Estimation of the interaction between groundwater and surface water based on the flow routing using an improved nonlinear Muskingum-Cunge method

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Research Article

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Abstract

The interaction of groundwater (GW) and surface water (SW) not only sustains the runoff in dry seasons, but also plays an important role in regulating aquatic ecosystems. Hydrological engineers proposed the idea of modeling flood routing using the Muskingum-Cunge method. This study proposes an improved nonlinear Muskingum-Cunge flood routing model considering lateral inflow, which is denoted as NMCL1 and NMCL2 that can simulate the flood routing and calculate GW-SW exchange. In addition, both the linear and nonlinear lateral inflow (with the channel inflow) are discussed, and both the stable lateral inflow due to GW-SW exchange and the lateral inflow changing with the river inflow are considered for the first time. Sensitivity analysis has shown that different parameters have different effects on the simulation results. Three different flood cases documented in literature with one measured from Zhongtian River, China, were selected to compare the classical and the updated Muskingum-Cunge methods. Two different floods of the River Wye are selected to verify the accuracy of the calibrated model. Comparison has shown that, for several cases, the proposed method is capable of obtaining the optimal simulation results. The proposed method can estimate the GW-SW interaction and lateral inflow reliably, and inherits the ability of Maskingum-Cunge in flood routing. Moreover, the new Muskingum-Cunge method can quantify GW-SW exchange, and the estimation has reliably owned to the nonlinearity and sign flexibility of the calculated exchange process.

Full Text

Due to technical limitations, full-text HTML conversion of this manuscript could not be completed. However, the latest manuscript can be downloaded and accessed as a PDF.

Figures

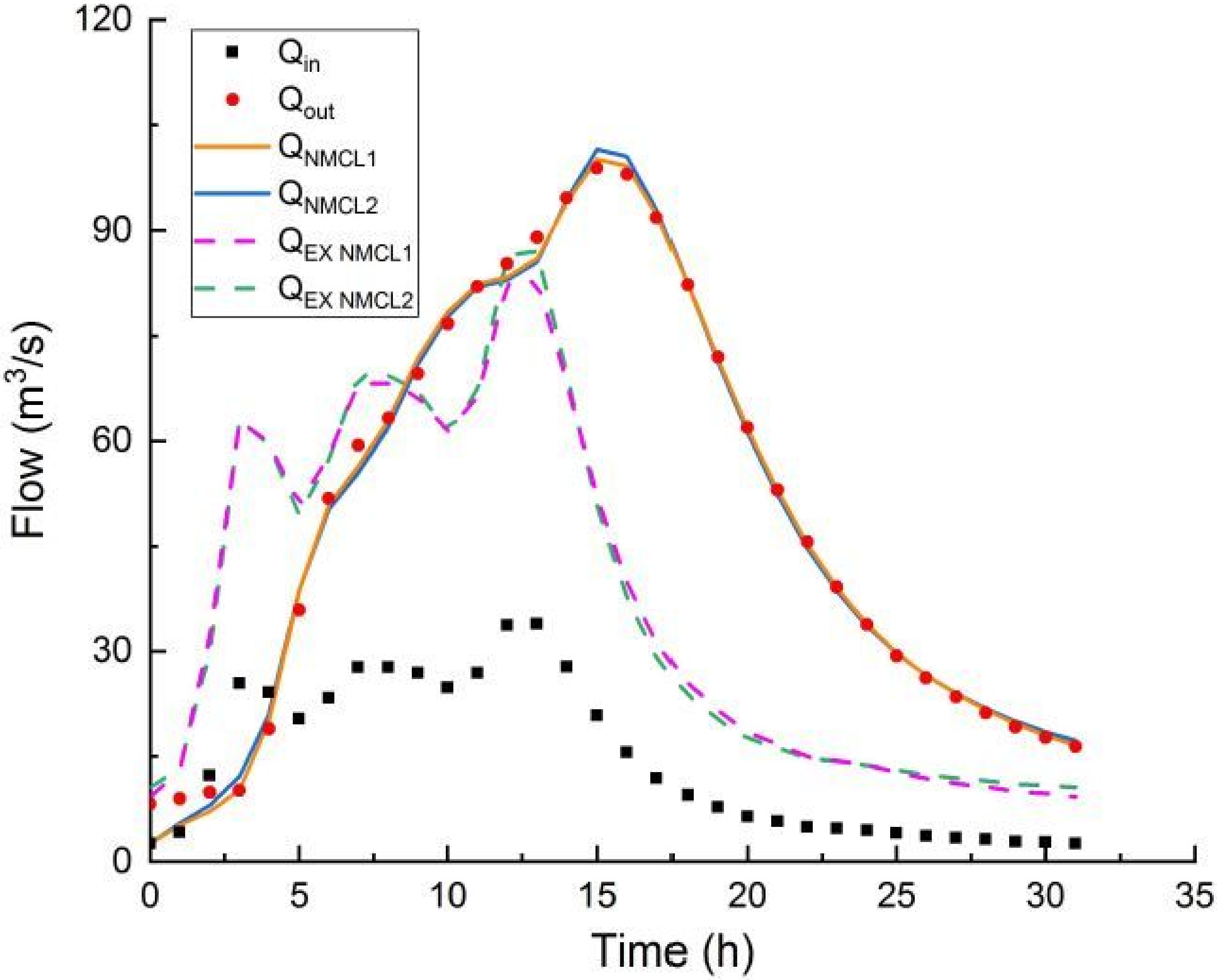

Figure 1

Flood routing simulation at the River Wyre using the NMCL1 and NMCL2 models. Qin and Qout are the measured inflow and outflow, respectively. QNMCL1 and QNMCL2 are the best-fit outflow using the NMCL1 model and the NMCL2 model, respectively, and QEX represents the sum of the transient/conventional lateral inflow and the stable inflow due to GW-SW interaction.

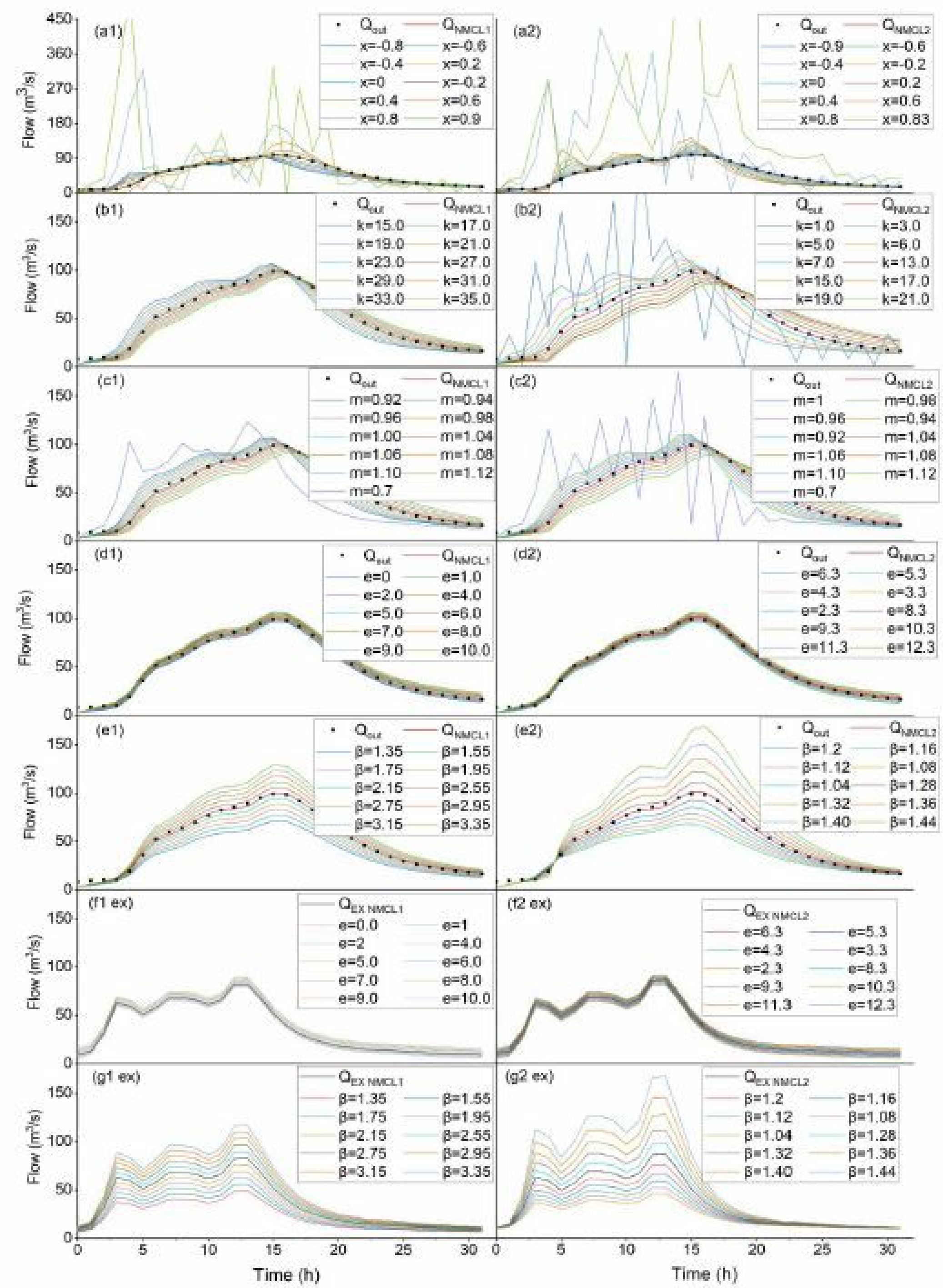

Figure 2

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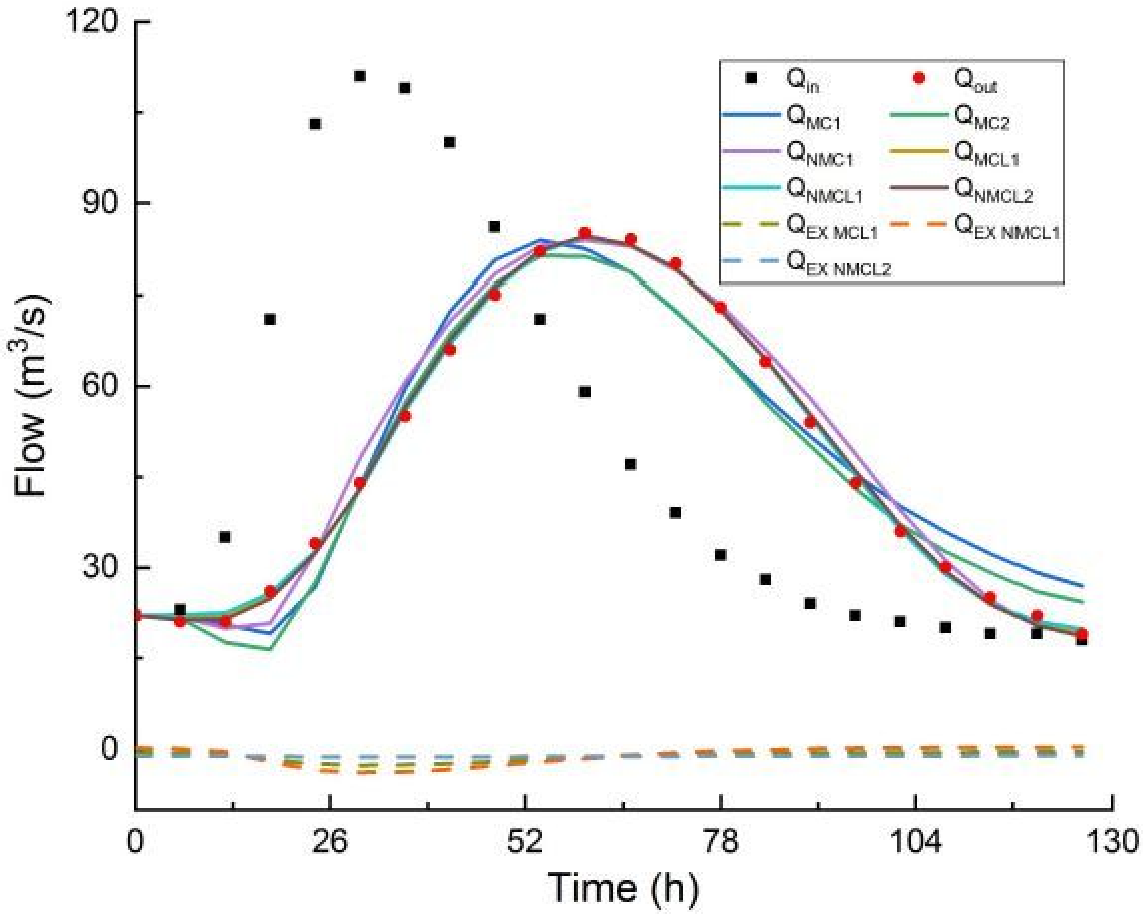

Figure 3

The measured versus the modeled results for the flow data from Wilson (1974). Qin and Qout are the measured inflow and outflow, respectively. QMC1 is the estimated outflow using MCL1, QMC2 is the estimated outflow using MC2, QNMC1 is the estimated outflow using NMC1, QMCL1 is the estimated outflow using MCL1, QNMCL1 is the estimated outflow using NMCL1, QNMCL2 is the estimated outflow using NMCL2. QEX represents the sum of the transient/conventional lateral inflow and the vertical inflow due to the interaction between GW and SW.

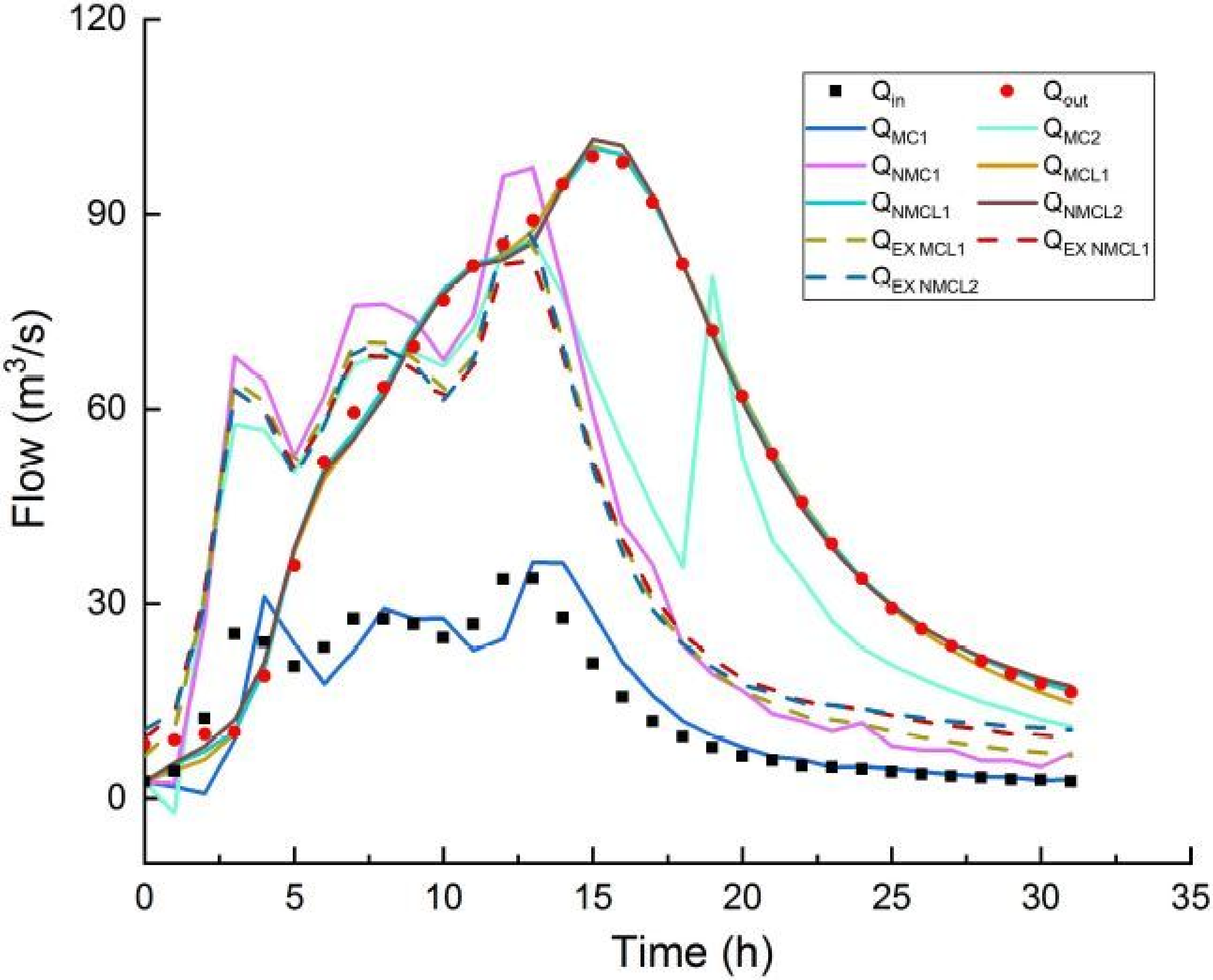

Figure 4

The measured versus the simulated flow for River Wyre from O'Donnell (1985). Qin 39 and Qout are the measured inflow and outflow, respectively. QMC1 is the estimated outflow using MCL1, QMC2 is the estimated outflow using MC2, QNMC1 is the estimated outflow using NMC1, QMCL1 is the estimated outflow using MCL1, QNMCL1 is the estimated outflow using NMCL1, QNMCL2 is the estimated outflow using NMCL2. QEX represents the sum of the transient/conventional lateral inflow and the vertical inflow due to the interaction between GW and SW.

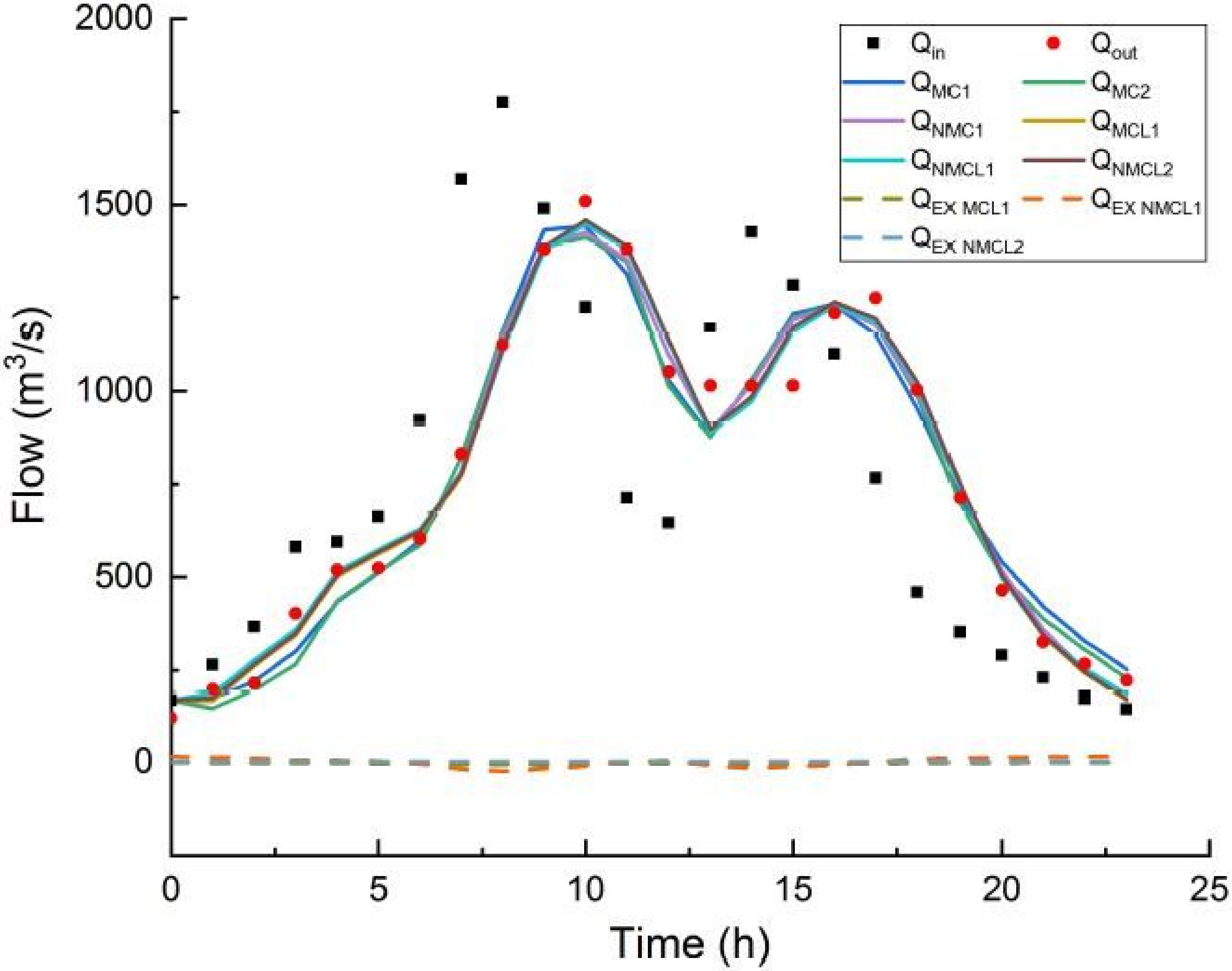

Figure 5

The measured versus the modeled results for the flow data from Viessman and Lewis (2003). Qin and Qout are the measured inflow and outflow, respectively. QMC1 is the estimated outflow using MCL1, QMC2 is the estimated outflow using MC2, QNMC1 is the estimated outflow using NMC1, QMCL1 is the estimated outflow using MCL1, QNMCL1 is the estimated outflow using NMCL1, QNMCL2 is the estimated outflow using NMCL2. QEX represents the sum of the transient/conventional lateral inflow and the vertical inflow due to the interaction between GW and SW.

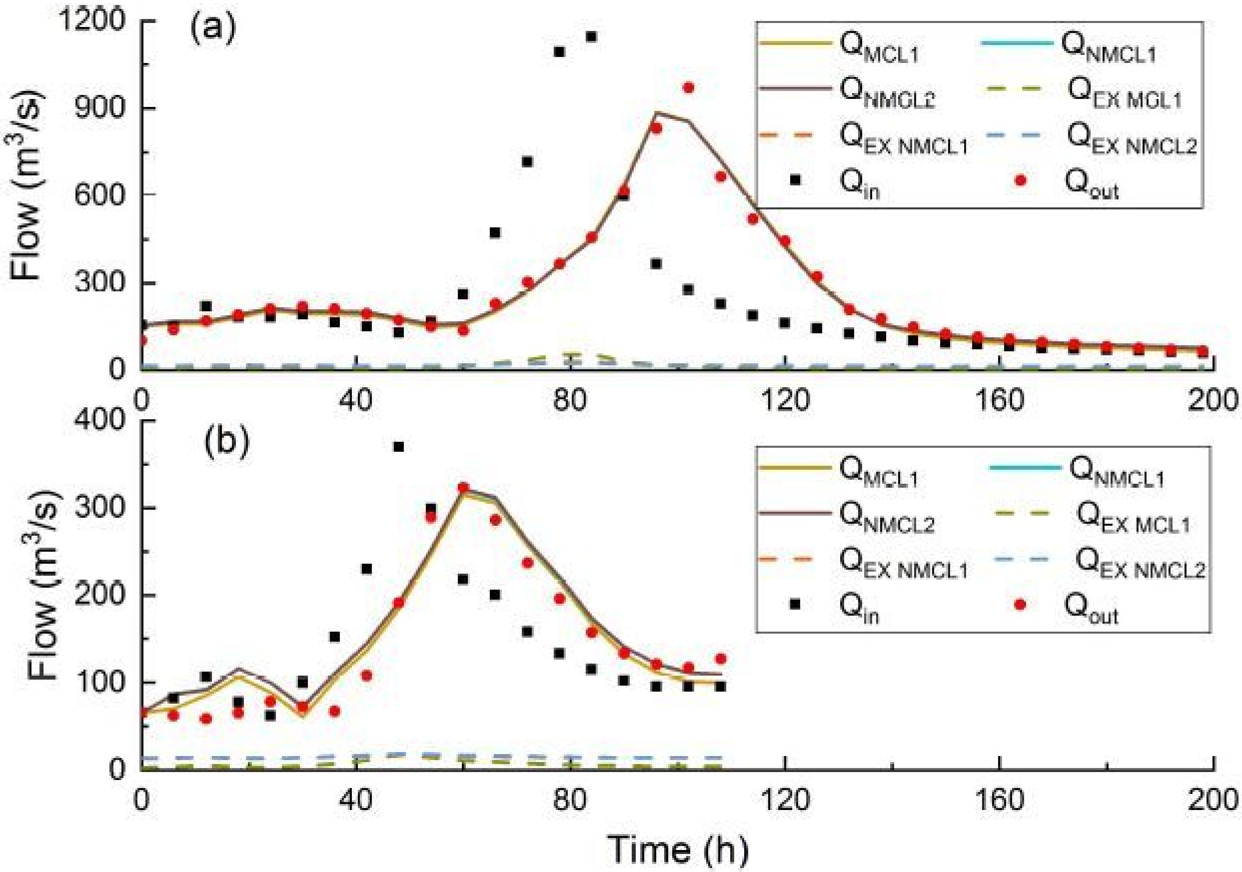

Figure 6

The measured versus the modeled results for the two different flow data of the River Wye from O'Donnell (1985). Qin and Qout are the measured inflow and outflow, respectively. QMCL1 is the estimated outflow using MCL1, QNMCL1 is the estimated outflow using NMCL1, QNMCL2 is the estimated outflow using NMCL2. QEX represents the sum of the transient/conventional lateral inflow and the vertical inflow due to the interaction between GW and SW.

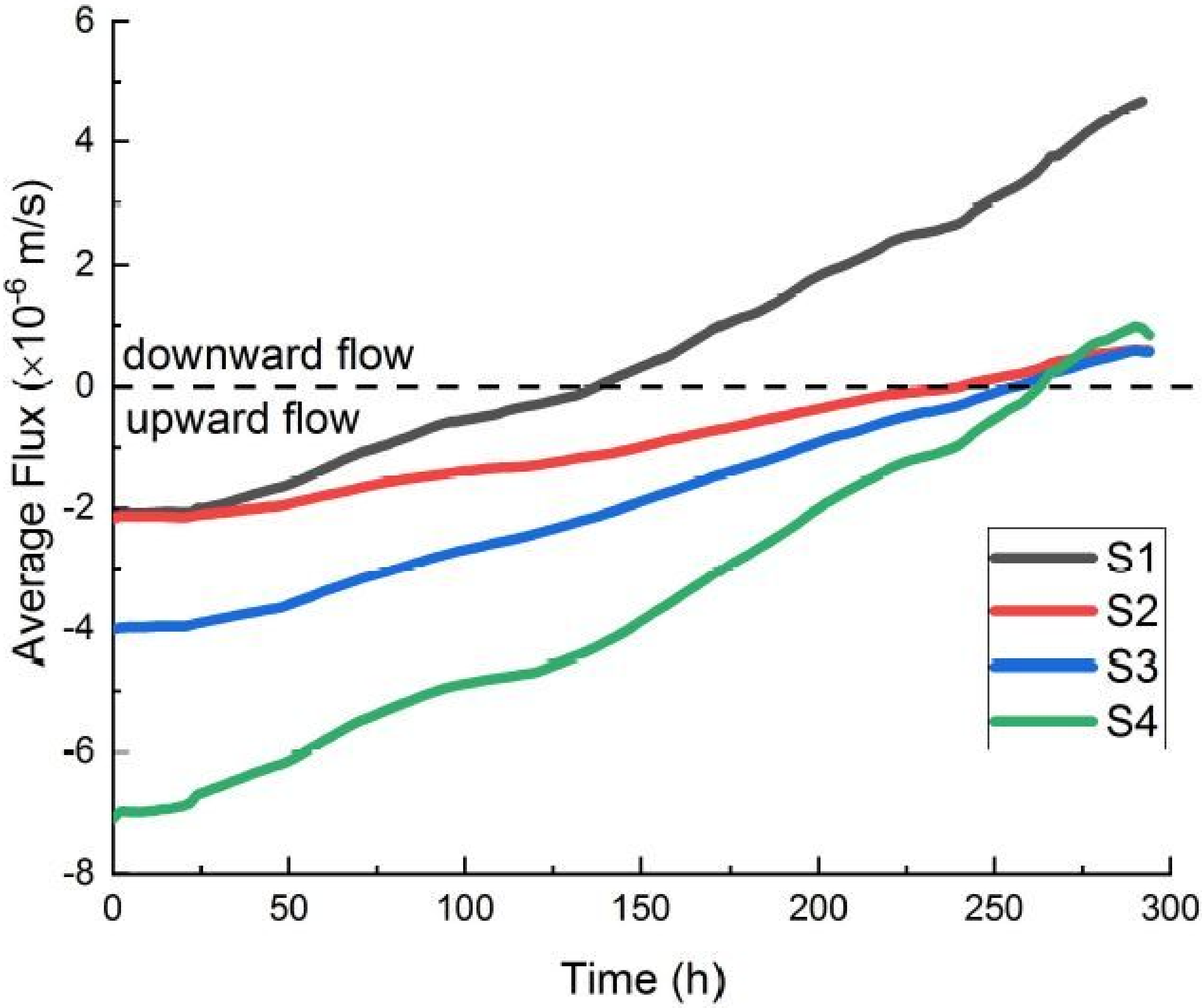

Figure 7

Flux across the four cross sections S1, S2, S3 and S4. The average flux of each section is estimated by VFLUX using the measured temperature at these four sections. The negative flux means upward flow, and the positive flux means downward flow.

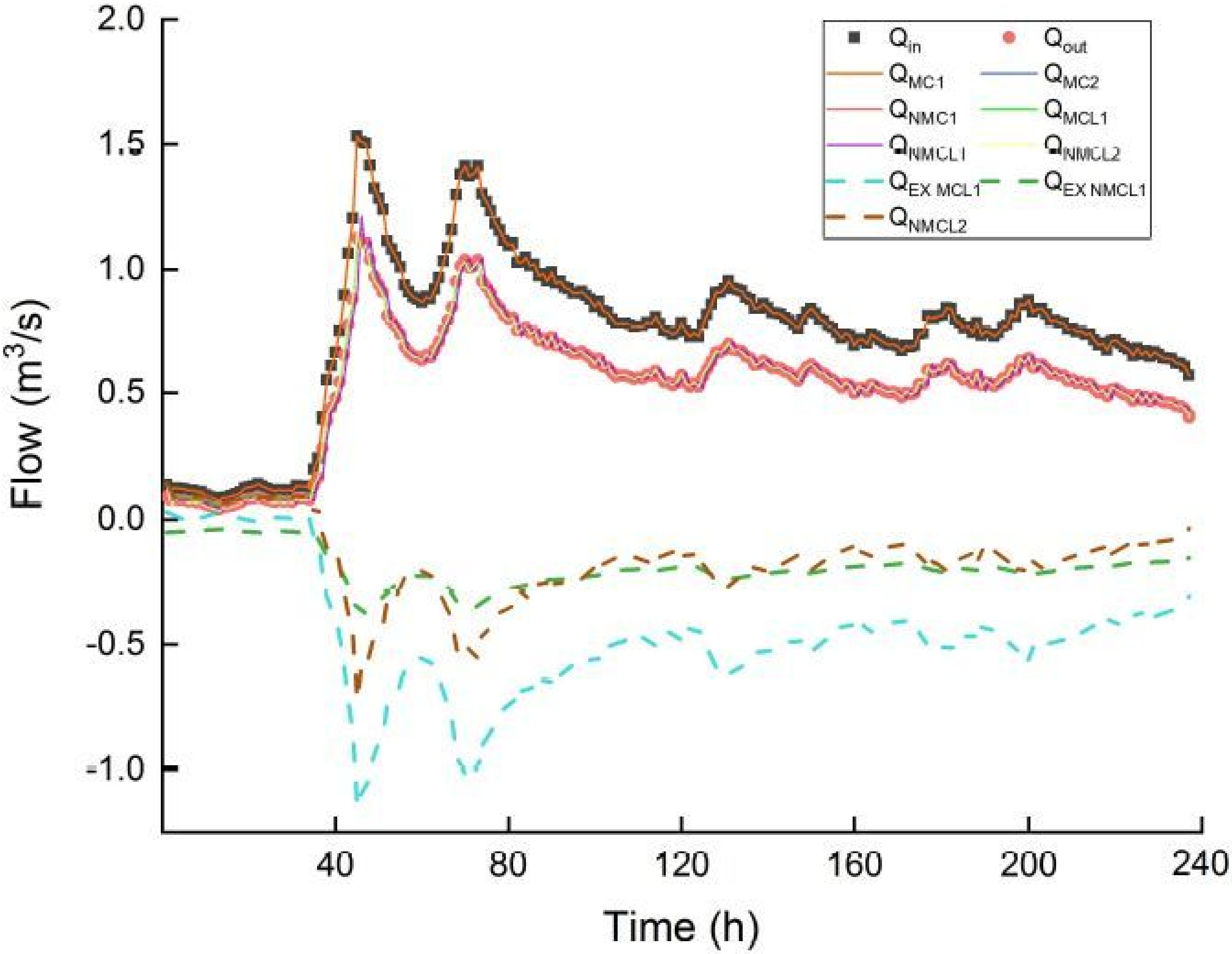

Figure 8

The measured versus the simulated flow for Zhongtian River. Qin and Qout are the measured inflow and outflow, respectively. QMC1 is the estimated outflow using MCL1, QMC2 is the estimated outflow using MC2, QNMC1 is the estimated outflow using NMC1, QMCL1 is the estimated outflow using MCL1, QNMCL1 is the estimated outflow using NMCL1, QNMCL2 is the estimated outflow using NMCL2. QEX represents the sum of the lateral inflow and the flow due to GW-SW interaction.

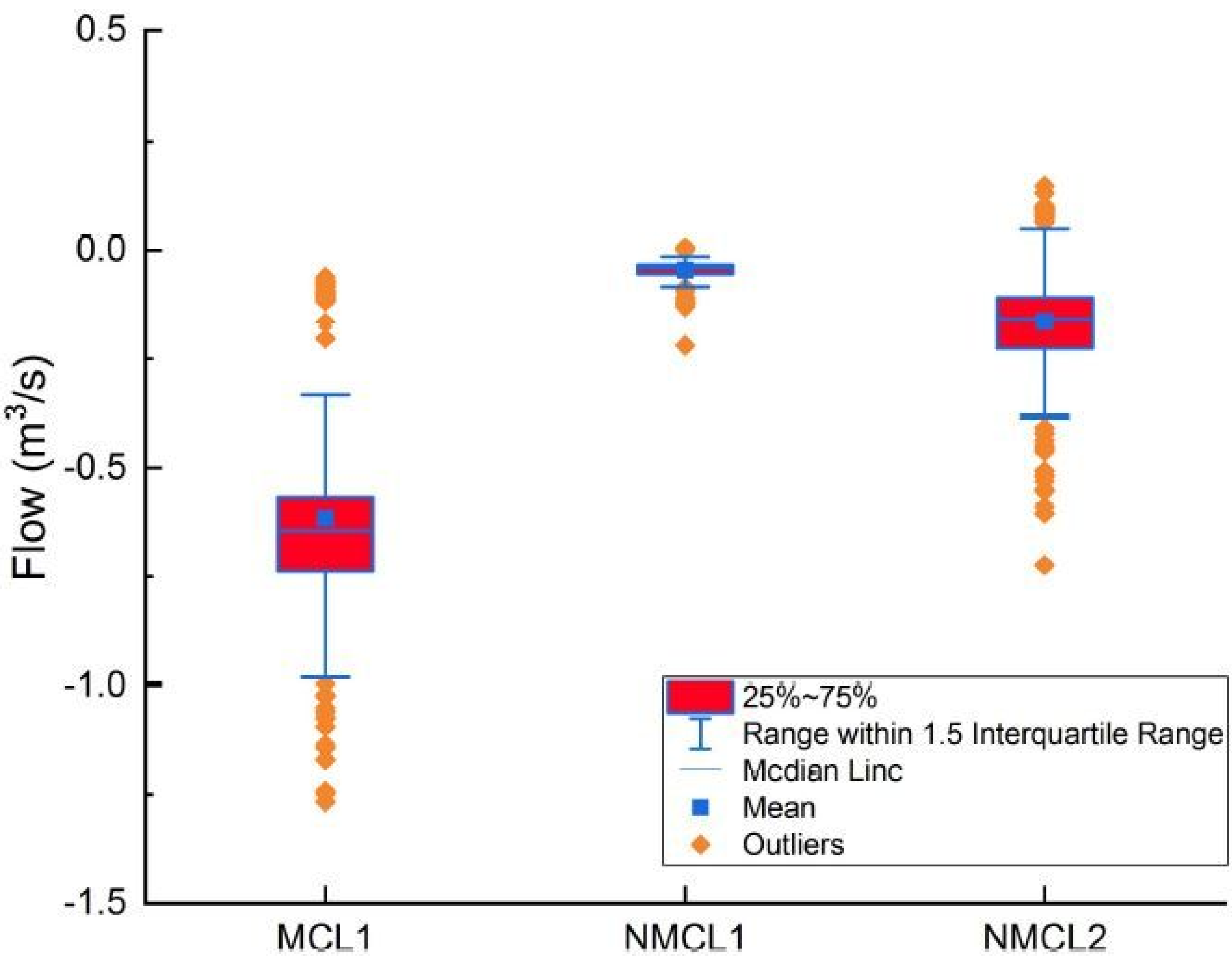

Figure 9

Boxplot of the GW-SW exchange volume. The GW-SW exchange volume and the sum of lateral and vertical inflow estimated by MCL1, NMCL1, and NMCL2 are analyzed by the box plot. The green box represents the data in the middle of the upper and lower quartiles. The middle line in the green box represents the median, and the small box in the middle represents the average.