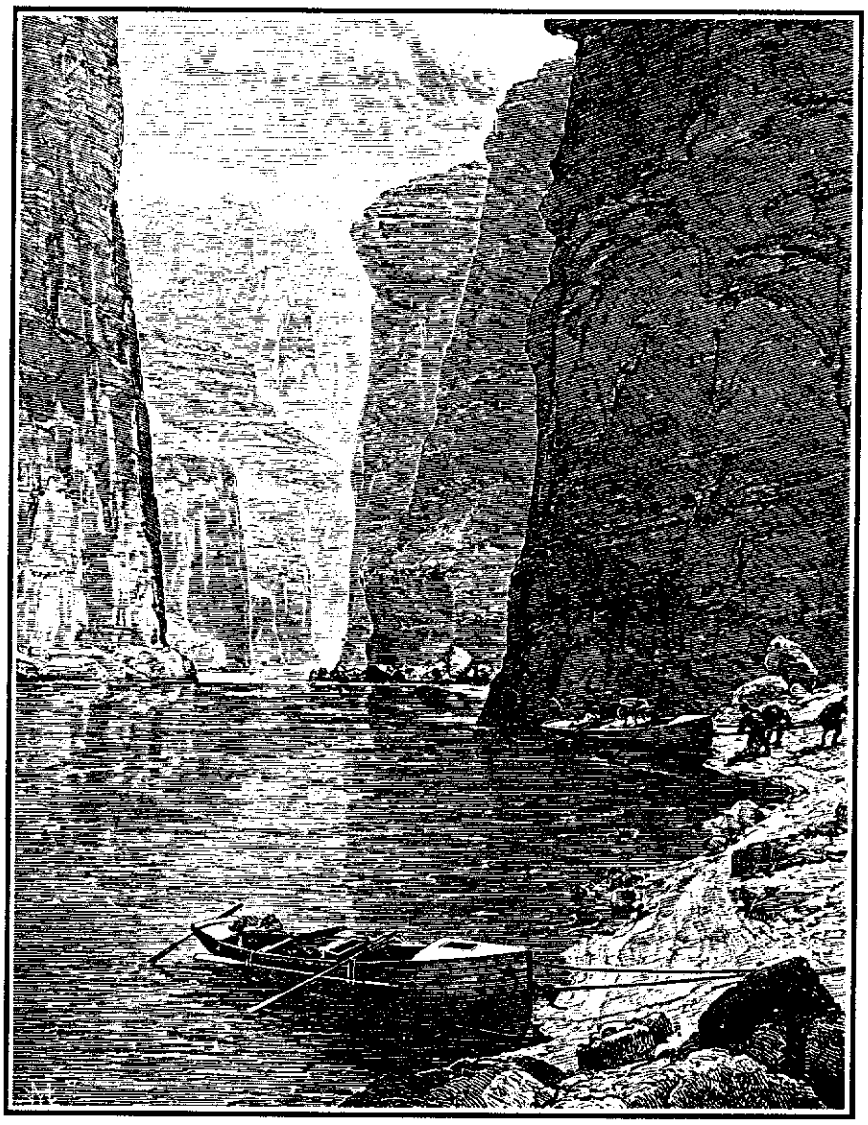
# Life History and Ecology of the Humpback Chub (Gila cypha) in the Colorado River, Grand Canyon, Arizona

## Supplement No. VI:
## *Flow Routing Model*

A simple method for estimating stream discharge on the Colorado River below Glen Canyon Dam



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Cover drawing from Powell (1875)

# Life History and Ecology of the Humpback Chub (Gila cypha) in the Colorado River, Grand Canyon, Arizona

Supplement No. IV
Flow Routing Model: A Simple Method for Estimating Stream Discharge on the Colorado River below Glen Canyon Dam

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# Table of Contents



## LIST OF FIGURES

# FLOW ROUTING MODEL

## INTRODUCTION

This effort was undertaken to develop a method for estimating streamflows on the Colorado River below Glen Canyon Dam. In their conduct of studies to evaluate the response of the Colorado River fishery to variable releases from Glen Canyon Dam, BIO/WEST fish researchers required flow information for specific river locations. Fish are generally flow sensitive, and seek particular flow velocities (which are a function of stream discharge) for specific activities. Researchers investigating fish activities therefore needed a means to estimate stream discharge so that its effect on fish activities could be quantified.

Though the several gages provide a record of flow conditions on the Colorado River, long reaches of the river are ungaged. Additionally, though much of the BIO/WEST work was conducted in the vicinity of the confluence with the Little Colorado River (from RM. 56.0 to RM 76.6) the discharge records at the gage above the Little Colorado River (Gage No. 9383100) were often unreliable. Discharge measurements at this gage would become spurious when affected by the Little Colorado River when that river was flooding. This gage was discontinued in April 1993, and replaced by a GCES gage. However, overlapping records from these two gages yielded slightly different streamflow values. The requirement for streamflow data for the fisheries investigation, and the lack of available data prompted conducting this investigation.

## BACKGROUND

Streamflow in the Colorado River in the Grand Canyon is almost entirely controlled by Glen Canyon Dam, located about 15 miles upstream of the Lees Ferry. Flow releases at Glen Canyon Dam can vary dramatically during a 12-hour period. Under recent operational criteria, releases have been lowest at night and highest during the day. The cyclic daily release pattern is based upon operational criteria designed to meet electrical power demands while simultaneously limiting impacts on the Colorado River riparian environment. Though several tributaries including the Paria River, Little Colorado River, and Havasu Creek enter the Colorado River below Lake Powell, releases from Glen Canyon Dam amount to over 98 percent of the flow in the river.

For many rivers, where streamflow fluctuates little during the day, an estimate of streamflow at an ungaged location can readily be made using the daily average flow value from a nearby gaging station. On the Colorado River below Glen Canyon Dam, where flows vary substantially over 12 hours, such an estimation procedure is not usable. Because of the large diurnal streamflow fluctuations, flow records from a gaged site cannot be directly used to estimate flow at an ungaged site.

In simplest terms, the cyclic flow releases at Glen Canyon Dam can be thought to travel downstream as waves, quite similar to flood waves. Figure 1 illustrates the travel of one releasewave measured at three gaging stations on the Colorado River. Most apparent is the time lag between the wave at an upstream location and a downstream location. From Lees Ferry to the mouth of the Little Colorado River, the wave is lagged about 16 hours; another five hours of lag occurs down to the Bright Angel gage.

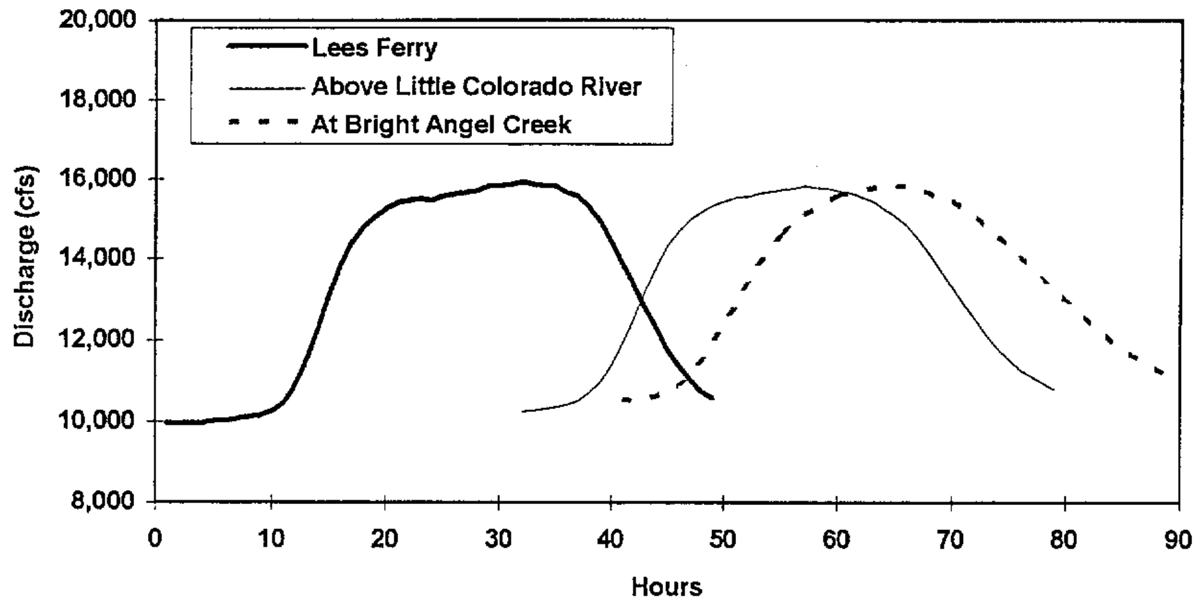


Figure 1. Hydrograph illustrating a release wave traveling down the Colorado River below Glen Canyon Dam. The above Little Colorado River gage is 61.2 miles downstream from Lees Ferry, and the Bright Angel gage is 87.4 miles downstream of Lees Ferry.

In addition to being lagged, as a wave progresses downstream, it tends to subside and disperse or become longer and lower. Figure 1 also illustrates this phenomenon. The peak of the hydrograph lowers as the wave progresses downstream. (Note that the increase in the peak discharge at Bright Angel is the result of inflow from the Little Colorado River). The endpoints of each hydrograph, which are located at the beginning and end of one wavelength, show a greater discharge for downstream waves. This greater discharge is the result of the wave's attenuation.

## APPROACH

Several methods of transposing a streamflow hydrograph from a gaged location to an ungaged location can be developed, including the use of flood wave routing theory, utilizing simple uniform flow routing equations, or by transposing a streamflow hydrograph from a gaged location to an ungaged location. The simplest approach is to purely transpose the hydrograph from a gage to an ungaged location. As illustrated by Figure 1, this approach would be approximately correct, though not totally accurate. However, if factors such as hydrograph attenuation are incorporated into the model equations, a high degree of accuracy might be achieved. Because of the time and budget constraints of the project, this simple hydrograph translation approach was taken.

Discharge estimates from upstream gages can be transposed downstream by "lagging" the upstream hydrograph by a given length of time. The amount of lagging required is, however, variable and dependent upon discharge. As discharge increases, flow velocities increase and the release wave travels downstream at a faster rate. Because discharge for the peak of a wave is greater than for the trough, the peak of a wave actually travels faster than the trough. It is possible for a wave peak to overtake its leading trough as the wave travels downstream, and this does occur in the lower reaches of the Grand Canyon. Therefore, the hydrograph translation equations must account for a variable lag dependent upon discharge.

A second factor that must be accounted for in transposing a hydrograph downstream is wave attenuation, whereby the wave flattens, the trough rises, and the peak falls. This phenomenon can be implemented in the translation equations by averaging several hydrograph flow periods. In essence, a moving average is used to filter the original hydrograph - a process which lowers the peak and raises the trough of the output hydrograph.

The translation equations developed herein implemented variable hydrograph lagging and wave attenuation through a step function. The approach used is best illustrated by presenting the step function used to translate the hydrograph recorded at Lees Ferry to RM 61.2 (above the Little Colorado River). The step function is:

If $Q_{[RM\ 61.2]-0.5} > 16{,}000$ cfs
Then use the average of $Q_{[Lees\ Ferry]}$ for the previous 8 to 14 hours.

If $12{,}000 \text{ cfs} < Q_{[RM\ 61.2]-0.5} < 16{,}000$ cfs
Then use the average of $Q_{[Lees\ Ferry]}$ for the previous 9.5 to 16 hours.

If $10{,}000 \text{ cfs} < Q_{[RM\ 61.2]-0.5} < 12{,}000$ cfs
Then use the average of $Q_{[Lees\ Ferry]}$ for the previous 11 to 14.5 hours.

If $8{,}000 \text{ cfs} < Q_{[RM\ 61.2]-0.5} < 10{,}000$ cfs
Then use the average of $Q_{[Lees\ Ferry]}$ for the previous 12 to 14.5 hours.

If $6{,}000 \text{ cfs} < Q_{[RM\ 61.2]-0.5} < 8{,}000$ cfs
Then use the average of $Q_{[Lees\ Ferry]}$ for the previous 12 to 21.5 hours.

If $Q_{[RM\ 61.2]-0.5} < 6{,}000$ cfs
Then use the average of $Q_{[Lees\ Ferry]}$ for the previous 12 to 22.5 hours.

If $12{,}000 \text{ cfs} < Q_{[RM\ 61.2]-0.5} < 16{,}000$ cfs
Then use the average of $Q_{[Lees\ Ferry]}$ for the previous 9.5 to 16 hours.

where

$Q_{[RM\ 61.2]-0.5}$ is the estimated discharge for the previous 30 minute (0.5 hour) period at RM 61.2

and

$Q_{[Lees\ Ferry]}$ is the recorded discharge at Lees Ferry.

Because of the step nature of the function, discontinuities occur when discharge changes from one step to the next. These discontinuities were filtered using a 2.5 hour centered moving average to smooth the output from the step function.

## RESULTS AND DISCUSSION

The overall results of using hydrograph translation equations on the Colorado River is acceptable, though far from perfect. Figure 2 below illustrates a comparison of actual discharge at the above

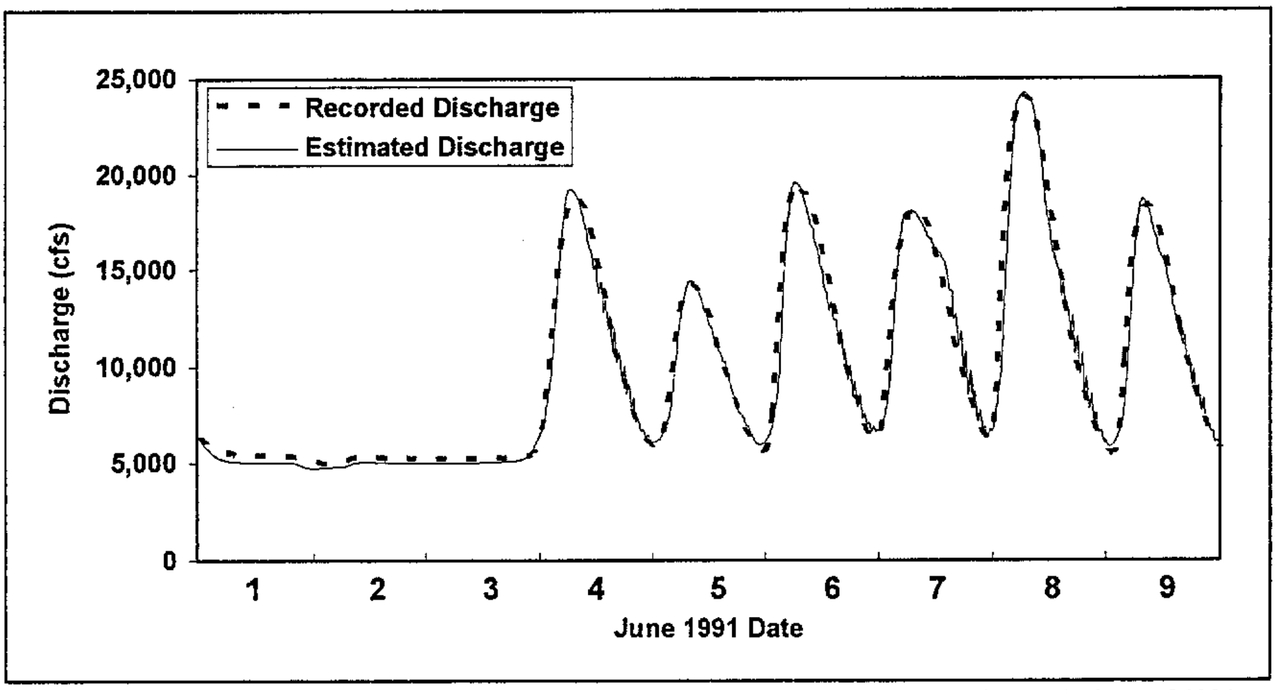


**Figure 2. Comparison of recorded discharge and estimated discharge at RM 61.2 during early June of 1991.**

Little Colorado River gage with discharge estimated using the step function presented above. The hydrograph illustrates the period from June 1 to June 9, 1991, in which a 5,000 cfs research release was made during the first few days of the month.

The average error between the estimated discharge and the actual discharge at the above LCR location is about 600 cfs. Most of the discrepancies are much less than 600 cfs (plus or minus 600 cfs). However, a few high error values skew the result. The greatest errors occur when releases from Glen Canyon Dam are rapidly ramped upward. In the situation where discharge is increased from 8,000 cfs to 25,000 cfs during a 4-hour period, a 5,000 cfs underestimation of discharge is likely. At present, the model equations do not account for the rate of change in discharge. Instead, they only utilize the previous 30-minute period discharge as a reference. Undoubtedly, accuracy of the translation equations could be increased by accounting for ramping rates.

A printout of streamflow estimates using this model at 30-minute intervals is provided for 1991, 1992, and 1993 as Appendix A.