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A reach-averaged model of diurnal discharge wave propagation down the Colorado River through the Grand Canyon

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Abstract. As part of the Glen Canyon Environmental Studies, we have developed a discharge model that routes daily discharge waves released from Glen Canyon Dam to Diamond Creek, 386 km downstream. Owing to the length of the diurnal discharge wave and the sparseness of the available topographic data, the latter were averaged over the entire length of the system. Terms too small to be significant in the momentum equation were identified by scaling arguments based on data from past dam releases and on channel hydraulic geometry. Channel friction results primarily from form drag on large topographic elements and from variations in cross-sectional area and flow depth, rather than bed roughness, producing a stage-dependent friction that is not well represented by a constant value of standard channel roughness parameters, such as Manning's n. Channel friction as a function of stage was determined from field data available at high discharge (792 m^3/s) and intermediate discharge (425 m^3/s) and by using simple kinematic wave theory together with wave speed measurements to determine channel friction at low discharge (about 142 m^3/s). Model predictions of wave speed and shape agree well with data from five streamflow gaging stations and 42 stage gaging stations located along this segment of the Colorado River.

Introduction

Accurate prediction of the progression and evolution of discharge waves released from Glen Canyon Dam is required for studies of the riparian environment along the Colorado River in the Marble and Grand Canyons (Figure 1). The effect of daily variations in discharge on sand bars [*Beus et al.*, 1991; *Budhu and Contractor*, 1991; *Carpenter et al.*, 1991; *Carruth et al.*, 1991; *Cluer*, 1991; *Werrell et al.*, 1991; *Kaplinski et al.*, 1992], recreation, [*Kearsely et al.*, 1994; *Bishop et al.*, 1987; *Brown and Hahn-O'Neill*, 1987], birds and fish [*Brown and Johnson*, 1987; *Maddux et al.*, 1987; *Brown and Leibfried*, 1990; *Brown and Stevens*, 1991; *Persons et al.*, 1985], macroinvertebrates [*Leibfried and Blinn*, 1987], native riparian trees [*Anderson and Ruffner*, 1987], and lizards [*Warren and Schwalbe*, 1988] has been the subject of intense interest during research for the Glen Canyon Environmental Studies (GCES), a program that has focused on evaluating the effects on the river corridor of the operation of Glen Canyon Dam. As part of an investigation of flow and sediment transport through that reach, we have developed a one-dimensional model to route discharges released from Glen Canyon Dam through the canyons below. Although the shape of the channel and hydraulics of the river are complicated locally, they can be represented on a scale comparable to that of the lengths of the waves, about 200 km, by average channel properties and relatively simple fluid mechanics. Splitting the 386-km-long channel into two or three parts produced little improvement in the predictions. Our model, developed with this approach in mind and employing an accurate treatment of channel friction, has shown good accuracy over a wide variety of flow conditions.

The model has been used to predict the rates of increasing and decreasing discharge and peak and trough discharges as functions of space and time for measured and proposed dam releases. A primary purpose of the model is calculation of hydrographs at points along the river in support of field studies and establishment of upstream boundary conditions on discharge for detailed quasi-steady pool-scale models of flow, sediment transport, and bed evolution. The model also has been used to reconstruct flood flows from tributaries and, with additional information about local conditions, to calculate stage during bathymetry surveys. It also forms the foundation for computation of suspended sand transport through the Grand Canyon from the two remaining major sources of sand, the Paria and Little Colorado Rivers, that flow into the main stem 25 and 124 km, respectively, below the dam. Routing the discharge waves as described in this paper, along with the construction and application of detailed flow, sediment transport, and bed evolution models of specific reaches of particular interest, has proven to be a cost-effective and computationally efficient method for accurately characterizing flow and sediment transport in this complex system.

This paper describes our discharge wave model in detail and compares model results with data from streamflow gaging stations at which discharge can be computed from a stage discharge relation and with data from streamflow gaging stations for which only stage data are available.

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Previous Work

Modeling of flow in the Marble and Grand Canyons was of little concern before the start of GCES in 1983. Wave propagation was modeled by *Lazenby* [1987], who used data from the streamflow gaging stations to calibrate a three-parameter unsteady discharge model that employs a single wave speed for waves of all magnitudes. The Bureau of Reclamation accurately modeled routine dam releases with the National Weather Service DAMBRK model [*Fread*, 1988] in the reach