircraft (such as airplanes, helicopters, and unmanned aerial systems [UAS], or drones) can improve field safety and increase the total number and frequency of streamflow measurements, particularly for isolated rivers (fig. 3). Measurements can be taken during floods without exposing hydrologic technicians to dangerous river conditions. River flow measurement during ice breakup, which is difficult or impossible with traditional streamgaging techniques, becomes feasible with remote sensing. Remote sensing can help the USGS expand its monitoring network to cover more rivers, which is a major focus of the agency, particularly in Alaska (figs. 4 and 5).

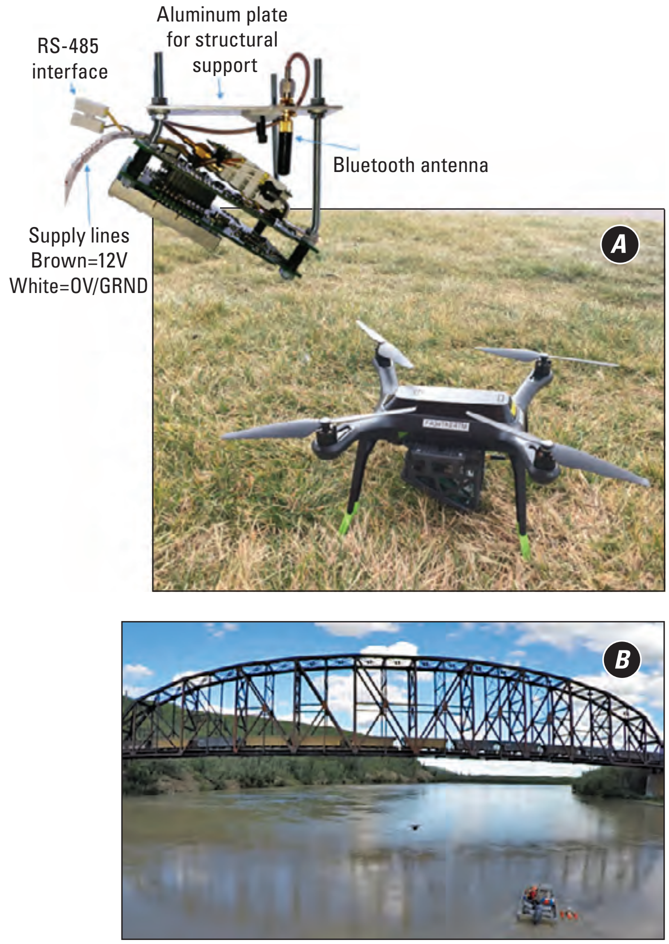

Figure 3. River surface velocities can be measured with (*A*) doppler radar mounted on small unmanned aerial systems as shown during field trials (*B*) at the Tanana River, Nenana, Alaska, July 2018.

New Remote Sensing Technology

Monitoring flow from the air or space is now possible using new technology and improvements in:

- the number of satellites;
- image processing techniques;
- unmanned aerial systems (UAS);
- advanced sensors for water-velocity and depth measurements; and,
- data storage and processing capabilities.

Analysis of remote sensing data yields estimates of river properties such as width, depth, water-surface slope, and water-surface velocity. River discharge is calculated by using hydrodynamic equations and measurements made by multiple sensors.

Surface Velocimetry

Measurement of water velocities on a river surface (surface velocimetry) is based on time-lapse images of the river surface and computer analysis of features moving on the river surface. Surface velocity data is then paired with channel bathymetry (water depth) data to calculate river discharge.

Image processing techniques such as Large-Scale Particle Image Velocimetry (LSPIV), calculate displacement of surface features such as foam or other debris, on a river surface.

Figure 4. Measurements of river flow have been tested using a helicopter-mounted thermal camera, optical camera, and lidar; all fully integrated with a global navigation satellite system (GNSS) for direct geo-referencing, Anchorage, Alaska.

Displacement distances and time between frames in the video are used to compute flow velocities at many locations on the river surface (fig. 6). A variety of velocimetry techniques and imagery can be used to compute surface velocities. For example, thermal cameras with high sensitivity to medium and long wavelengths can resolve features on the water surface caused by turbulent mixing. Thermal images are then processed to compute surface velocities based on the displacement of thermal features on the surface as they move downstream (Legleiter and others, 2017).

Doppler Radar

Doppler radar technology, commonly used to track weather conditions and to measure vehicle speeds, can also be used to measure river surface velocities. Radar signals are transmitted towards the surface of the water and the reflected signal is shifted to a different frequency because the water is moving. This Doppler shift is used to calculate the velocity of the water surface relative to the radar. Both hand-held and bridge-mounted radar Doppler velocity sensors are currently in use (Fulton and Ostrowski, 2008) and UAS mounted sensors are being tested.

Bathymetry Measurement

Knowledge of river depths (bathymetry) improves flow estimates. In clear-flowing rivers, sunlight reflected from the river bed can be measured to estimate bathymetry using spectral analysis, as demonstrated using reflectance measurements made from a bridge over the Salcha River in Alaska (Legleiter and others, 2017). In other rivers, airplane-mounted green lidar (light detection and ranging) systems have been used to measure river bathymetry (fig. 7; Miller-Corbett, 2018). New technologies are being tested for UAS deployment including midar (multispectral imaging, detection and active reflectance) that uses multispectral light-emitting diodes (LEDs). These techniques are limited to relatively clear and shallow streams in which sunlight, lasers, or LED light can penetrate the water and reflect from the river bed back to the surface (fig. 8).

Ground penetrating radar is another promising technology for measuring bathymetry (Costa and others, 2006) and, unlike the other methods mentioned here, can also be used in turbid or muddy streams but performs poorly in high conductance (salty) water and against channel beds comprised of low-reflectance materials.

Figure 5. River surface height and slope of large rivers can be measured by radar altimetry from satellites, such as the Jason-2 OSTM shown here (image from NASA Jet Propulsion Laboratory, California Institute of Technology, https://www.jpl.nasa.gov/news/news.php?feature=6890).

Altimetry

Satellites are used to measure river surface altitudes or elevations of wide rivers (more than 100 m) with an accuracy of 5 cm (Zlinszki and others, 2017) and can measure changes in river elevation with accuracies of less than 1 cm. River surface altitudes measured by satellite can be converted to river flow values using hydraulic equations such as Manning's equation (Bjerklie and others, 2018) and at-many-stations hydraulic geometry equations (Gleason and Smith, 2014).

The Future of Remote Sensing Streamgages in Alaska

In Alaska, the USGS is establishing remote sensing streamgages on river reaches that have frequent satellite overpasses and channel shapes—ideally straight and steep, more than 100 m wide, and with little turbulence or flood debris such as boulders or trees that are well suited for measurement by satellite. The first four remote sensing streamgages have been established at the Tanana River at Nenana, Tanana River at Fairbanks, Susitna River at Sunshine, and Yukon River at Stevens Village. These locations coincide with existing streamgaging stations so that the accuracy of remotely sensed flow measurements can be assessed. The goal is to expand the network of remote sensing streamgages to cover additional rivers, including some of the many rivers in Alaska that are not currently monitored. As methods for computing river flow with remote sensing become more refined from this effort in Alaska,

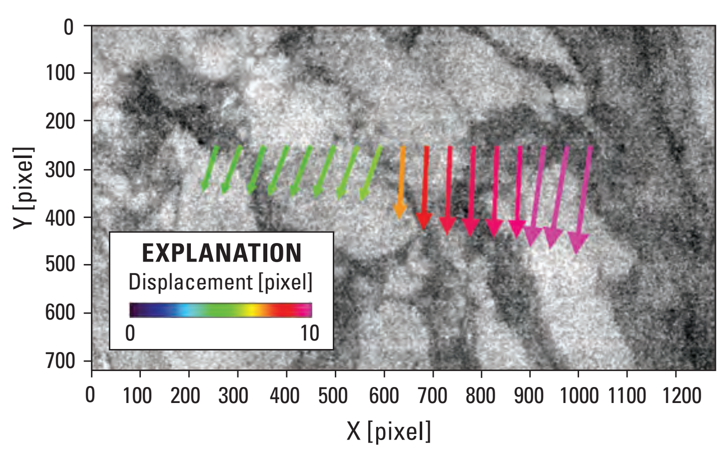

Figure 6. Infrared image overlain with flow velocity vectors derived from infrared video velocimetry analysis, Chena River, Alaska (from Kinzel and others, 2017).

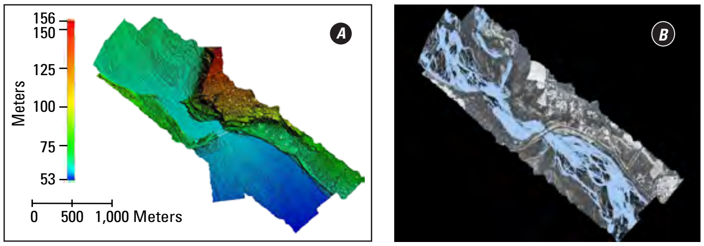

Figure 7. Images showing (*A*) topography and (*B*) laser intensity, Matanuska River near Palmer, Alaska. Water surfaces shown in blue. Data collected by helicopter-mounted Riegl VQ-580 lidar (light detection and ranging) scanning system (data from U.S. Army Corp of Engineers).

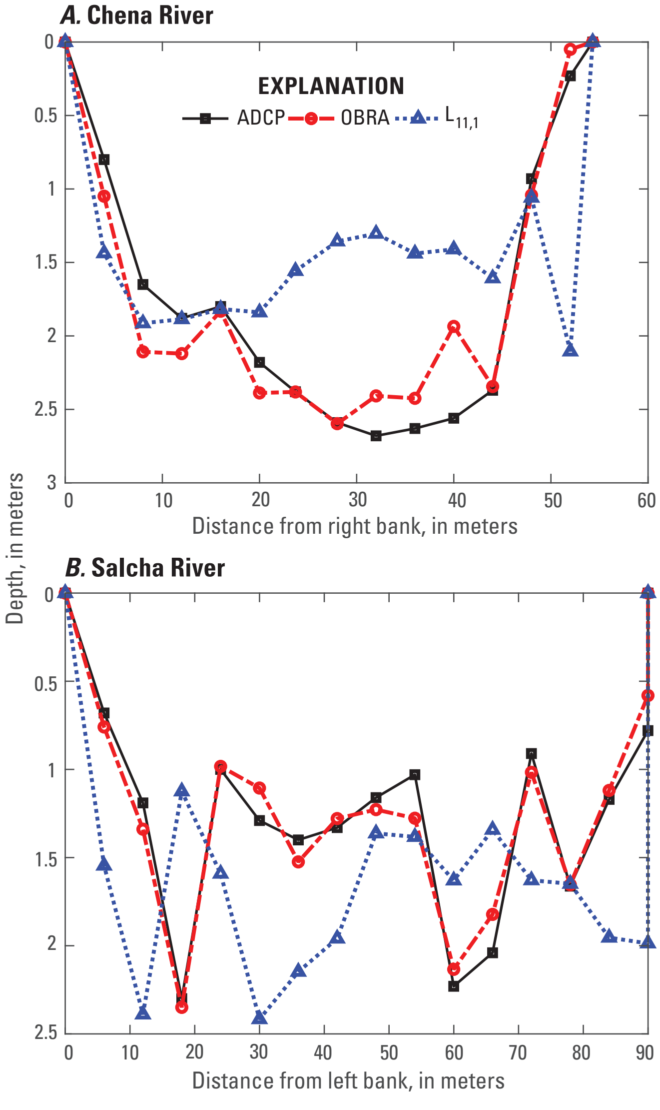

Figure. 8. River bathymetry for two study sites in Alaska, the Chena and Salcha Rivers. Field-based ADCP data provided measured ground truth for evaluating depths estimated from field spectra based on Optimal Band Ratio Analysis (OBRA) and from the length scale (L_{11,1}) of turbulent features expressed at the river surface and captured in thermal image time series

they can be applied elsewhere in the United States and the world to provide valuable data for use in emergency response, water-supply development, hydroelectric planning and operation, transportation, and natural resource management.

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