

Water Clarity of the Colorado River—Implications for Food Webs and Fish Communities

The closure of Glen Canyon Dam in 1963 resulted in drastic changes to water clarity, temperature, and flow of the Colorado River in Glen, Marble, and Grand Canyons. The Colorado River is now much clearer, water temperature is less variable throughout the year, and the river is much colder in the summer months. The flow—regulated by the dam—is now less variable annually, but has larger daily fluctuations than during pre-dam times. All of these changes have resulted in a different fish community and different food resources for fish than existed before the dam was built. Recent monitoring of water clarity, by measuring turbidity, has helped scientists and river managers understand modern water-clarity patterns in the dam-regulated Colorado River. These data were then used to estimate pre-dam turbidity in the Colorado River in order to make comparisons of pre-dam and dam-regulated conditions, which are useful for assessing biological changes in the river over time. Prior to dam construction, the large sediment load resulted in low water clarity almost all of the time, a condition which was more favorable for the native fish community.



Humpback chub (*Gila cypha*) are endemic to the Colorado River Basin, meaning that they are natives not found elsewhere. Dam-regulated water conditions in Glen, Marble, and Grand Canyons are not favorable for the species, and they are federally listed as an endangered species. (USGS photo by David Ward.)

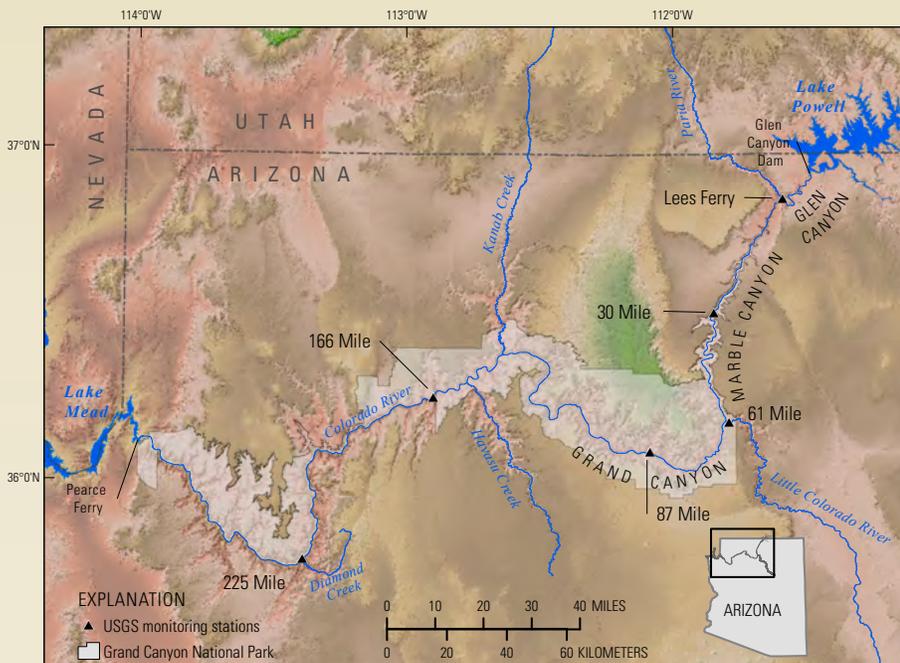


© 2013, Dave Herasimtschuk and Freshwaters Illustrated, used with permission.

During flooding, the Paria River contributes a significant sediment load to the Colorado River. At the confluence of the Paria and Colorado Rivers, sediment from the Paria River on the left side of the photo mixes with clear Colorado River water on the right.

Water Clarity in Grand Canyon

Water clarity determines the amount of light penetration through water and thus the distance that objects can be seen in water. It is often monitored by measuring turbidity, which specifies the amount of light scattered and absorbed in water (a turbidity value of 0 indicates clear water). However, turbidity is not an ideal measure of water clarity largely because readings made using different instruments are not always equal. While it is important to recognize its limitations, one advantage to using turbidity is that it is relatively easy to measure continuously using remotely deployed instruments. Water clarity in the Colorado River, like most rivers, is influenced primarily by sediment suspended in the water column (as opposed to suspended organic material such as algae or dissolved organic compounds). The water clarity of the Colorado River has been profoundly changed by the construction and operation of Glen Canyon Dam; because Glen Canyon Dam blocks the supply of sediment from upstream, turbidity in Glen, Marble, and Grand Canyons is controlled by sediment entering the Colorado River during floods in tributaries downstream of the dam. Turbidity in the Colorado River is monitored by water-quality instruments that are distributed along the river corridor, located upstream and downstream of the major tributaries that contribute sediment to the Colorado River, as well as in key areas where native fish live. These water-quality instruments record turbidity, water temperature, dissolved oxygen, and specific conductance (a



Base map modified from U.S. Geological Survey, National Elevation Dataset and other digital data, various scales. Image is Grand Canyon 10-meter DEM. Coordinate reference system: NAD 1983 StatePlane Arizona Central FIPS 0202. Horizontal datum is North American Datum of 1983

Map of northwestern Arizona showing the Colorado River, its tributaries, and locations of monitoring stations. At these stations, the U.S. Geological Survey collects measurements of water temperature, dissolved oxygen, specific conductance, and turbidity.

Measuring Water Clarity

Because water clarity (and turbidity) is primarily affected by suspended sediment, one might think that suspended-sediment concentration is a good proxy for water clarity. This is not always the case, however, because water clarity is strongly dependent on grain size. Suspended sediment that is composed of fine grain sizes, such as silt and clay, results in much lower water clarity (and higher turbidity) than an equal concentration of sediment composed of coarser grain sizes, such as sand. For this reason, turbidity, which essentially measures how much light passes through water, is a better indicator of water clarity and is, in most cases, a more useful parameter to biologists than suspended-sediment concentration.

measure of salinity) every 15 minutes (data available at http://www.gcmrc.gov/discharge_qw_sediment/stations/GCDAMP).

There is a well-established connection between water clarity and the food webs of lakes and rivers. Light is necessary for the growth of algae, which are an important food source for invertebrates such as insects. Some of these invertebrates, in turn, are an important food source for fish. Because many fish species rely primarily on eyesight for finding food, water clarity directly influences competition and predation amongst fish.

In Grand Canyon, for example, the native humpback chub (*Gila cypha*) population has significantly decreased in the dam-regulated river partly because the river is now, on average, much clearer and cooler than it was prior to the dam's construction. Humpback chub are now competing for food resources and are preyed upon by other fish species, like nonnative rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*), that are better adapted to the dam-regulated conditions.

Comparing Pre-Dam and Dam-Regulated Water Clarity

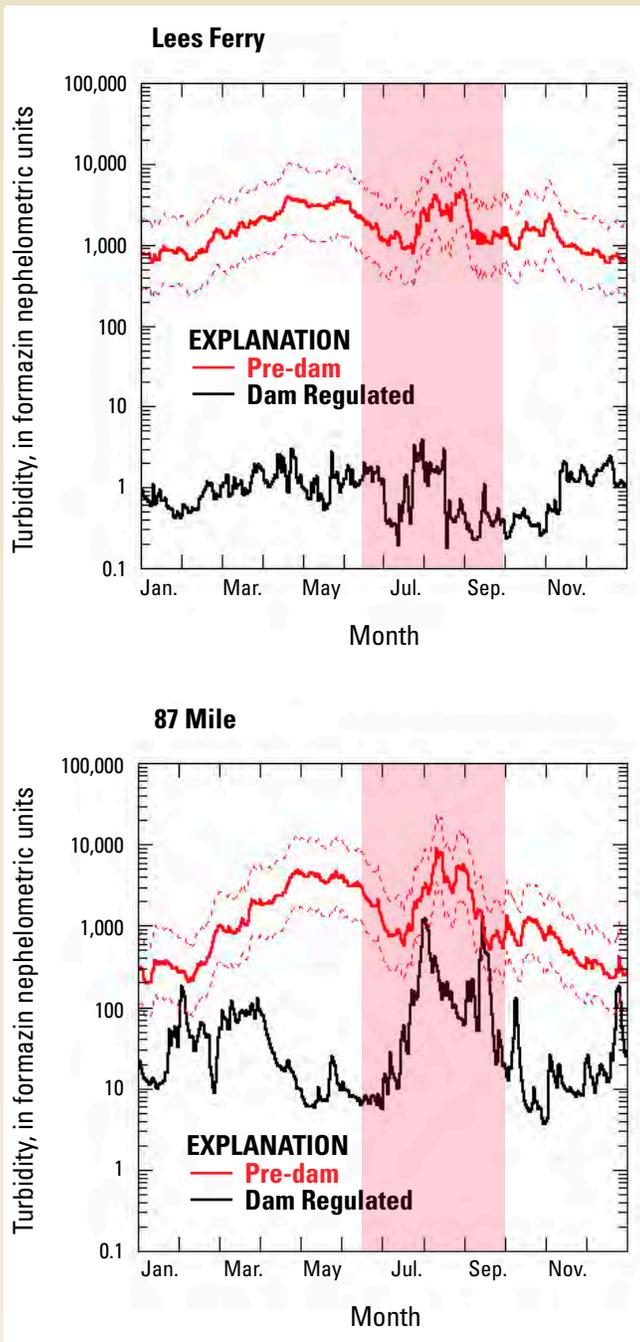
Knowing the pre-dam conditions of the Colorado River, particularly water clarity and temperature, is important to better understand the habitat that favors native fish species. In the pre-dam era, turbidity was not routinely measured, but suspended-sediment concentrations were measured daily. Because most sediment in suspension in the pre-dam river was composed of silt and clay, pre-dam turbidity was estimated from pre-dam suspended-sediment concentration by using the relation between turbidity and suspended-silt-and-clay concentration in the dam-regulated river (Voichick and Topping, 2014).

In Glen Canyon, with few exceptions, the 15-mile stretch of the river from the dam downstream to Lees Ferry is clear year round (see graphs on next page). In Marble and Grand Canyons, there are only two tributaries that account for most of the suspended sediment and almost all the resultant turbidity in the Colorado River: the Paria River and the Little Colorado River. Sediment inputs from these two tributaries result in a stepwise change in water clarity, with marked increases in turbidity just downstream of the input of the Paria and the Little Colorado Rivers.

Glen Canyon Dam has blocked all upstream sediment from entering the reach of Glen Canyon downstream of the dam, and has reduced suspended sediment in Marble Canyon from pre-dam levels by approximately 95 percent, so it is not surprising that pre-dam turbidity estimates are much higher than dam-regulated measurements. Pre-dam turbidity estimates were, on average, 2,000 times higher



Turbidity is measured in units called Formazin Nephelometric Units, which describes how a beam of light is scattered by the particles suspended in water. A higher value indicates more scattering, that is, higher turbidity. But the size of the particles in suspension matters. The two cylinders shown above contain equal concentrations of sediment but the grain sizes are different. The cylinder on the left, which has much lower water clarity and higher turbidity, holds primarily silt- and clay-sized particles, whereas the cylinder on the right contains larger, primarily sand-sized particles. (USGS photo by Jason Fobair.)



Graphs showing pre-dam (red) and dam-regulated (black) geometric daily mean turbidity at the Lees Ferry (upper) and 87-mile (lower) monitoring stations through the course of the year. The y-axes are in Formazin Nephelometric Units, which is a commonly used unit for measuring turbidity. Higher numbers are higher turbidity (less clear water). The scale of the y-axis is logarithmic, where each labeled scale mark is 10 times the value of the preceding labeled mark. The pink shaded areas show the thunderstorm season in summer and fall, when turbidity levels are generally higher downstream of Lees Ferry. Pre-dam values are estimated using a known relation between turbidity and suspended sediment. (See Voichick and Topping, 2014, for more information on this calculation.)

than dam-regulated turbidity in the Colorado River at Lees Ferry and 20 times higher than dam-regulated turbidity in Grand Canyon at the 87-mile station (see graphs on left).

As water clarity decreases, sight-feeding fish, such as trout, are less able to see their prey. One study showed that when turbidity reaches a value of approximately 40 Formazin Nephelometric Units (FNU, see photo on next page), additional increases in turbidity do not make much of a difference in the visual acuity of fish such as trout (Sweka and Hartman, 2001). In the pre-dam river at the 87-mile station, turbidity was always at a high enough level where sight-feeding fish would have had difficulty detecting their prey (native fish employ other senses to perceive prey items). However, in the dam-regulated Colorado River at the 87-mile station, turbidity is at lower levels approximately half the time, such that trout are able to see their prey more easily. Before Glen Canyon Dam was built, turbidity estimates at the Lees Ferry and 87-mile stations were very similar to each other, but modern measurements show that the water at Lees Ferry is very clear while the water downstream is more turbid. These differences indicate that, prior to the construction of the dam, the Paria River and Little Colorado River were relatively minor influences on water clarity compared to sediment inputs from the Colorado River upstream from where Glen Canyon Dam was later constructed. Today, however, those two tributaries provide the vast majority of sediment in the Colorado River downstream from Glen Canyon Dam.

Seasonal variations in water clarity were also very different before and after Glen Canyon Dam was built. Although the pre-dam river was relatively turbid year round, the lowest turbidity (clearest water) occurred in the winter when flows were low and the highest turbidity was during the spring runoff and summer and fall thunderstorm season. The dam-regulated Colorado River is generally clear (less than 10 FNU) in Marble and Grand Canyons in the spring and late fall when tributaries are not flooding. The river has higher turbidity during winter storms and the summer and fall thunderstorm season when turbidity can approach pre-dam levels.



At the confluence of the Colorado and the Little Colorado Rivers, the difference in sediment load is apparent. The Colorado, entering at the top of the photo, is relatively clear, while the Little Colorado, emerging from its canyon at the right edge of the photo, is laden with sediment. The lower left of the photo shows the mixing of the two. (USGS photo from the 2009 overflight of the river corridor.)

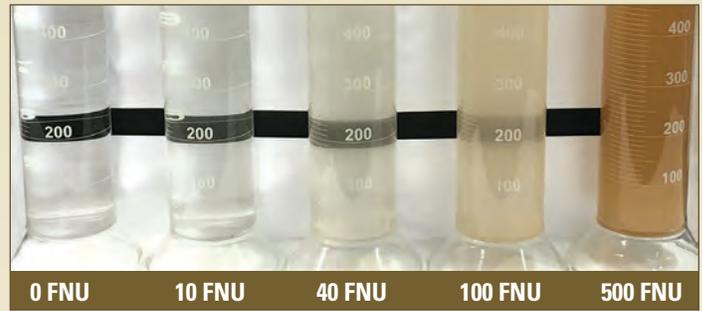
The cylinders in this photo show five different turbidity levels, labeled in Formazin Nephelometric Units (FNU). Turbidity was measured using the same instrument that was used in the Grand Canyon study. (USGS photo by Taylor Roe.)

Water Clarity, Temperature, and Biology

Water clarity has an overriding influence on key biological processes in rivers. The large change in water clarity that occurred following closure of Glen Canyon Dam fundamentally changed the structure of Colorado River food webs. For example, clearer water has allowed algae to proliferate, and algae now fuels the production of more than 50 percent of invertebrates (such as insects) and fish throughout Glen, Marble, and Grand Canyons (Hall and others, 2015; Kennedy and others, 2013). Additionally, nonnative rainbow trout, which is the most common fish species in Glen Canyon and has been a dominant species in Marble Canyon, would likely not be present in the Colorado River downstream from Glen Canyon Dam if pre-dam turbidity levels existed today.

Colder water temperature in the Colorado River downstream of Glen Canyon Dam also affects fish and food webs in the river corridor, because fish growth and reproduction is optimal at specific water temperature ranges, which vary among species. The growth of humpback chub is slowed in the cold Colorado River, and smaller humpback chub have higher mortality rates than larger fish and are more susceptible to being preyed on by trout.

Humpback chub are most plentiful near the confluence of the Little Colorado River, which is their primary spawning area. Nonnative trout prey upon the humpback chub in this critical area, and water clarity affects these native-nonnative interactions (Yard and others, 2011): clear water conditions allow trout to more easily see their prey; however, the feeding behavior of trout and their distribution relative to the shoreline, where they may be more likely to interact with small prey fish, are also influenced by water clarity. Whether trout encounter and consume more humpback chub in the Colorado River during clear water conditions or when turbidity levels are high is unresolved and may depend on other factors such as the number and size of predator and prey fish as well as water temperature. Continuing to monitor turbidity as well as water temperature in the Colorado River will aid biologists in determining how changes in these parameters affect the fish community and the rest of the food web.



References Cited

- Hall, R.O., Jr., Yackulic, C.B., Kennedy, T.A., Yard, M.D., Rosi-Marshall, E.J., Voichick, N., and Behn, K.E., 2015, Turbidity, light, temperature, and hydropeaking control primary productivity in the Colorado River, Grand Canyon: *Limnology and Oceanography*, v. 60, no. 2, p. 512–526.
- Kennedy, T.A., Cross, W.F., Hall, R.O., Jr., Baxter, C.V., and Rosi-Marshall, E.J., 2013, Native and nonnative fish populations of the Colorado River are food limited—Evidence from new food web analyses: U.S. Geological Survey Fact Sheet 2013–3039, 4 p., <http://pubs.usgs.gov/fs/2013/3039>.
- Sweka, J.A., and Hartman, K.J., 2001, Influence of turbidity on brook trout reactive distance and foraging success: *Transactions of the American Fisheries Society*, v. 130, p. 138–146.
- Voichick, N., and Topping, D.J., 2014, Extending the turbidity record—making additional use of continuous data from turbidity, acoustic-Doppler, and laser diffraction instruments and suspended-sediment samples in the Colorado River in Grand Canyon: U.S. Geological Survey Scientific Investigations Report 2014–5097, 31 p., <http://pubs.usgs.gov/sir/2014/5097>.
- Yard, M.D., Coggins, L.G., Baxter, C.V., Bennett, G.E., and Korman, J., 2011, Trout piscivory in the Colorado River, Grand Canyon; effects of turbidity, temperature, and fish prey availability: *Transactions of the American Fisheries Society*, v. 140, no. 2, p. 471–486, <http://www.tandfonline.com/doi/pdf/10.1080/00028487.2011.572011>.

*Nicholas Voichick, Theodore Kennedy, David Topping,
Ronald Griffiths, and Kyrie Fry*

Design and layout by *Bill Gibbs* and *Vivian Nguyen*
Edited by *Claire Landowski*

For more information:

U.S. Geological Survey, Southwest Biological
Science Center
Grand Canyon Monitoring and Research Center
Flagstaff, Arizona
<http://www.gcmrc.gov>

ISSN 2327-6932 (online)
<http://dx.doi.org/10.3133/fs20163053>