A Dryland River Transformed—The Little Colorado, 1936–2010

The Little Colorado River, in northeastern Arizona, is a major tributary of the Colorado River. Over a span of 74 years, the U.S. Geological Survey (USGS) has mapped substantial migration of the river channel between the City of Winslow and the Navajo Nation community of Leupp (Tólchíí kooh). In a human lifetime, the river has moved more than 1 mile across its valley floor. Channel migration and flooding pose a considerable risk to the life and property of people living near the river. USGS scientists are working to better understand the potential for further channel adjustments and flooding to help provide communities at risk with the information they need to address these threats and make future development decisions.

Flooding along the Little Colorado River poses a serious threat to communities between Winslow and Leupp, Arizona. This photograph shows the intersection of Indian Routes 2 and 71 in the Navajo Nation, which was closed by flooding along the Little Colorado River in January 2008. Because there are few main roads and bridges in the region, such closures can have serious consequences. Nearby homes were also threatened by the flooding. (USGS photo by Lee Amoroso.)

The Little Colorado River is a major northwest-flowing tributary of the Colorado River in northeastern Arizona. Water flows year round in the headwaters and where there is groundwater discharge. Above Winslow, minor spring and seep inflow rises from bedrock fractures in the Little Colorado River channel and a large artesian spring wells up above the mouth of a perennial tributary stream. This groundwater discharge sustains base flow in the range of 4 to 5 cubic feet per second near Winslow. However, between the City of Winslow and the Navajo Nation community of Leupp (Tólchíí kooh), streamflow depends on runoff from rainfall and snowmelt, and the channel is frequently dry.

Map showing the Little Colorado River watershed in Arizona.

U.S. Geological Survey (USGS) scientists have documented changes in the channel position, length, and width of the Little Colorado River using a sequence of aerial photographs taken from 1936 to 2010. In 1936, the river meandered for 43 miles between Winslow and Leupp, a straight-line distance of 30 miles. In 2010, the river meandered for 57 miles between the same locations. In addition, the average width of the channel decreased from 1,250 to 110 feet between 1936 and 2010, a reduction of more than 90 percent. Thus, the river became longer, narrower, and more sinuous over this 74-year period.

The USGS is working to gain a better understanding of changes in the Little Colorado River channel morphology (shape and pattern) to evaluate the potential for further channel adjustments. This information may be used to help aid in risk abatement and guide future development decisions and planning by Winslow and the Navajo Nation communities of Leupp and Birdsprings (Tsidii to´ii). Many people in these communities live within 1 mile of the river channel, where channel change and flooding pose a considerable risk to life and property.

Recent flood events have caused substantial damage to infrastructure in the region. For example, a flood control levee was overtopped and breached in several locations by flooding and channel migration in December 1978. A new levee was constructed in 1989. However, despite improvements to the levee in 1991, breaching again occurred during flood events in January 1993, January 1995, and December 2004. The levee improvements were intended to provide 100-year flood protection, but peak discharge (the highest rate of flow reached during a flood event) in each of these floods was well below the 100-year flood level of 65,000 cubic feet per second (U.S. Army Corps of Engineers, 1976).

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

Fact Sheet 2011-3099
November 2011

Channel Movement Across the Valley

In just 74 years, the Little Colorado River channel moved laterally more than 1 mile across the valley floor between Winslow and Leupp. Three processes account for the shifting of the Little Colorado River across its flood plain—(1) erosion of channel banks and deposition of sediment, (2) meander cutoff, and (3) avulsion. A meandering channel migrates across its valley floor by eroding the outer bank of each bend and depositing sediment on the inner bank of the next meander bend downstream. Channel abandonment can occur through either meander cutoff or avulsion. Cutoff is the breaching of the concave banks of adjacent meanders, producing a shorter, straightened river segment. Avulsion is the breaching of the channel bank and the establishment of a new channel at a different location on the flood plain. From 1936 to 2010, there were notable increases in meander cutoff events along the Little Colorado River between Winslow and Leupp, while two major avulsions resulted in considerable changes in the position of the channel.

There have also been significant changes in the surface area of the Little Colorado River between Winslow and Leupp. Here, the Little Colorado River occupied more than 10 square miles of surface area in 1936, when it flowed in a broad, largely unvegetated channel. By 2010, the river occupied only 1 square mile of surface area and flowed in a much narrower channel through extensive stands of nonnative tamarisk (*Tamarix* spp). Tamarisk, woody vegetation native to Eurasia, began to noticeably colonize flood plains in the Southwest in the 1930s.

Dense vegetation can stabilize stream banks and promote sedimentation. The tamarisk invasion of stream banks and channels in the Western United States has long been assumed to cause channel constriction through dense growth that increases bank resistance to erosion and through excessive consumption of groundwater. However, these assumptions may not always hold true. Established tamarisk thickets have been removed by flood flows of even moderate magnitude along the Little Colorado River between Winslow and Leupp. Moreover, recent studies indicate that native species use equal or greater amounts of water when compared to tamarisk (Nagler and others, 2009).

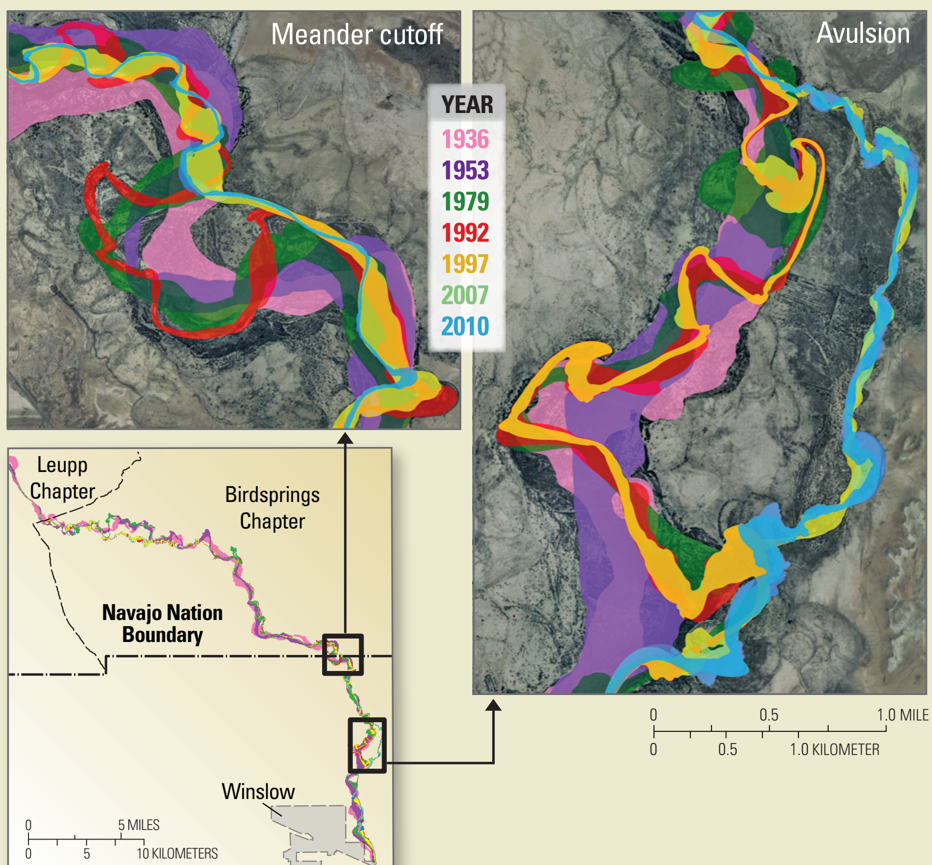
Flood Events and Dryland Rivers

Spatial and temporal variability of precipitation is particularly high in dryland drainage basins like that of the Little Colorado River. Because dryland rivers often have little or no continuously flowing water, flood events have the potential to move large amounts of sediment and significantly change the morphology or shape and position of channels. Scientists assessing river channel instability in arid and semiarid regions have found that erosion caused by channel migration resulted in economic losses that were five times greater than potential flood inundation losses (Graf, 1984). However, potential channel migration resulting from flood events is rarely accounted for in flood risk assessment. This poses a problem for flood-hazard mitigation.

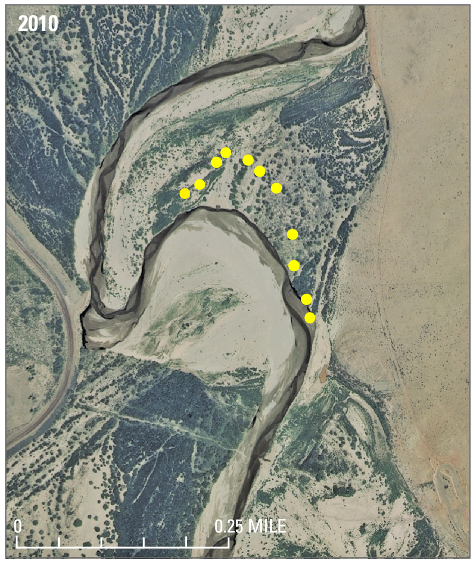
Flood-frequency analyses, used for flood-plain management and infrastructure design, provide estimated flood magnitudes for selected recurrence intervals such as 5, 10, and 100 years. The recurrence interval, or return period, is an average time interval within which a flood of a given size will recur as the annual maximum. These analyses are based on streamgage records of peak discharges. For locations that have no streamflow data, basin characteristics such as drainage area, mean elevation, and mean annual precipitation are used for predicting discharge as a function of recurrence interval. Flood hazard mapping is typically based on predicted 100-year flood levels.

Statistical methods of flood risk assessment make assumptions that are generally incorrect for dryland rivers. Two such assumptions are (1) that individual flood size is directly related to the size

Meander Cutoff and Avulsion Along the Little Colorado River



Using a sequence of aerial photographs taken from 1936 to 2010, U.S. Geological Survey scientists have documented changes in the channel of the Little Colorado River between Winslow and Leupp, Arizona. On this map, varying colors represent the position of the river channel over the past 74 years. These aerial photographs, taken in 2010, show enlarged examples of areas of meander cutoff and avulsion shown on the map. Cutoff is the breaching of the concave banks of adjacent meanders, producing a shorter, straightened river segment. Avulsion is the breaching of the channel bank and the establishment of a new channel at a different location on the flood plain.



These aerial photographs taken in 2007 and 2010 show the migration of a meander bend on the Little Colorado River in northeastern Arizona (USDA National Agriculture Imagery Program). White dots in the 2007 image show the location of the channel bank in 2010. Yellow dots in the 2010 image show the location of the bank in June 2011. From June 2010 to June 2011, the axis of the meander bend migrated at least 325 feet. The inset photo shows channel bank erosion despite dense tamarisk (*Tamarisk* spp.) growth. (USGS photo by Debra Block.)

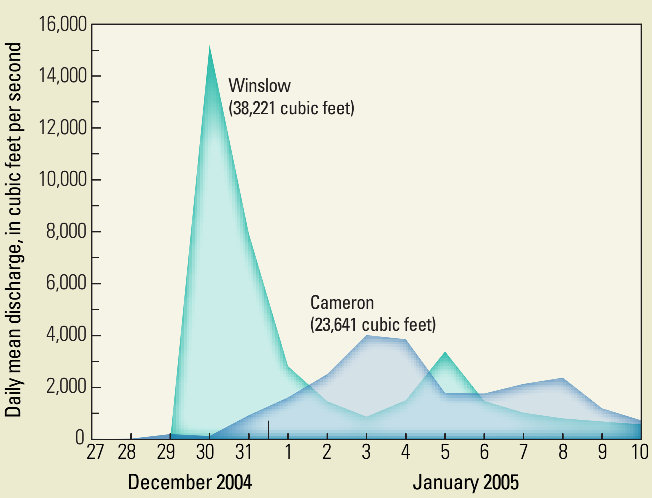
of the area drained by the stream and (2) that discharge increases downstream. The record for the Little Colorado River, however, shows that floods are often relatively localized, that no clear relationship exists between flood size and drainage area, and that discharge typically decreases downstream. For example, during a storm event with widespread precipitation on December 30, 2004, the USGS streamgage at Winslow (which records drainage from an area of 16,192 square miles) recorded a daily mean discharge of 15,200 cubic feet per second (cfs), whereas the USGS streamgage at Cameron (which records drainage from a much larger area of 26,091 square miles) recorded a much smaller daily mean discharge of 134 cfs on that same day. It took 4 days for the flood wave to reach Cameron, about 90 miles downstream of Winslow, at a greatly reduced volume. An estimate of the total flow volume for this storm shows a downstream reduction of 38% between the two gages. Water is typically lost downstream in dryland channels as a result of infiltration into channel beds and banks.

Recent overbank flooding between Winslow and Leupp is likely related to the decrease in channel width there. On January 29, 2008, peak discharge recorded at Winslow was 11,200 cfs and the stage, or elevation of the water surface, was 17.46 feet. Flood stage is considered to be 19 feet for the Little Colorado River at Winslow by the Advanced Hydrologic Prediction Service (http://www.weather.gov/oh/ahps/). However, about 22 miles downstream, where two bridges provide access for the Navajo community of Birdsprings, the river crested at or near the decking beneath the bridges and spread for nearly 2 miles across the flood plain. As the flood water receded, sediment was left piled against the bridge piers and abutments, requiring dredging.

Over the past century, changes in the amount and timing of precipitation across the Colorado Plateau region have been notable (Hereford and others, 2002). The Little Colorado River, like other channels in semiarid regions, is particularly sensitive to changes in precipitation and runoff, and therefore changes in climate affect its channel characteristics.

Implications

The trend toward a hotter and drier climate in the Southwest is superimposed on the inherent seasonal, annual, and decadal climate variability of the Little Colorado River region (http://globalchange.gov/publications/reports/scientific-assessments/us-impacts/regional-climate-change-impacts/southwest). Increased temperatures, earlier snowmelt timing, a reduction in the relative amount of snowfall to rainfall, and decreased peak streamflow have already been observed. As temperatures rise, more surface water evaporates. More moisture in



A storm beginning on December 29, 2004, caused significant flooding on the Little Colorado River in northeastern Arizona. This graph shows the daily mean discharge of the river recorded at USGS streamgages at Winslow (which records drainage from an area of 16,192 square miles) and downstream at Cameron (which records drainage from a much larger area of 26,091 square miles). It took 4 days for the flood wave to reach Cameron, about 90 miles downstream of Winslow, at a greatly reduced volume. The estimated volumetric difference in flow, for the period of the hydrograph, is calculated from the area under the "curves" on the graph. The difference of 14,580 cubic feet amounts to a downstream transmission loss of 38%. The large reduction in flood peak occurs downstream because flow is rapidly diminished by infiltration into the unconsolidated sediments of channel beds and banks.

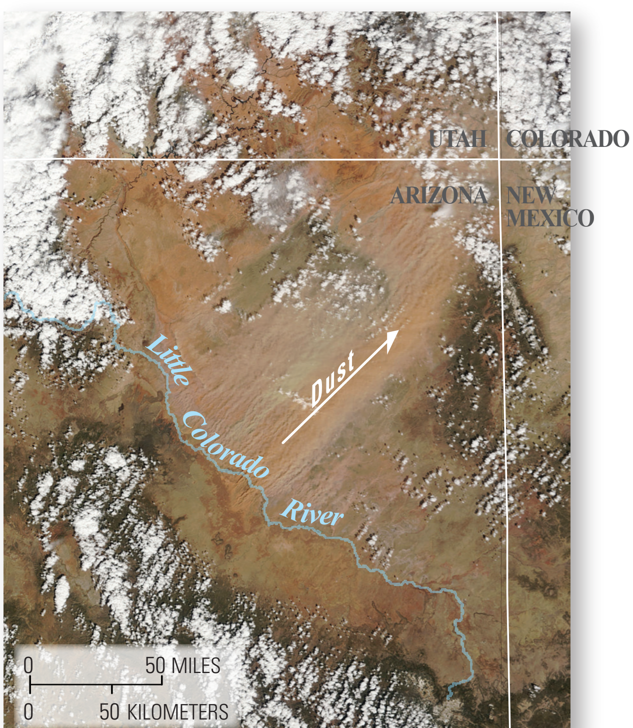
Flooding along the Little Colorado River in northeastern Arizona in January 2008 reached the decking of the Birdsprings Bridge in the Navajo Nation (photo at left). The photo at right taken in March 2008 shows the large amount of sediment deposited against the bridge by the flood. (USGS photos by Lee Amoroso.)

the atmosphere brings more intense precipitation events. These conditions set the stage for floods in a time of drought.

Flood models, however, cannot effectively simulate changes in channel form, which affect hydrological behavior. USGS scientists have mapped substantial changes in the width and position of the channel of the Little Colorado River over a short historical period—74 years. Decreasing streamflow and channel narrowing have transformed the Little Colorado River into a laterally unstable river that is susceptible to increased incidences of meander cutoff and channel avulsion. Reduction in channel carrying capacity through narrowing has also likely increased the risk of overbank flooding.

Not only has the behavior of the river changed, the availability of fine sediment for wind transport has been amplified. Dust from the dry channel and flood plain of the Little Colorado River has traveled as far as Colorado. Dust deposited on mountain snow accelerates the rate of snowmelt by increasing the amount of solar radiation absorbed. In the Little Colorado River valley, sand and dust storms threaten housing, health, and transportation. The combination of water and wind erosion and sediment transport processes, in an increasingly arid climate, are leaving the land of the Little Colorado River valley susceptible to accelerated degradation and related hazards.

The work of USGS scientists studying channel change and flood hazards in the Little Colorado River valley is helping residents better understand and prepare for natural hazards in the region. This work is only part of USGS efforts to understand natural hazards in the United States and to help protect the lives and property of our Nation's citizens.



This Moderate Resolution Imaging Spectroradiometer (MODIS) satellite image taken on April 3, 2009, shows a dust storm (tan, northeast-trending streaks in middle of image) originating in the Little Colorado River valley, Arizona. In the image, dust from the dry channel and flood plain of the river is blown into Colorado. Dust deposited on mountain snow accelerates the rate of snowmelt by increasing the amount of solar radiation absorbed. In the Little Colorado River valley, sand and dust storms threaten housing, health, and transportation, moving northeastward across the Colorado Plateau. (NASA image; http://earthobservatory.nasa.gov/IOTD/view.php?id=37791.)

References

Graf, W.L., 1984, A probabilistic approach to the spatial assessment of river channel instability: Water Resources Research, v. 20, p. 953–962.

Hereford, R., Webb, R.H., and Graham, S., 2002, Precipitation history of the Colorado Plateau region, 1900–2000: U.S. Geological Survey Fact Sheet 119-02, 4 p., available at http://pubs.usgs.gov/fs/2002/fs119-02/.

Nagler, P.L., Morino, K., Didan, K., Erker, J., Osterberg, J., Hultine, K.R., and Glenn, E.P., 2009, Wide-area estimates of saltcedar (*Tamarix* spp.) evapotranspiration on the lower Colorado River measured by heat balance and remote sensing methods: Ecohydrology, v. 2, p. 18–33.

U.S. Army Corps of Engineers, 1976, Flood plain information, Little Colorado River, vicinity of Winslow, Navajo County, Arizona: prepared for City of Winslow by Corps of Engineers, U.S. Army, Los Angeles District, California, March 1976, 27 p., 27 plates.

Debra Block and *Margaret Hiza Redsteer*

Edited by *James W. Hendley II*
Layout by *Jeanne S. DiLeo*

Field work on the Navajo Nation was conducted with the cooperation of, and under written permit from, the Navajo Nation Minerals Department. All scientific study on the Navajo Nation requires a permit from the Navajo Nation Minerals Department, P.O. Box 1910, Window Rock, Arizona 86515, (928) 871-6587.

For more information, contact:
Debra Block
U.S. Geological Survey
2255 North Gemini Drive
Flagstaff, AZ 86001
Tel. (928) 556-7138
dblock@usgs.gov
http://geomaps.wr.usgs.gov/

This Fact Sheet and any updates to it are available at
http://pubs.usgs.gov/fs/2011/3099/