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Importance of measuring discharge and sediment transport in lesser tributaries when closing sediment budgets

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ABSTRACT

Sediment budgets are an important tool for understanding how riverine ecosystems respond to perturbations. Changes in the quantity and grain size distribution of sediment within river systems affect the channel morphology and related habitat resources. It is therefore important for resource managers to know if a river reach is in a state of sediment accumulation, deficit or stasis. Many sediment-budget studies have estimated the sediment loads of ungaged tributaries using regional sediment-yield equations or other similar techniques. While these approaches may be valid in regions where rainfall and geology are uniform over large areas, use of sediment-yield equations may lead to poor estimations of loads in regions where rainfall events, contributing geology, and vegetation have large spatial and/or temporal variability.

Previous estimates of the combined mean-annual sediment load of all ungaged tributaries to the Colorado River downstream from Glen Canyon Dam vary by over a factor of three; this range in estimated sediment loads has resulted in different researchers reaching opposite conclusions on the sign (accumulation or deficit) of the sediment budget for particular reaches of the Colorado River. To better evaluate the supply of fine sediment (sand, silt, and clay) from these tributaries to the Colorado River, eight gages were established on previously ungaged tributaries in Glen, Marble, and Grand canyons. Results from this sediment-monitoring network show that previous estimates of the annual sediment loads of these tributaries were too high and that the sediment budget for the Colorado River below Glen Canyon Dam is more negative than previously calculated by most researchers. As a result of locally intense rainfall events with footprints smaller than the receiving basin, floods from a single tributary in semi-arid regions can have large (≥10×) differences in sediment concentrations between equal magnitude flows. Because sediment loads do not necessarily correlate with drainage size, and may vary by two orders of magnitude on an annual basis, using techniques such as sediment-yield equations to estimate the sediment loads of ungaged tributaries may lead to large errors in sediment budgets.

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1. Introduction

Sediment budgets are an important tool used by scientists and resource managers to evaluate changes in sediment mass and sediment-associated riverine habitat (e.g., Andrews, 1986; Randle and Pemberton, 1987; U.S. Department of the Interior, 1993; Topping et al., 2000; Singer and Dunne, 2001; Grams and Schmidt, 2005; Erwin et al., 2012; Grams et al., 2013; Dean et al., 2016). The standard mass-balance sediment-budget equation for a given river reach is:

$$\Delta S = I + I_{GT} + I_{UT} - E \quad (1)$$

where ΔS is the calculated change in the sediment mass stored in the reach, I is the mass of the sediment input from upstream, I_{GT} is the mass of the sediment input from gaged tributaries entering the reach, I_{UT} is the mass of the sediment input from ungaged tributaries entering the reach, and E is the mass of the sediment exported downstream. Each of the four terms on the right side of Eq. (1) has an associated uncertainty arising from potential biases in the measurements or estimates of sediment loads (Topping et al., 2000, 2010). Unlike random errors that cancel out over time, biases accumulate over time leading to uncertainties that are best expressed as a fixed percentage of each of the four terms on the right side of Eq. (1) (Topping et al., 2000, 2010; Dean et al., 2016). Propagation of these uncertainties through Eq. (1) yields the calculated uncertainty in ΔS. All of the terms on the right side of Eq. (1) are typically based on measurements except for the I_{UT} term. The I_{UT} term is almost always estimated, thus allowing the sediment budget to be closed and solve for ΔS. Owing to recent advances in surrogate technologies for continuously measuring suspended sediment (Gray and Gartner, 2009; Rasmussen et al., 2009; Topping and Wright, 2016), all of the terms on the right side of Eq. (1) can now be measured with greater accuracy than ever before, except for the I_{UT} term, which is still typically estimated. In most rivers, ΔS is small relative to $I + I_{GT}$ and E (i.e., it is a small difference between large numbers). Thus, bias from estimation of the I_{UT} term could result in ΔS that is not

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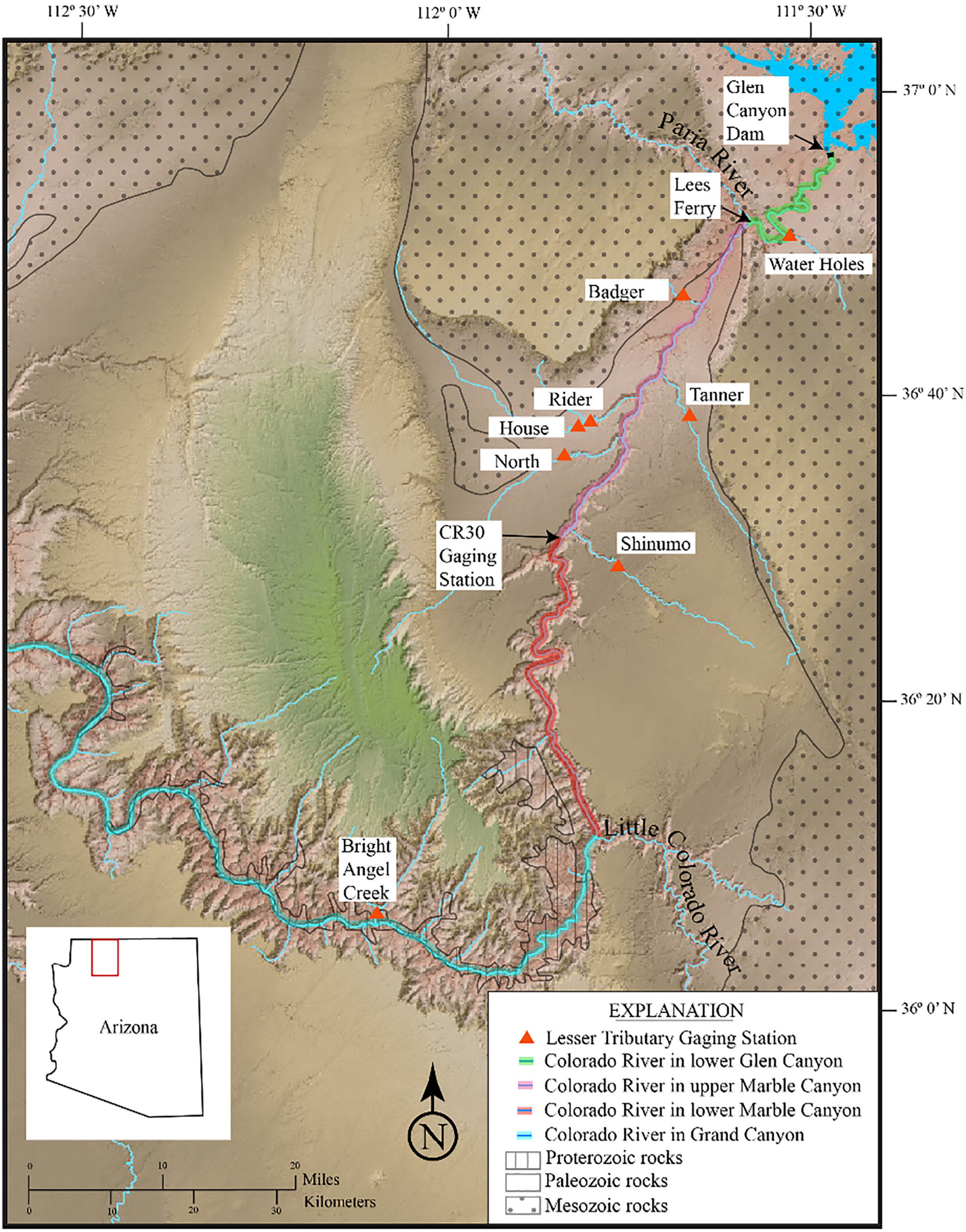
112° 30' W
112° 0' W
111° 30' W
37° 0' N
36° 40' N
36° 20' N
36° 0' N
Glen Canyon Dam
Paria River
Lees Ferry
Water Holes
Badger
Rider
House
North
Tanner
CR30 Gaging Station
Shinumo
Little Colorado River
Bright Angel Creek
Arizona
N
0 10 20 Miles
0 10 20 30 Kilometers
EXPLANATION
Lesser Tributary Gaging Station
Colorado River in lower Glen Canyon
Colorado River in upper Marble Canyon
Colorado River in lower Marble Canyon
Colorado River in Grand Canyon
Proterozoic rocks
Paleozoic rocks
Mesozoic rocks