Grand Canyon Monitoring and Research Program

U.S. Department of the Interior
U.S. Geological Survey

Modeling of Sand Movement and Storage in the Colorado River Through the Grand Canyon

USGS

Recent plans to maintain and restore sandbars along the Colorado River through the Grand Canyon focused on releasing water from the Glen Canyon Dam at levels about 50 percent higher than maximum possible powerplant releases. The controlled flood during late March and early April 1996 (Bureau of Reclamation, 1994; Anderson and others, 1996) was the first such high release for resource management. The high discharges scour sand on the channel bottom, carry it in suspension, and redeposit some of it along the channel sides. These new deposits help maintain the riparian ecology and replenish camp sites used by visitors to Grand Canyon National Park. An important component of future plans to use high releases as a management tool will be estimation of the volume of sand in storage that is available for redistribution. To keep track of the sand storage in the main channel, the U.S. Geological Survey (USGS) has implemented a program combining field measurements and modeling.

Tracking Sand Supplies

Most of the sand supplied to the 386 kilometers (km) of the Colorado River between Glen Canyon Dam and Diamond Creek since the closure of the dam comes from two tributaries: the Paria River, about 25 km below Glen Canyon Dam, and the Little Colorado River about 125 km below the dam (fig. 1). The USGS measures cross sections concentrated below these two tributaries to monitor changes in bed elevation due to sand deposition and erosion at discrete locations (Graf and others, 1995a, 1995b; Jansen and others, 1995) Widely distributed measurements, however, are not sufficient to estimate sand volumes.

The shape of the channel bottom in the Colorado River through the Grand Canyon is much more complicated than in most rivers because the channel is carved into bedrock and lined with large talus blocks and gravel that are not moved by normal releases from the dam. The irregular shape causes complicated flow patterns and, as a result, complicated patterns of sand erosion and deposition that can change rapidly. Accurately monitoring sand volumes would require a large number of frequently repeated measurements. The required measurements, however, can be reduced to a manageable number with the aid of a computer model designed to account for the complicated flow, depositional, and erosional processes that shape the sand deposits between measurements. This method of using both field measurements and a model of the geomorphic processes permits accurate accounting of the sand storage. In addition, the construction and application of specially designed models are helpful in studying and understanding complex flow and transport processes.

How Does the Model Work?

The model is based on the equations that govern the physics of flow of water and the movement of sand. A computer is used to combine the equations and to solve them iteratively. The model starts with an initial set of conditions, such as the starting channel shape and the amount of sand stored on the bed, discharge through the reach, and sand entering the reach at the upstream end. The model then calculates the flow field which consists of the flow speed and direction at regularly spaced locations throughout the reach. Then the amount of sand deposited or eroded can be calculated for a small increment of time, which determines a new shape of the channel bottom. A new flow field using the new channel shape is then calculated followed by recalculating the suspended-sand distribution and the amount of deposition or erosion. This process is repeated until the desired time period has elapsed.

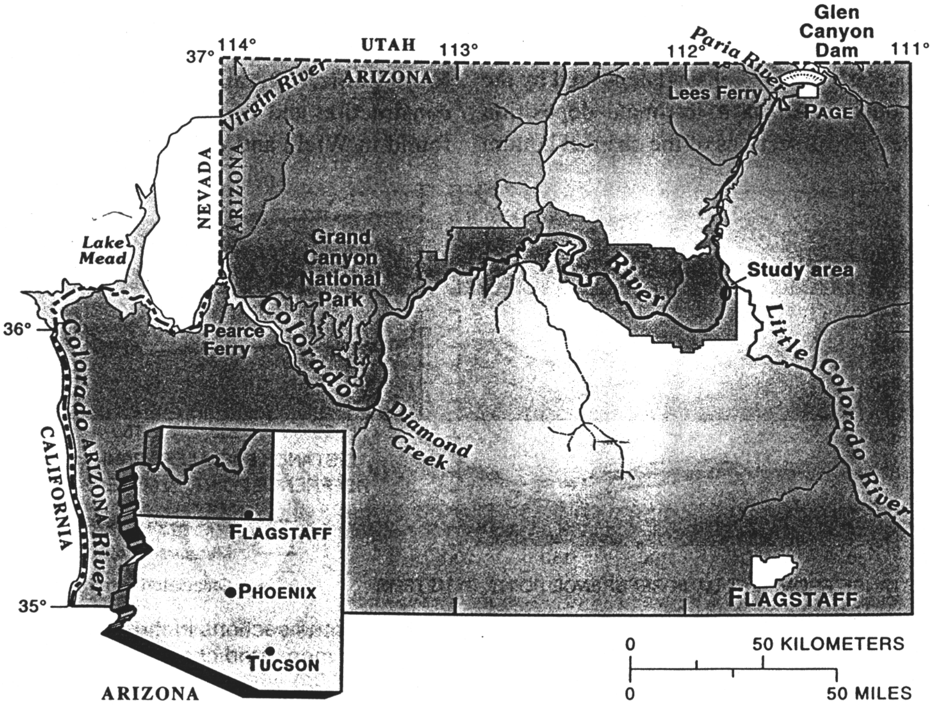

Figure 1. The Paria River and the Little Colorado River contribute most of the sand to the Colorado River.

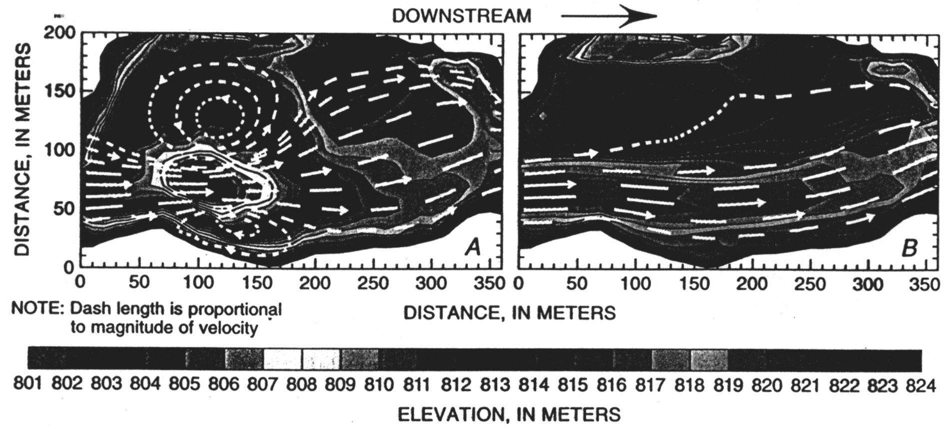

Figure 2. Flood of January 1993, Little Colorado River. *A,* Measured bathymetry and calculated flow field before the flood. *B,* Calculated bathymetry and calculated flow field after the flood. The white lines show the calculated flow fields, and the arrows indicate flow direction. The deepest areas are red and the shallowest areas are dark blue.

An Example

During January 1993, intense rains produced high discharges in the Little Colorado River. As a result, over a period of about 6 days, the discharge in the Colorado River was increased by 470 cubic meters per second (m^3/s) to a peak of about 950 m^3/s (Wiele and others, 1996) and 4.2 million metric tons of sand were transported into the main stem Colorado River (G.G. Fisk, USGS, hydrologic technician, written commun., 1994). The model was applied to four pools downstream from the confluence. These are pools of tranquil flow, bounded upstream and downstream by flow constrictions formed by fans at the base of side canyons. The model was used to calculate volumes of sand deposited by the flood as well as to estimate deposition rates. Cross sections of the channel bottom measured before and after the flood were used to check model accuracy. The calculated flow field and the channel shape before the flood and the calculated shape and flow field after 6 days of flooding for the pool that collected the most sand are shown in figure 2. Note that after the flood the deep part of the channel downstream from the inlet filled with sand, and a large sandbar formed along the left side (looking downstream) of the channel. Comparisons of the measured and calculated cross sections are shown in figure 3. This pool had the deepest deposits, up to 12 meters, and the model accuracy also is highest for this pool. Overall, there was a 6-percent difference between the total area of the measured cross sections and the areas of the model-predicted cross sections for the four pools. Details of the model construction and this application can be found in Wiele and others (1996).

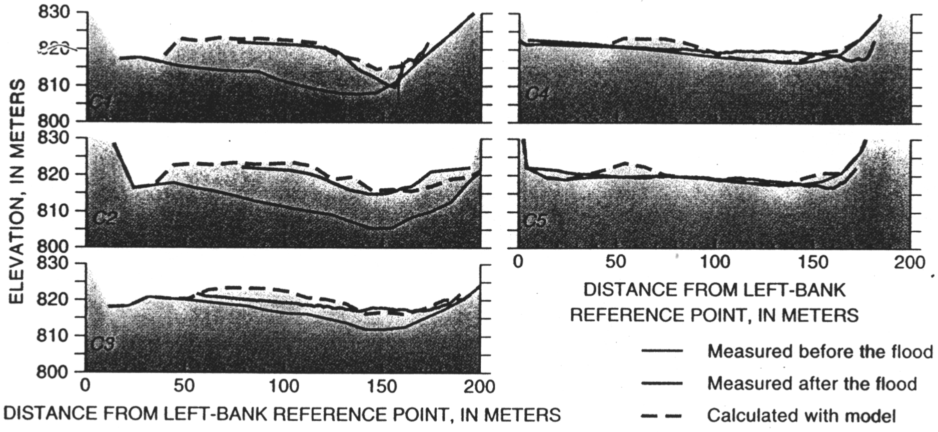

Figure 3. Comparisons of measured and calculated cross sections in the pool shown in figure 2 show that model results agree well with the measured changes. The cross sections are arranged upstream (*C1*) to downstream (*C2*) with *C1* located upstream from the deepest part of the channel shown in figure 2*A*.

One conclusion that can be drawn from this application is that a volume of sand equal to the volume that came into the main stem from the Little Colorado River was deposited within about 20 km of the confluence. However, fresh deposits of sand were observed all the way to Diamond Creek, 262 km downstream. This observation suggests that the increase in discharge in the main stem that resulted from the Little Colorado River flood scoured sand already residing on the channel bottom before the flood and redistributed that sand to form deposits along the channel farther downstream. The results of this model application supported the idea that if sufficient sand is residing on the channel bottom, high releases from the dam can be used to suspend and redistribute the sand to the channel sides. Monitoring of sand resources can be used to evaluate whether sufficient sand is available for such a redistribution by high-flow releases in the future.

References

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