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Citation	Journal of Disaster Research (2013), 8(1): 193-194
Issue Date	2013-02
URL	http://hdl.handle.net/2433/172458
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Type	Journal Article
Textversion	author

Simultaneous estimation of inflow and channel roughness using 2D hydraulic models and particle filters

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Abstract. The Sequential Importance Resampling (SIR) method is introduced to a 2D hydraulic model to estimate inflow and Manning roughness coefficient (Manning's n) simultaneously. The equifinality problem between the Manning's n and the inflow is considered using the proposed method. To solve the problem, we introduce the variance reduction factor and the correction factor in the perturbation step of the proposed method. The perturbed inflow and Manning's n are updated according to the observed water stage with state variables. The result of the proposed method shows good agreement with the observed discharge, which enable us to estimate the Manning's n and inflow discharge at the same time considering the uncertainties of the existing rating curve. Finally, it showed that the methodology is not only to estimate the appropriate Manning's n, but also to improve the existing rating curve.

Keywords: 2D hydraulic model, Particle Filter, Discharge Estimation, Manning roughness coefficient, Rating curve

1. INTRODUCTION

Discharge data at the basin outlet are utilized in water resource management, hydrological model calibration, flood prediction, and so on. These data are obtained by measuring the flow velocity or constructing a rating curve, or through the installation of a specific gauging station such as a flume. Among them, a general method uses a rating curve, which depicts the relationship between stage and discharge at the section based on occasional measurements. Even if a rating curve is based on measurement data, it assumes that the flow is steady state and the channel bed does not change as time passes; which means the dynamic river flow estimation with a rating curve has limitations. . Therefore the accuracy of the discharge obtained by transforming a time-series observed water stage to discharge using the rating curve is uncertain. Baldasassarre and Montari (2009) investigated the uncertainties of the discharge using a 1D hydraulic model and classified the uncertainty into three categories: one is due to the interpolation and extrapolation of a rating curve; another is due to the presence of unsteady flow conditions; and the last one is generated by the seasonal change in the channel roughness.

Therefore, this study aims to present a simultaneous estimation method, which can consider an uncertain Manning's n with spatial distributions and an uncertain inflow. We use the 2D dynamic wave model, which can reflect the effect of river geomorphology and is sensitive to variations in the water stage. The Monte Carlo sequential data assimilation scheme (the so-called Particle Filters) which is applicable for non-linear and non-Gaussian systems is combined with the 2D dynamic wave model. The proposed method is verified through real observed discharge, and the applicability of the proposed method is confirmed with another flood event.

2. METHODOLOGY

The proposed method builds on the assumption that a rating curve and the Manning's n include uncertainties and sequential updating of the observed water stage reduces these uncertainties. To understand that framework in regard to the proposed method, we need to consider the sequential procedure shown in Fig. 1 and structure of it. With regard to the structure, it consists of a two dimensional dynamic wave model (2D model) and a particle filter (PF). The 2D dynamic wave model calculates variables inside the calculation domain. The particle filter incorporates noise to the boundary conditions of each 2D model at the perturbation step before implementing the 2D model and compares the results against the observed water stage at the weight calculation step. Concerning the sequential procedure, the estimation process repeats every one hour because we utilize the hourly observed data. At first, the boundary conditions of inflow and the roughness coefficient including uncertainties are incorporated with some errors at the perturbation step, so the 2D model run with the various boundary conditions, so called particles. The 2D model is a deterministic model unless many similar systems run

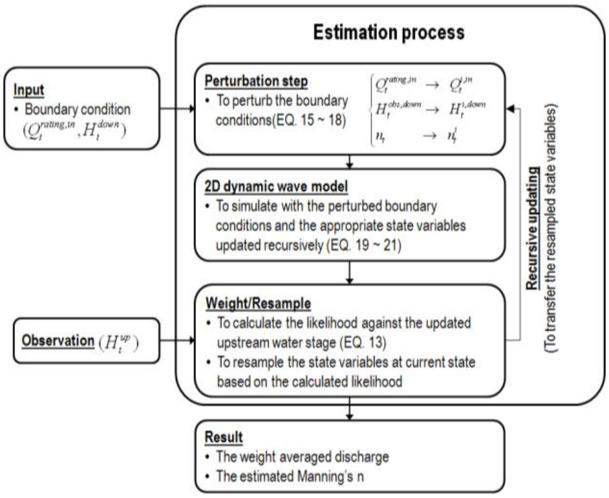

Figure 1 Procedure of the proposed estimation process.

simultaneously and independently and the result of each particle is evaluated by the updated water stage every updating step. The weight of each particle is calculated against the observed water stage for every updating step, and the weight recursively updates the state variables consecutively. In terms of using a 2D model, channel roughness, inflow, and water stage have the closest connections with each other for estimating one of them. Manning's n is determined by the engineer on the basis of the small number of investigation of the bed material, vegetation, channel shape, and so on. In addition, the inflow obtained from a rating curve or a hydrological model involves many uncertainties and the 2D model is highly nonlinear., Thus, we select the Sequential Importance Resampling (SIR) method for this approach since the resampling step, which entails removing particles with low weights and duplicating particles with heavier weights with a brief process, makes the system reflect the variables more accurately than the typical PFs, Sequential Importance Sampling (SIS).

To verify the proposed method, we apply the method to the Katsura River located in Kyoto, Japan. Because natural flood event data are affected by many anonymous factors, we designed experiments based on the natural river reach instead of using the experiment implemented in a laboratory. The experiment implemented with two events.

3. SIMULATION RESULTS

Manning's n and inflow are simultaneously estimated by the proposed method. The five parameters, three roughness values, inflow, and downstream water stage, which are essential and sensitive factors for hydraulic modeling, construct one particle. Each particle is

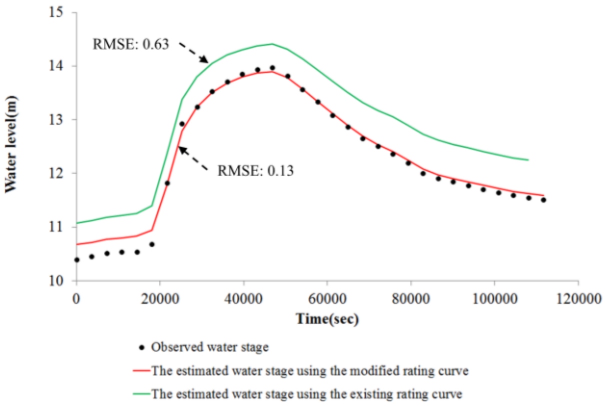

Figure 2 Comparison of the water stage at Hazukashi station from each deterministic simulation using the event occurred in Sep., 2004

disturbed with some errors through the perturbation step. With various particles, the simulations are implemented. For the verification, the flood event from 6:00 on October 20 to 14:00 on October 21, 2004 is utilized. The simulation is implemented with 300 particles as 300 particles are enough to present the stabilized results. To confirm the reproducibility of another event, the procedure above applies to another event of September 2004. Fig. 2 shows the results of the application. As we have seen from the result and the RMSE against the observed water stage, using the Manning's n and the modified rating curve obtained from the proposed method improves the estimated water stage using the existing rating curve.

4. CONCLUSION

The proposed method enables estimation of the inflow and the Manning's n simultaneously. Using the provided results from the method, the relationship between the water stage and the discharge at the water stage station could be constructed. The modified rating curve and Manning's n of each separated zone obtained from the proposed method is applied to another event to confirm the reproducibility.

Through the above verifications and application of the method, we confirm that it is a feasible alternative to the traditional method, in which the Manning's n estimated empirically and the discharge converted from an existing curve are utilized.

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