Rating curve fails to model discharge in a backwater affected river reach

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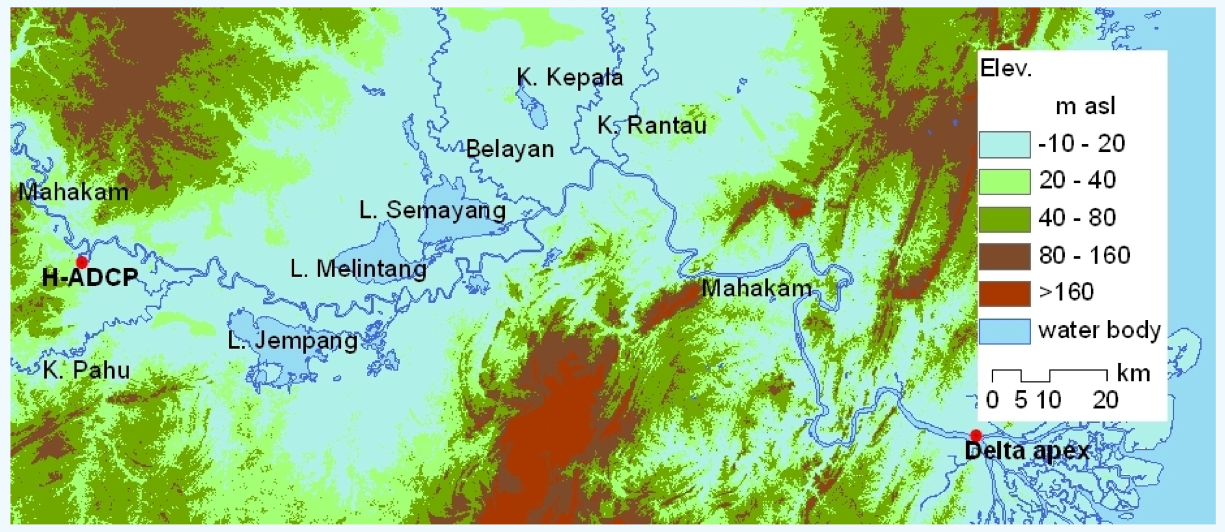
1. Background

In areas influenced by backwater effect, a single-parameter rating curve techniques are often inapplicable. Recent developments allow flow velocity to be continuously monitored by the Horizontal Acoustic Doppler Current Profiler (H-ADCP).

2. Study area & data collection

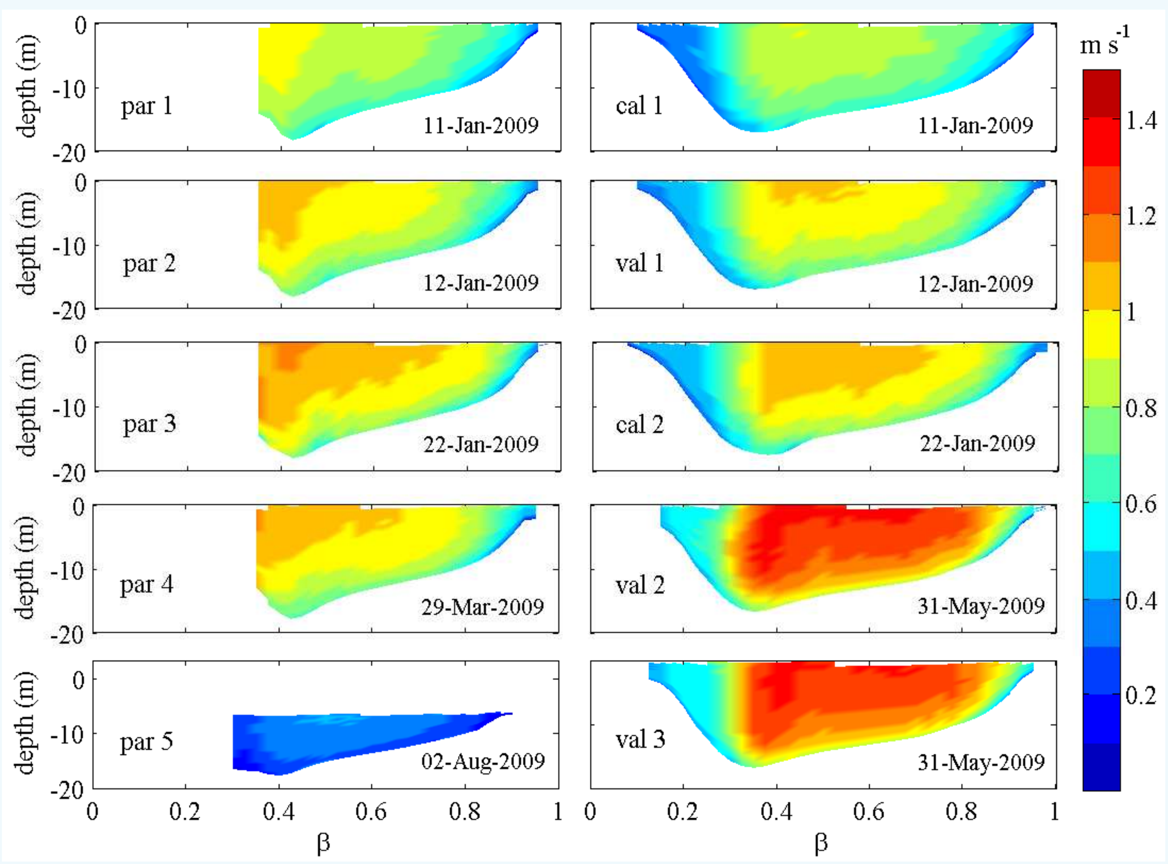
The study is based on measurements carried out in the River Mahakam, East Kalimantan - Indonesia. The H-ADCP measurement station is located in Melak in the middle Mahakam area about 300 km from the delta apex. This area is an extremely flat lowland with about thirty lakes.



Location of H-ADCP discharge station.

The H-ADCP discharge station was operational at a 250 m wide cross section of the river in March 2008 - August 2009. A 600 kHz H-ADCP was mounted on a solid jetty in the concave side of the river bend.

Boat-mounted ADCP measurements were periodically taken at the cross-section to establish water discharge through the river section. The ADCP velocity measurements were projected into normalized (β, σ) coordinates.



Streamwise velocity during boat-mounted ADCP campaign.

3. Method

We applied the semi-Determinictic semi-Stochastic Model (DSM)[1] and the standard Index Velocity Method (IVM) to obtain a continuous discharge estimate from H-ADCP data. A stage-discharge relation using the Jones' formula is also included.

1. DSM: Time-series of single point velocity u_c, measured at the relative height σ_c, are translated into depth-mean velocity U according to:

$$U = F u_c \qquad (1)$$

$$F = \frac{\ln\left(\frac{H}{\exp(1+\alpha)}\right) - \ln(z_0)}{\ln(\sigma_c H) + \alpha \ln(1-\sigma_c) - \ln(z_0)} \qquad (2)$$

H is depth, α is dip-correction factor, z_0 is the roughness length.

$$\alpha = \frac{1}{\sigma_{max}} - 1 \qquad (3)$$

σ_{max} is the relative height where the maximum velocity occurs.

$$z_0 = \frac{H}{\exp\left(\frac{\kappa U}{u_*} + 1 + \alpha\right)} \qquad (4)$$

κ is the Von Karman constant and u_* is the shear velocity. Specific discharge q is obtained from $q = UH$. Discharge Q is obtained from:

$$Q(t) = f(\beta) W q(\beta, t) \qquad (5)$$

W is the river width, $f(\beta)$ is constant amplification factor obtained from total discharge divided by Wq from ADCP campaigns.

2. IVM: The sectionally integrated velocity obtained from the boat-mounted ADCP is regressed against the width-averaged along channel velocity (i.e. the index velocity) obtained with the H-ADCP.

3. Jones' formula:

$$Q = Q_{kin}\left\{1 + \frac{1}{cS_0}\frac{\partial h}{\partial t}\right\}^{1/2} \qquad (6)$$

Q_{kin} is the kinematic discharge, c is wave celerity, S_0 is bed slope, and $\partial h/\partial t$ is rate of water level change in time t.

$$Q_{kin} = \frac{1}{n} S_0^{1/2} A R^{2/3} \qquad (7)$$

n is Manning roughness coefficient, A is cross sectional area, and R is hydraulic radius.

4. Results & discussion

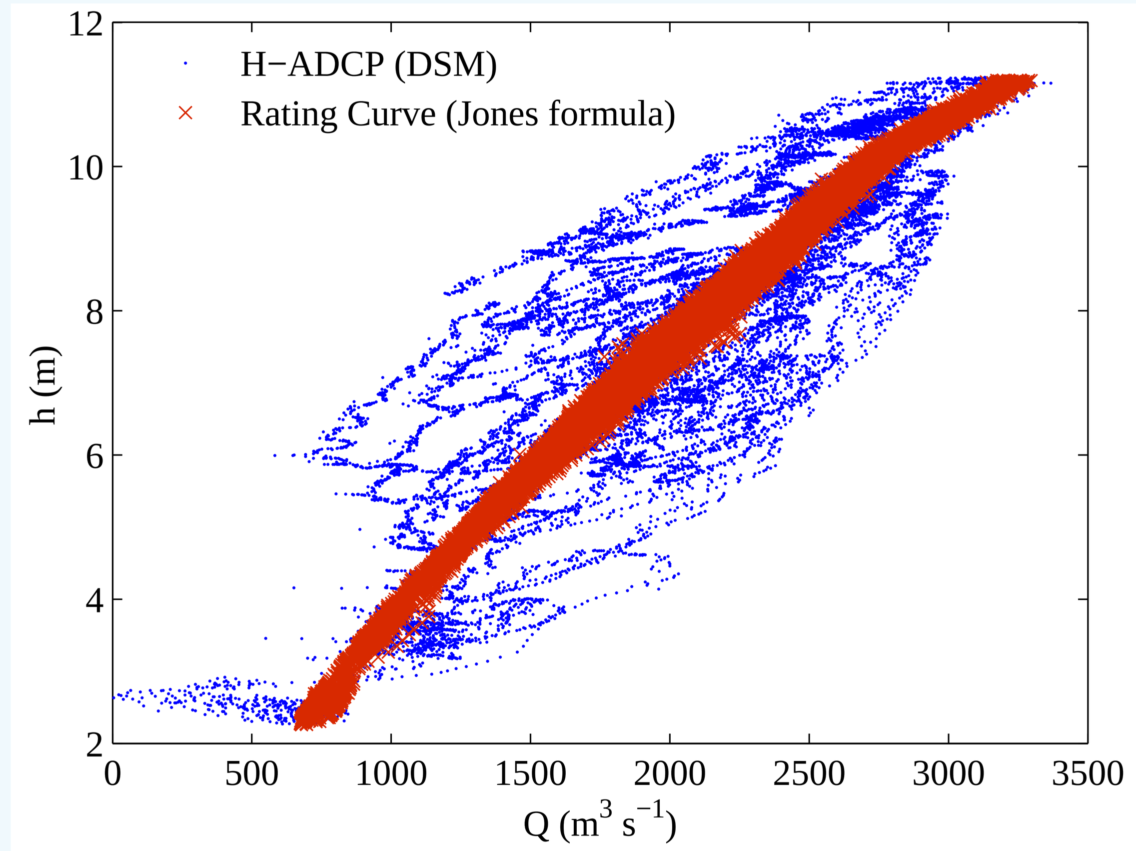
Referring to discharge from boat surveys, the DSM outperforms the IVM.

Results of the three validation surveys of the DSM and IVM

Val.	Q_{BS}	Q_{DSM}	Q_{IVM}	Q_{DSM}/Q_{BS}	Q_{IVM}/Q_{BS}
1	1823	1897	2241	1.04	1.23
2	2438	2445	2924	1.00	1.20
3	2387	2437	2857	1.02	1.20

Q_{BS} denotes the discharge calculated from the boat survey.

The range of discharges for a specific stage can span over more than 2000 m^3s^{-1}, which is large in comparison with the maximum discharge of 3370 m^3s^{-1}. Such variation can be considered far beyond the rising stage and falling stage explanation.

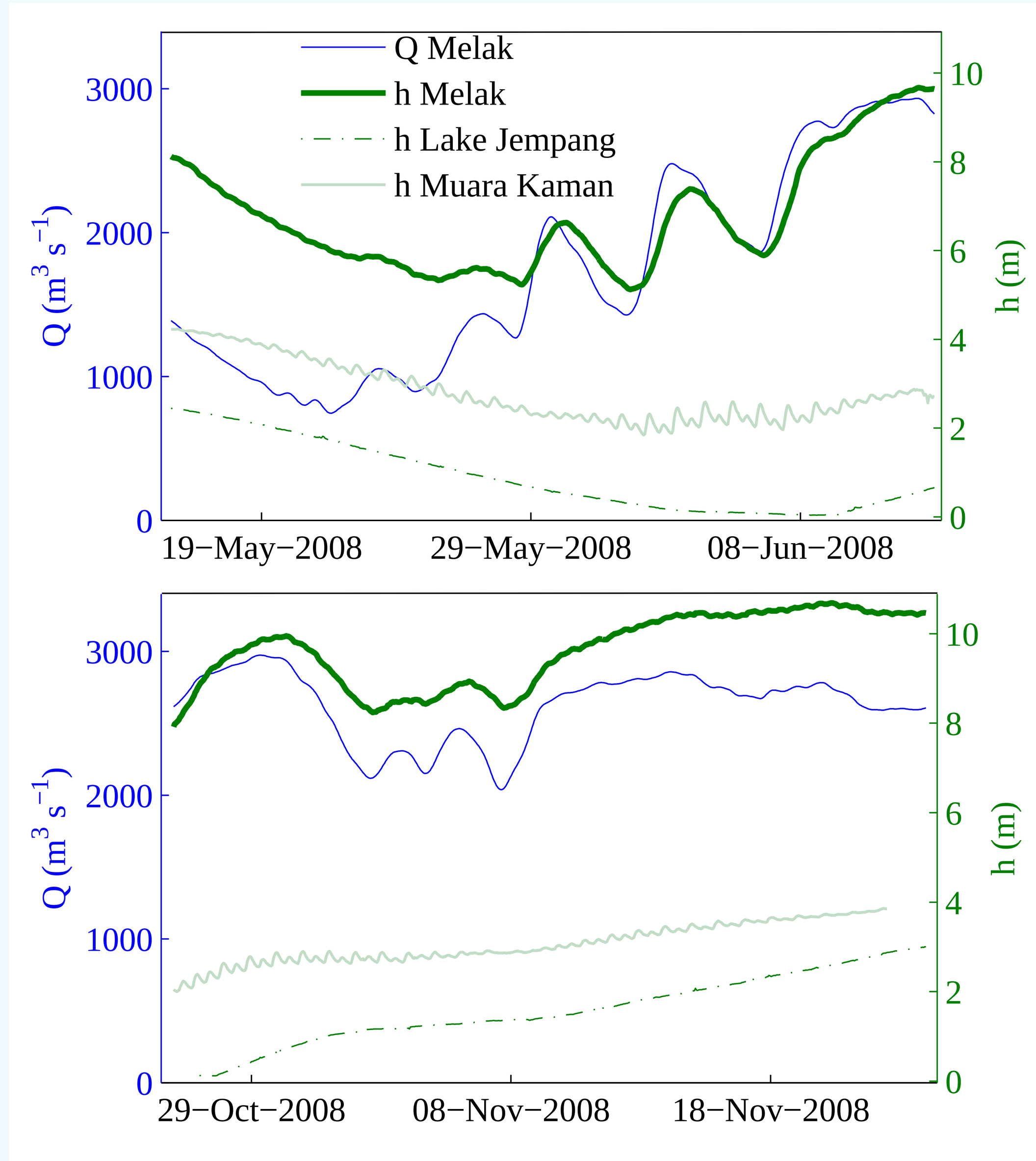


Stage and discharge from rating curve and from H-ADCP data.

The discharge estimates obtained from the Jones' formula did not capture the detailed discharge dynamics as revealed by the H-ADCP measurements.

The key assumption used to derive the Jones' formula is the applicability of the kinematic wave equation to deal with the surface gradient term in the non-inertial wave equation, which is invalid.

The wide loops in the stage-discharge plots are the result of the geographical complexity of the region where the station is located, experiencing a flashy discharge from upstream and backwater effects from downstream. At low discharges, the tidal signal is clearly visible in the discharge series. Lake emptying and filling processes contribute to retarding and accelerating the river flow velocity.



Stage and discharge during lake emptying and lake filling.

5. Conclusions

The stage-discharge model based on Jones's formula captured only a small portion of the discharge dynamics, which was attributed to the invalidity of the kinematic wave assumption. A discharge range of about 2000 m^3s^{-1} was established for a particular stage in the recorded discharge series, which is about 60% of the peak discharge.

The large range of discharge occurring for a given stage was attributed to multiple backwater effects from lakes and tributaries, floodplain impacts and effects of river-tide interaction

Reference, affiliation & funding

[1] Sassi, M. G. Hoitink, A. J. F. Vermeulen, B., and Hidayat, Discharge estimation from H-ADCP measurements in a tidal river subject to sidewall effects and a mobile bed, *Water Resour. Res.*, 2011.

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This research has been supported by the Netherlands organisation for scientific research, under grant number WT 76-268.