

# Flood routing in ungauged catchments using Muskingum methods

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## Abstract

River stage or flow rates are required for the design and evaluation of hydraulic structures. Most river reaches are ungauged and a methodology is needed to estimate the rates of flow, at specific locations in streams where no measurements are available. Flood-routing techniques are utilised to estimate the stages, or rates of flow, in order to predict flood wave propagation along river reaches. Models can be developed for gauged catchments and their parameters related to physical characteristics such as slope, reach width, reach length so that the approach can be applied to ungauged catchments within the same region.

The objective of this study is to assess the Muskingum-Cunge method for flow routing in ungauged river reaches, both with and without lateral inflows. The Muskingum-Cunge method was assessed using catchment-derived parameters for use in ungauged river reaches. Three sub-catchments in the Thukela catchment in KwaZulu-Natal, South Africa were selected for analyses, with river lengths of 4, 21 and 54 km. The slopes of the river reaches and reach lengths were derived from a digital elevation model. Manning's roughness coefficients were estimated from field observations. Flow variables such as velocity, hydraulic radius, wetted perimeters and flow depth were determined both from empirical equations and assumed cross-sections of the reaches. Lateral inflows to long river reaches were estimated from the Saint-Venant equation. The performance of the methods was evaluated by comparing both graphically and statistically the simulated and observed hydrographs. The results obtained show that the computed outflow hydrographs generated using the Muskingum-Cunge method, with variables estimated using both the empirical relationships or assumed cross-sectional shapes, resulted in reasonably accurate computed outflow hydrographs with respect to volume, peak discharge, timing of peak flow and shape of the hydrograph.

From this study, it is concluded that the Muskingum-Cunge method can be applied to route floods in ungauged catchments using derived variables in the Thukela catchment and it is postulated that the method can be used to route floods in other ungauged rivers in South Africa.

**Keywords:** flood routing, channel routing, hydrology, hydraulics, Muskingum-Cunge equation, river routing, river engineering

## Introduction

As defined by Fread (1981) and Linsley et al. (1982), flood routing is a mathematical method for predicting the changing magnitude and celerity of a flood wave as it propagates down rivers or through reservoirs. Numerous flood-routing techniques, such as the Muskingum flood-routing methods, have been developed and successfully applied to a wide range of rivers and reservoirs (France, 1985). Generally, flood-routing methods are categorised into two broad, but somewhat related applications, namely reservoir routing and open channel routing (Lawler, 1964). These methods are frequently used to estimate inflow or outflow hydrographs and peak flow rates in reservoirs, river reaches, farm ponds, tanks, swamps and lakes (NRCS, 1972; Viessman et al., 1989; Smithers and Caldecott, 1995).

Flood routing is important in the design of flood protection measures in order to estimate how the proposed measures will affect the behaviour of flood waves in rivers so that adequate protection and economic solutions can be found (Wilson, 1990). In practical applications, two steps are involved in the prediction and assessment of flood level inundation. A flood-routing model is used to estimate the outflow hydrograph by routing a flood event from an upstream flow-gauging station to a downstream location. Then the flood hydrograph is input to a hydraulic model in order to estimate the flood levels at the downstream site (Blackburn and Hicks, 2001).

Flood-routing procedures may be classified as either hydrological or hydraulic (Choudhury et al., 2002). Hydrological methods use the principle of continuity and a relationship between discharge and the temporary storage of excess volumes of water during the flood period (Shaw, 1994). Hydraulic methods of routing involve the numerical solutions of either the convective diffusion equations or the one-dimensional Saint-Venant equations of gradually varied unsteady flow in open channels (France, 1985).

As noted by the US Army Corps of Engineers (1994), several factors should be considered when evaluating the most appropriate routing method for a given situation. The factors that should be considered in the selection process include, *inter alia*, backwater effects, floodplains, channel slope, hydrograph characteristics, flow network, subcritical and supercritical flow (US Army Corps of Engineers, 1994). The selection of a routing model is also influenced by other factors such as the required accuracy, the type and availability of data, the available computational facilities, the computational costs, the extent of flood wave information desired, and the familiarity of the user with a given model (NERC, 1975; Fread, 1981).

The hydraulic methods generally describe the flood-wave profile adequately when compared to hydrological techniques, but practical application of hydraulic methods is restricted because of their high demand on computing technology, as well as on quantity and quality of input data (Singh, 1988). Even when simplifying assumptions and approximations are introduced, the hydraulic techniques are complex and often difficult to implement (France, 1985). Studies have shown that the simulated outflow hydrographs from the hydrological routing

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