Discharge Estimation in a Backwater Affected River Junction Using HPG

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***Abstract*-This study presents a method for estimating discharge at a stage-gauging station located in a backwater affected river junction. A hydraulic performance graph (HPG) summarizing the backwater profiles on all possible flow conditions was applied to the river system at the juncture of the main stream and the tributary. The HEC-RAS model for dendritic river was created, and the unsteady simulation was implemented for calibration and verification. The relationship between two water levels from existing stage stations at the main stream and the tributary and the discharge at the backwater affected section was estimated, and kriging interpolation was carried out. During a flood, the discharge was calculated using kriging-interpolated HPG and the water level measurements at two stage stations. It was then validated by comparing the automatic discharge measurements from ADVM. The result provides an economical and practical method for estimating discharge in a junction with a high hysteresis of looped stage-discharge relationships.**

Keywords- Discharge; Rating Curves; Backwater; Hydraulic Performance Graph; HEC-RAS

I. INTRODUCTION

River discharge observation data has been used in several fields including water balance, flood prediction, dam and reservoir operation, the design of hydraulic structures, water supply, and aquatic ecosystem conservation. It is essential data for the examination and calibration of rainfall-runoff models and flood routing models. Generally, discharge is observed directly through a field survey, but in the consideration of time and cost, it is difficult to observe discharge continuously for a long period of time. Therefore, in order to observe discharge, we use an indirect method to prepare a stage-discharge relation curve from empirical relationships between the observed discharge and water level of river for a limited period and convert the measured water level into discharge by applying the measured water level to this curve.

Generally, a single stage-discharge curve equation where water level and discharge is in a one-to-one correspondence applies for the practical prediction of discharge. This approach can be applied properly in the case of steady or unsteady flow with a steep bed slope ($>10^{-3}$) [1]. However, a looped type stage-discharge curve, not a single stage-discharge relationship, may be produced as the unsteady status showing the dynamic behaviour in an actual river except in the above cases [1-4]. Specifically, flow stagnation occurs frequently in a junction where the main stream and the tributary meet due to the interaction between two flows, and in a tributary with a relatively small flood discharge, flow velocity drops and the water level rises as a result of backwater effects, increasing the risk of flood damage [5, 6]. This occurs since the discharge is defined with functions such as water level, bed slope, water surface slope, and spatial and temporal changes of flow velocity [7]. Therefore, a serious error may occur when predicting discharge in an actual river junction by applying the single stage-discharge relation curve developed under the assumption of steady flow.

Several methods were suggested to overcome such problems [2, 3, 8-12]. These methods compensate a stage-discharge relation curve using empirical methods induced by empirical data or using a simplified dynamic wave equation, which can be applied in specific flow conditions and geometrical structure of rigid river bed. However, in practice, these methods have insufficient applicability [1, 13]. Recently, the stage-discharge relation curve based on water levels measured at two different places in the section with a backwater effect has been used. However, a relatively large amount of field survey data are required in order to apply this method [14]. In other words, water level changes on both ends of river channel section should be investigated at the same time for various discharge conditions. For this, a field survey should be conducting during a flood event, and time should be invested accordingly. Reference [15] suggested a hydraulic performance graph (HPG) for determining the hydraulic discharge capacity of the Boneyard Creek located in Illinois, U.S. HPG summarizes the characteristics of the drainage effect on all possible flow conditions at a certain river channel section. It is expressed as the water level or the depth of water at the upstream and downstream sections of a specific river channel under various discharge conditions [16]. HPG was also used for evaluating the hydraulic performance of flooding before and after embankment failure [17]. Reference [18] evaluated the applicability of HPG to unsteady flow routing, reporting that a successful result was obtained.

The purpose of this study is to develop a method for estimating discharge at a stage-gauging station established in a backwater affected river junction. For this purpose, HPG summarizing for all profiles, including a backwater effect for possible river flow conditions, was developed and applied to the system where the main stream and the tributary meet. For developing HPG, an HEC-RAS model for a dendritic river network was established and the unsteady flow model was calibrated and

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verified. The relationship between the two water levels measured from existing stage-gauging stations located at the main stream and the tributary discharge was prepared and kriging interpolation was carried out. The discharge in a backwater affected section was calculated using the interpolated HPG, and the water levels measured from the two stage-gauging stations. The results were then compared and analysed with the automatic discharge measurement data at the Seongseo station of the Geumho River in Korea.

II. STUDY AREA AND METHOD

The Geumho River, as a tributary of the Nakdong River, has a flow channel length of 114.6 km and a watershed area of 2,087.9 km^2, accounting for approximately 9% of the total watershed area (23,326.3 km^2) of the Nakdong River. The Dongchon stage-gauging station, located at 26.9 km upstream from the Nakdong River junction, was selected as the upstream boundary because this section was not effected by backwater, and the junction was selected as the downstream boundary. HPG is developed from the results of a steady, non-uniform equation. In this study, the HEC-RAS unsteady simulation for an actual flood event was carried out to calibrate the roughness coefficient, the model parameter. Steady flow analysis with various possible conditions was also carried out using the calibrated HEC-RAS model to develop the HPG.

The discharge hydrograph from the Dongchon stage-gauging station was used for the upstream boundary condition of the HEC-RAS model, and the water level hydrograph measured below the Gangjeong-Goryeong weir, 0.887 km upstream from the junction, was used for the downstream boundary condition. Fig. 1 shows the channel network and the schematic diagram of the study area in the Geumho River. As shown in Fig. 1, the Donghwa stream and the Sin stream flow in this area, and the Dongbyeun stage-gauging station is located in the Donghwa stream. The Chimsan stage-gauging station is located in the Sin stream so that discharge data from these stations was used as the inflow of tributary. However, there was no surveyed channel cross-section data of the Donghwa stream and the Sin Stream, so the lateral inflow boundary condition of the Geumho River was considered.

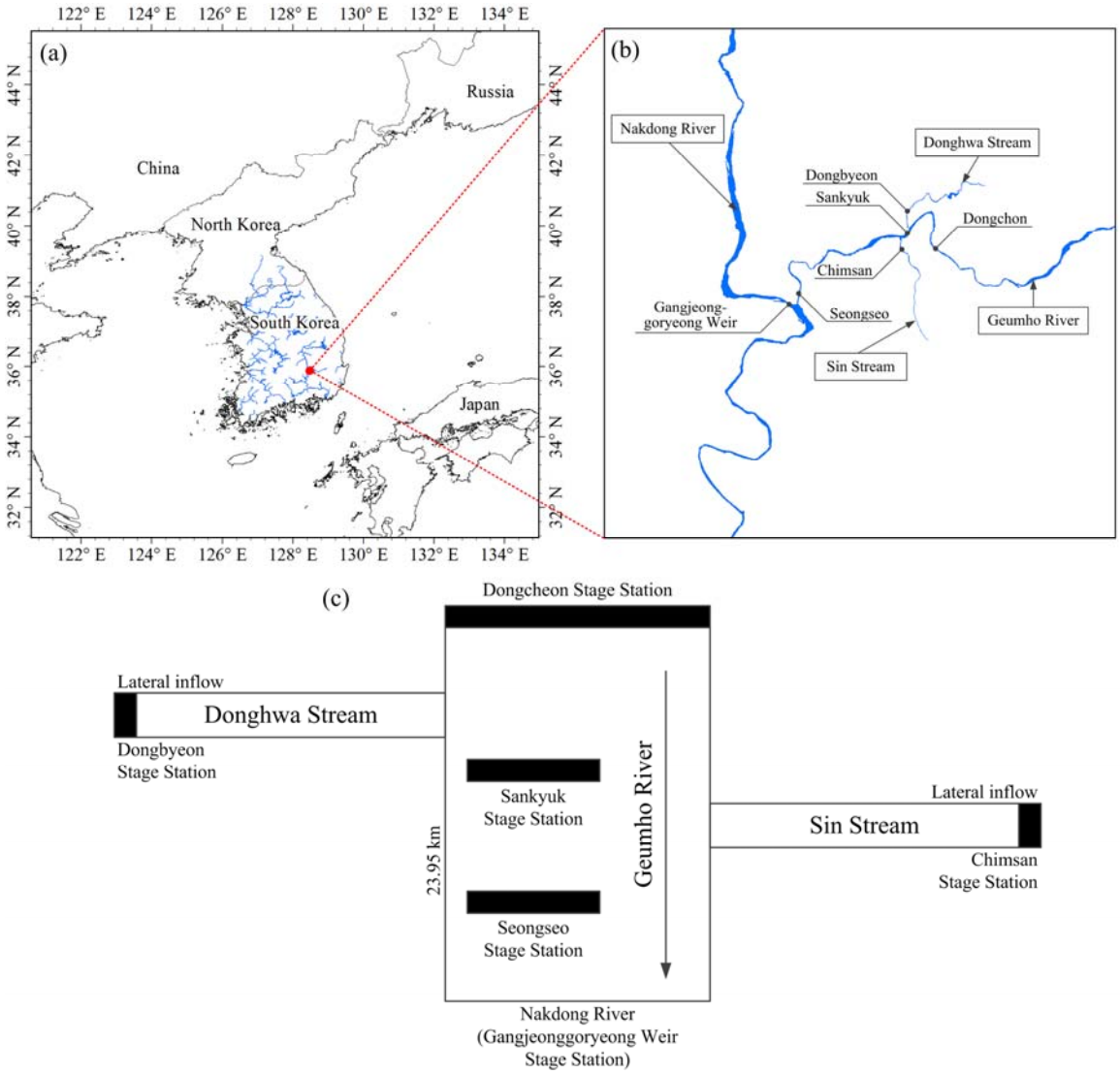

Fig. 1 (a) Location map, (b) channel networks, and (c) schematic diagram of study area

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For calibrating the model, an event that occurred from September 16, 2012 to September 19, 2012, the largest flood in the past five years, was used. Fig. 2 is the comparison between the observed water level and the calculated water level at the Seongseo station, indicating good agreement between the two water levels. This means that the model was properly calibrated. Table 1 shows the roughness coefficient according to the discharge for each section, the result of model calibration.

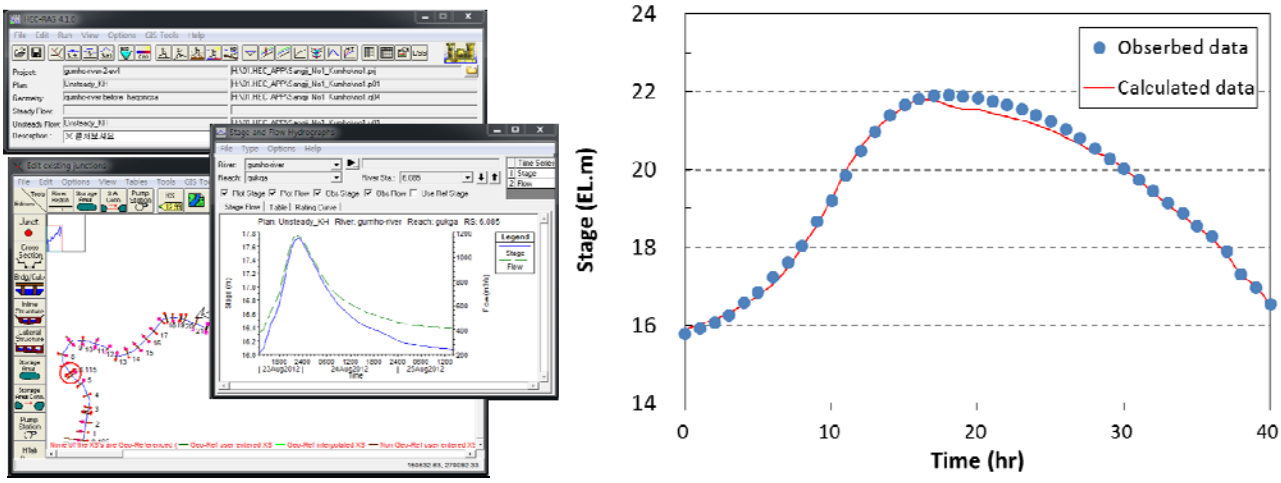

Fig. 2 Analysis results of the HEC-RAS model and the comparison between the simulated and observed stage data

TABLE 1 CALIBRATED ROUGHNESS COEFFICIENT OF THE STUDY REACH IN THE GEUMHO RIVER

Discharge (cms)	**Dongchon station ~ Mutae Bridge**	**Mutae Bridge ~ Weir**	**Weir ~ Paldal Bridge**	**Paldal Bridge ~ Geumho Bridge**	**Geumho Bridge ~ River junction**
0 ~ 100	0.027 ~ 0.034	0.017 ~ 0.022	0.023 ~ 0.030	0.022 ~ 0.028	0.028 ~ 0.030
100 ~ 500	0.024 ~ 0.027	0.016 ~ 0.017	0.021 ~ 0.023	0.020 ~ 0.022	0.028
500 ~ 1,000	0.020 ~ 0.024	0.013 ~ 0.016	0.018 ~ 0.021	0.016 ~ 0.020	0.027 ~ 0.028
1,000 ~ 1,500	0.014 ~ 0.020	0.009 ~ 0.013	0.012 ~ 0.018	0.011 ~ 0.016	0.026 ~ 0.027
1,500 ~ 1,800	0.014 ~ 0.016	0.009 ~ 0.010	0.012 ~ 0.014	0.011 ~ 0.013	0.026
1,800 ~	0.016	0.010	0.014	0.013	0.026

III. DEVELOPMENT AND VERIFICATION OF HPG USING HEC-RAS

The procedure to create HPG at a backwater affected section using the HEC-RAS model is as follows:

1. Determine the range of discharge first by considering the annual minimum and/or ordinary flow and design flood discharge of the relevant river channel section.

2. Set various discharges for the inflow condition and set critical depth to reach downstream boundary condition when carrying out steady and non-uniform HEC-RAS simulations.

3. Draw *Cd-curve* in Fig. 3 by connecting all points with the upstream and downstream water levels in a backwater affected section, calculated in Step 2.

4. Then, assign a specific water level as a boundary condition in each discharge, such as Q1, Q2, Q3, etc., and calculate the upstream water level, creating the hydraulic performance graph for this discharge condition, as shown in Fig. 3.

5. If the discharge reaches zero, the water level between the downstream and upstream areas will be the same. Therefore, the *z-line* in Fig. 3 means the case of no flow.

HPG shows the relationship between the section discharge and the water level of upstream and downstream in steady state. If trying to calculate the discharge in a backwater-affected section, the water level of upstream and downstream in the backwater-affected area should be measured. A point must be found where the two water levels meet from the created HPG. Therefore, HPG should be interpolated spatially, and in this study, HPG was interpolated using kriging.

The location of the Seungseo stage-gauging station in the Geumho River is significantly affected by the backwater of the junction. If the water level of the Nakdong River increases, the water level rises regardless of the discharge at the Seongseo station, and a single stage-discharge relationship which occurs in a location with no backwater effect, as shown in Fig. 5, cannot be expected. Therefore, an automatic discharge measurement device has been installed near the Seongseo stage-gauging station since 2008. When the stage-discharge relationship is drawn from the discharge and water level data measured during the flood period in 2012, a looped rating curve can be clearly confirmed.

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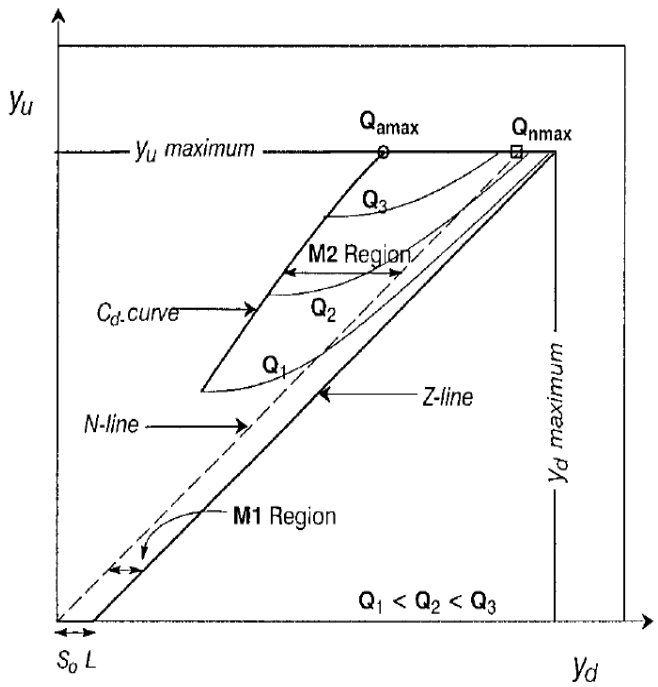

Fig. 3 HPG in upstream flow section [16]

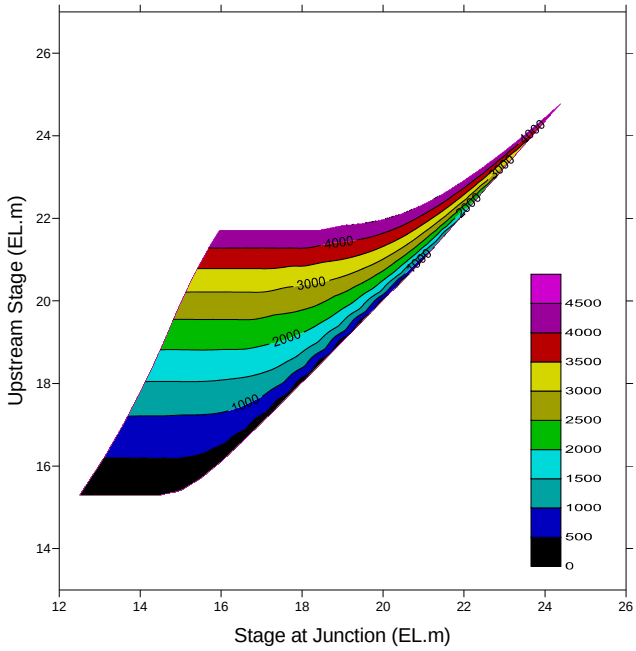

Fig. 4 HPG in the kriging-interpolated at the Seongseo

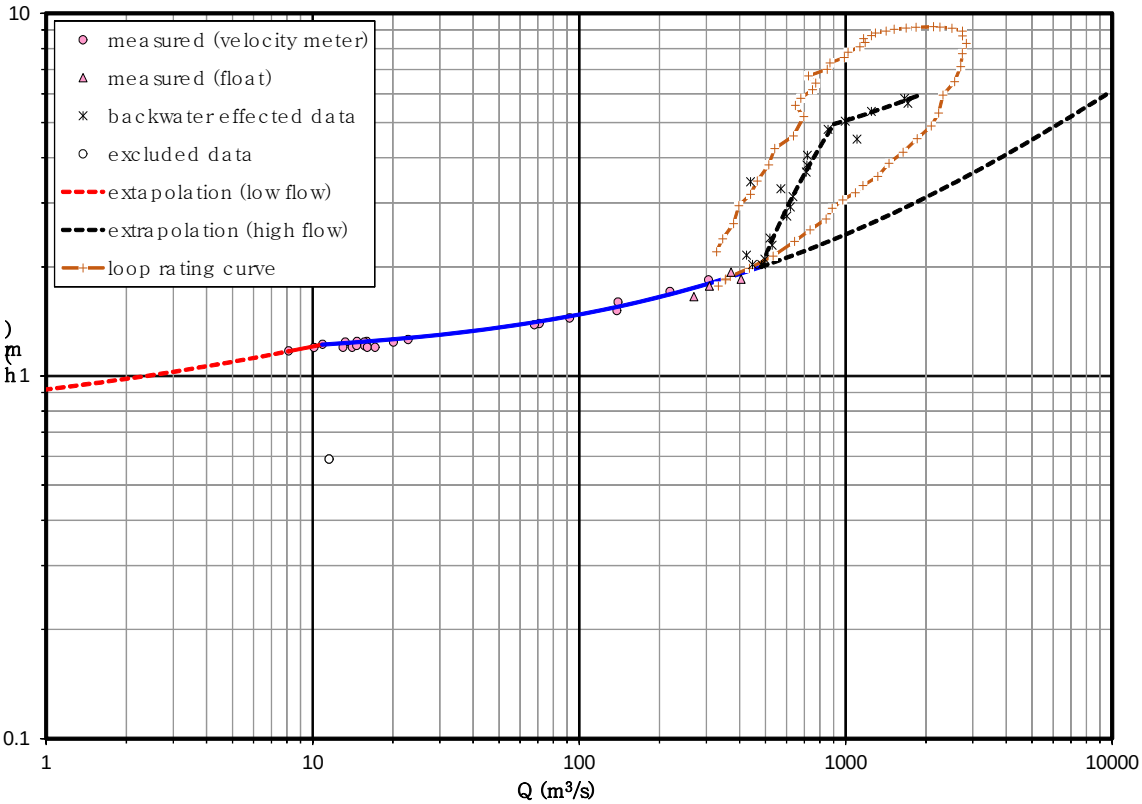

Fig. 5 Stage-discharge relation curves at the Seongseo stage gauging station of the Nakdong River

The result of calculating discharge in a backwater-affected section using kriging-interpolated HPG is as shown in Fig. 6. The single rating curve does not reflect the backwater effect, since the water level of the main stream drops down more slowly when the tributary flow decreases, showing a large difference from the measured discharge hydrograph. The total discharge volume during this flood event period was calculated to be approximately 50% larger. The peak flood discharge was also calculated to be 10% larger than measured ones. The tributary discharge by the HPG method developed in this study was not significantly different from the result of the actual measurement, and the error of total volume and the peak flood discharge were about 5% and 1%, respectively. Thus, our method showed a relatively more accurate result than the single rating curve method.

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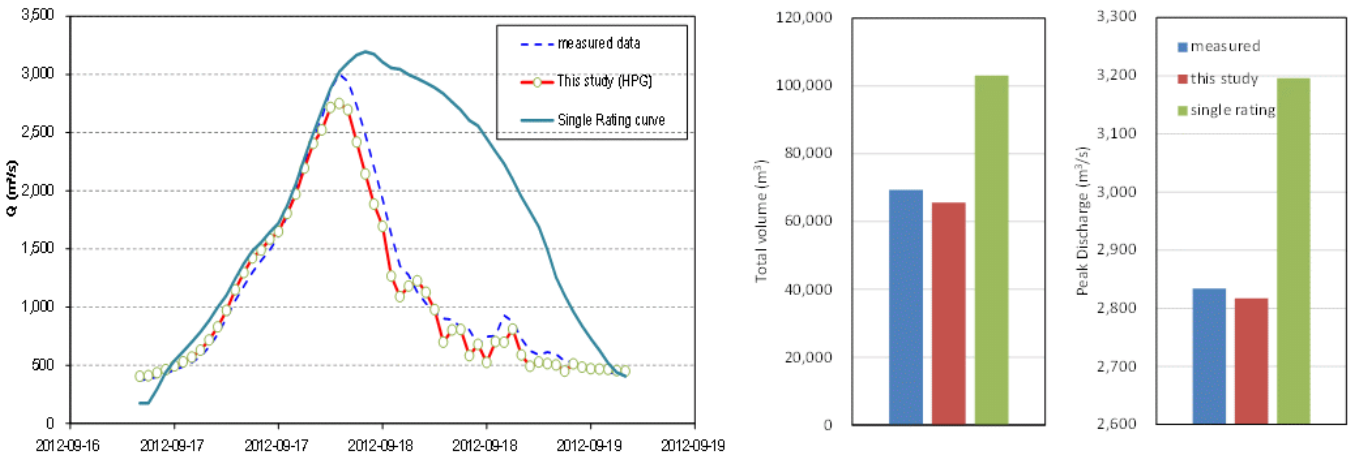

Fig. 6 Comparison of methods for computing discharge at the Seongseo stage gauging station

IV. CONCLUSION

Reliable discharge data is an essential element for studies regarding water management is important for hydrological balance analysis in the watershed scale [19]. In order to determine all inflow discharge from the tributary watershed, a stage-gauging station used to be installed at a location not far from the junction. However, the stage-gauging station produces discharge data through continuous water level observations and stage-discharge rating curves. The single stage-discharge relationship does not occur in a junction section that is significantly affected by backwater, so the discharge cannot be produced. This becomes the main reason to reduce accuracy in the calculation of discharge in tributary, as well as flood prediction in the main stream. In order to solve such problem, a practical method using HPG was developed in this study, and as a result of applying it to the Geumho River, it was confirmed that it coincided well with the automatic discharge measured result at the Seongseo station. The result of this study will provide an economic and practical alternative to calculating discharge in a section with a high hysteresis of looped stage-discharge relationships.

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