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Analysis of Water Balance Changes and Parameterization Reflecting Soil Characteristics in a Hydrological Simulation Program—FORTRAN Model

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Abstract: Efficient water resource management requires accurate analyses of hydrological components and water balance. The Hydrological Simulation Program—FORTRAN (HSPF) model serves this purpose at the watershed scale. It has limited accuracy in calculating runoff and infiltration because the model simulates hydrological processes using one representative parameter for each land use in the watershed. Accuracy requires field-scale analysis of hydrological components. We calculated the lower zone storage nominal parameter, which markedly affects runoff in HSPF, from effective moisture content and depth of each soil layer. Analysis of hydrological components suggested re-calculating the parameters reflecting soil characteristics. We investigated two scenarios through simulations: Scenario 1 used the existing method. Scenario 2 used parameters that reflected soil properties. Total flows for each sub-catchment were identical, but proportions of direct and intermediate runoff were larger in Scenario 1. Ratios of baseflow, evapotranspiration, and infiltration were larger in Scenario 2, reflecting soil characteristics. Comparing the baseflow ratio to total flow, Scenario 2 values were similar to observed values. Comparisons of R^2 and Nash–Sutcliffe Efficiency (NSE) at the end of the watershed were well matched (R^2 and NSE are higher than 0.9) in both scenarios, but proportions of each hydrological component differed. It is important to consider soil characteristics when applying water quantity and quality analyses in an HSPF simulation.

Keywords: available water capacity (AWC); Hydrological Simulation Program—FORTRAN (HSPF); soil properties; Lower Zone Storage Nominal (LZSN)

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1. Introduction

Globally, rising temperatures with climate change can cause changes in soil moisture content, which affects the water cycle process and water resources [1,2]. Associated changes in hydrological components (such as precipitation, evapotranspiration, surface runoff, baseflow, and soil water content) have a significant influence on water resource management [3]. To prepare for adverse impacts of climate change on hydrology cycles, water quality, and aquatic ecosystems, it must be a priority to conduct accurate water balance analyses [4–7]. Quantitative evaluation of water resources by identifying the hydrological cycle and reflecting watershed characteristics is a fundamental analysis for establishing a water resource management plan [8].

Various hydrological models, such as the Stanford Watershed Model (SWM-IV) [9], Système Hydrologique Europeén (SHE) [10], TOPMODEL [11], Precipitation Runoff Modeling System (PRMS) [12], National Weather Service River Forecasting System (NWSRFS) [13], and Soil & Water Assessment Tool (SWAT) [14], have been used to predict flow and water quality, quantitatively, in watersheds [15]. Among them, the SWAT and Hydrological Simulation Program—FORTRAN (HSPF) models are commonly used for quantitative and quality analysis of surface and ground water accounting for land use characteristics at the river basin scale [16]. Most of the watershed scale models, including the HSPF model, predict the flow at the outlet of the basin through calibration and validation. Thus, they are used to predict water quantity and quality, to understand hydrological phenomena in watersheds.

The HSPF model is suitable for application to drainage where impermeable urban and permeable rural areas are mixed. The model allows convenient management of input and output data, is usable for long-term simulations [17], and has been widely used, including in all the following studies: Lee et al. [18] quantitatively analyzed the circulation of water and pollutants in the urbanized Anyangcheon watershed. Yi et al. [19] studied the relationship between the concentration of suspended solids and the water balance in the Imha Lake inflow stream. Yan and Zhang [20] assessed the effect of a segmentation approach (investigating spatial discretization) on HSPF performance and parameter estimation. Lee [21] simulated river runoff under land use changes and investigated changes in total streamflow, direct flow, and baseflow during rainfall events. Seong [22] quantitatively identified the water balance and calculated the inflow of river water. Shin [23] improved the hydraulic accuracy of the HSPF model by using the measured river cross-section and rating curve. Hedrick et al. [24] proposed investigating the impact of climate variability on the water cycle by separating the water balance into its hydrological components. Chung and Lee [25] developed a methodology to assess alternatives using a continuous water quantity/quality simulation model.

The initial parameters of the HSPF model are usually estimated through a calibration process. Calibration with measured values is performed within an appropriate range based on initial values widely used in other studies [26]. However, the HSPF model has limited accuracy in predicting the hydrological components that reflect spatially distributed land characteristics because the HSPF model uses an average parameter value for the amount of sub-surface water stored for all land uses in the watershed [27–30]. Jung et al. [31] described limitations in the HSPF model in expressing runoff characteristics by simulating the same soil condition without classifying agricultural land use. The input data to HSPF are vast, and values are changed by adjusting the input parameters through the calibration process without adequately considering the spatial land/soil characteristics. Therefore, we aim to apply parameters that correctly reflect the watershed characteristics, especially the Available Water Capacity (AWC), and soil properties [26,32].

Variation in soil moisture with soil characteristics should also be considered in the calibration process, especially in a simulation targeting a complex watershed; it is important to calculate parameters reflecting the characteristics effective moisture content and depth of each soil layer [33]. However, this is not reflected in the current HSPF model and to the best of our knowledge has not been done before.

In addition, the ratio of baseflow to national river flow is approximately 40% on average per year [34], and changes in river flow and groundwater level related to direct baseflow can be caused by changes in hydrological phenomena and water circulation systems at watershed scales [35]. As baseflow plays an important role in maintaining the hydrological function of the river along with direct runoff, a quantitative analysis of the baseflow is important. In the HSPF model, the parameter that most affects the flow (e.g., surface runoff and baseflow) is the Lower Zone Storage Nominal (LZSN) parameter [36].

The purpose of this study was to (1) estimate the effective LZSN parameter that reflects the depth of each soil layer and the amount of effective soil moisture, (2) to compare and analyze the difference between hydrological components with and without considering the soil characteristics, and (3) to evaluate the baseflow characteristics after applying the soil characteristics in HSPF.

The novelty of this study is (1) the importance of accurate parameter estimation is shown through analysis of water balance for each hydrological component, even if the simulated flow at the end of the watershed is numerically well matched; (2) the importance of parameter estimation to reflect watershed properties is demonstrated by calculating parameters using soil properties and comparing the simulation results to the previous model that used average parameters for each watershed.

2. Methods

2.1. Study Area

The study area is the Uiam Dam basin located in Chuncheon-si, Gangwon-do, South Korea, which comprises downstream from Chuncheon Dam, downstream from Soyang-gang Dam, the Uiam Dam, and the Gongjicheon sub-watershed (Figure 1). The main water source for the basin is the effluent water from the Chuncheon and Soyanggang Dams. It is possible to quantitatively analyze the factors that affect the water body through simulation of the dam basin using a hydrological model [37]. The soil properties of the Uiam Dam basin differ depending on aspects of the soil profile, namely the number of soil layers (2 to 6), depth of each layer (0.06 to 0.27 m), and effective moisture content (0.02 to 0.48%) (Figure 2). In Figure 2, (a) is a soil map of the target area and (b) is different depths for each 3D soil type. Even within the same watershed, soil type and depth properties are different, as shown on the right side of Figure 2, so it is necessary to reflect the soil characteristics in the model and calibrate the related parameters. The results of the mean temperature precipitation analysis and flow data of the target area using the input data of the model are shown in Figure 3. The total area of the Uiam Dam basin is 7709 km^2, and the effective storage volume is 5,750,000 m^3. The discharges from the Soyang River Dam and Chuncheon Dam are approximately 55% and 40%, respectively, of the inflow of the Uiam Dam basin. Analysis of land use in the basin revealed that the urbanized dry area was 4.74%, agricultural area 17.72%, and forested area 49.66%. Forest occupied the largest area, followed by water and agricultural areas.

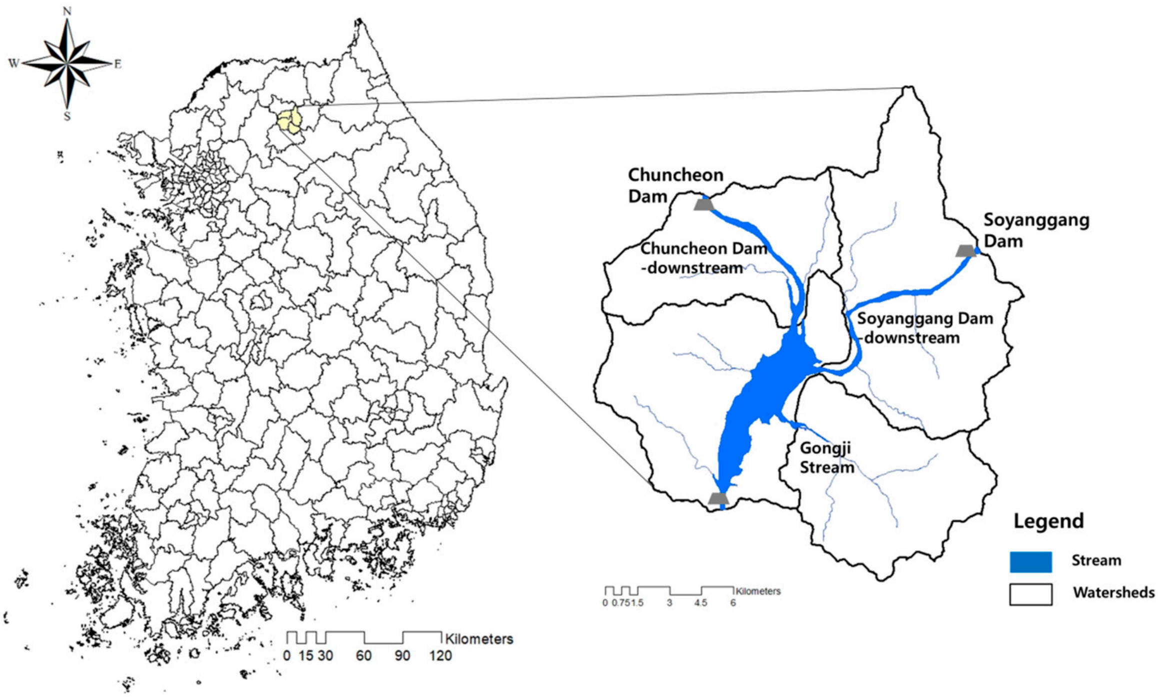
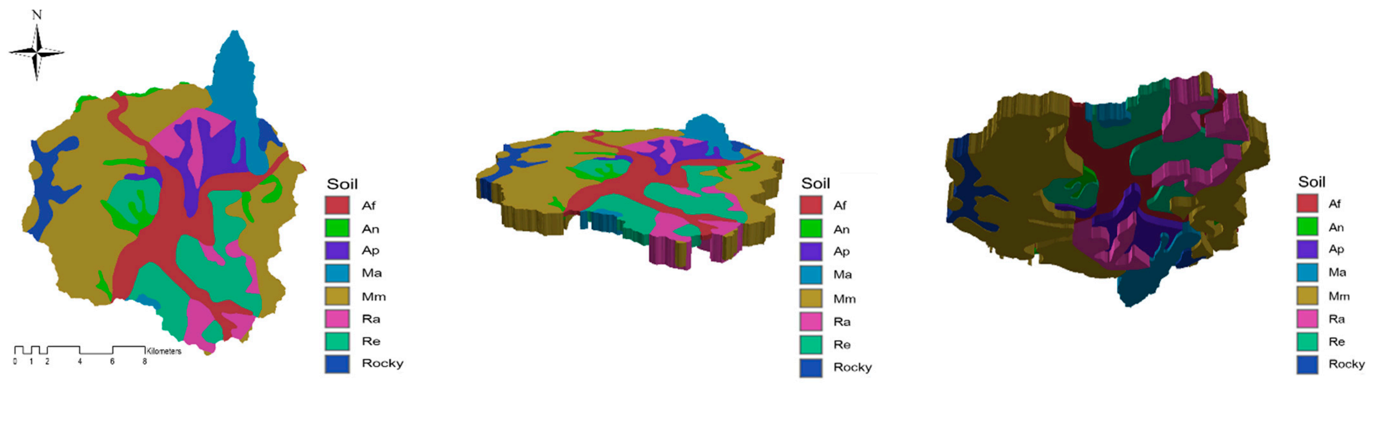
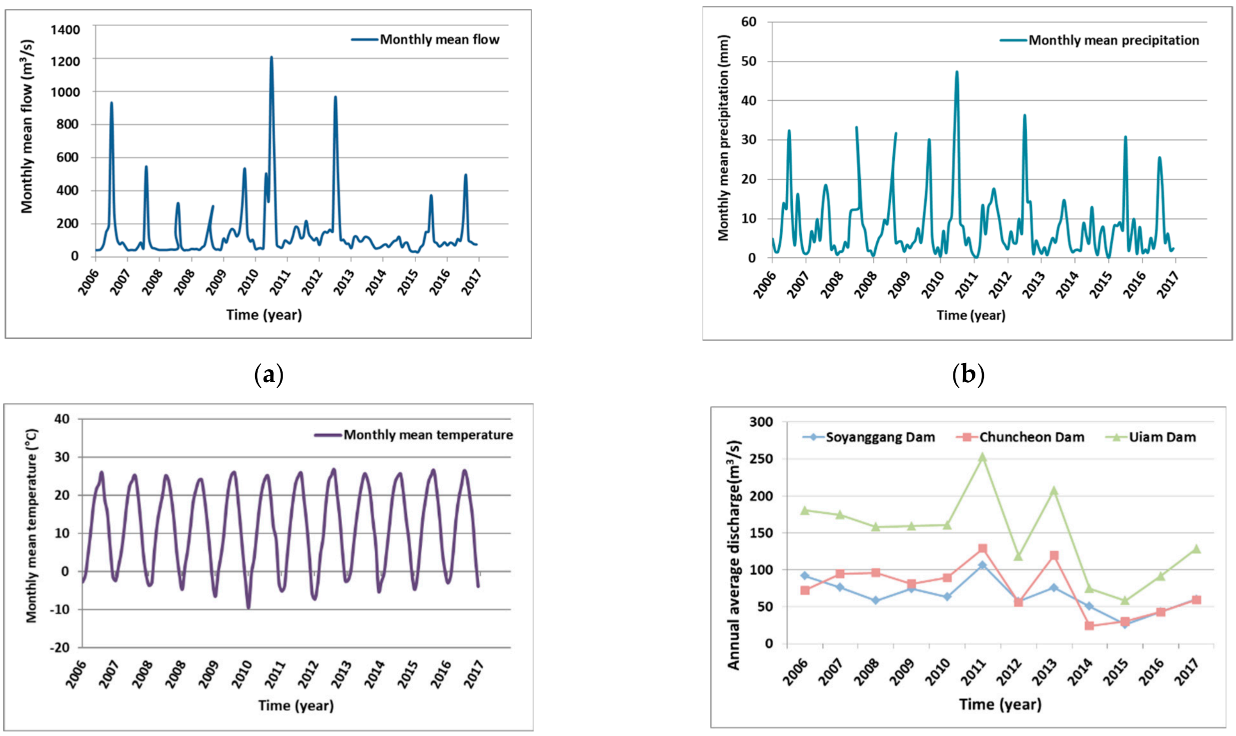


Figure 1. Location of study area: the Uiam Dam basin located in Chuncheon-si, Gangwon-do, in South Korea.



(**a**) (**b**)

Figure 2. Depth and properties of soil layers. (**a**) soil map of the target area; (**b**) different depths for each 3D soil type.



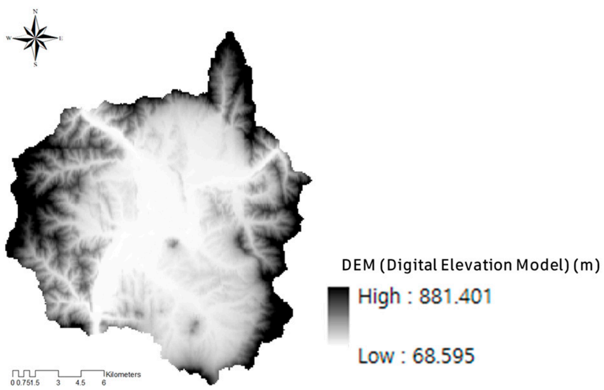
(**a**) (**b**)

(**c**) (**d**)

Figure 3. Monthly average temperature, precipitation, and flow in the target area (2006–2017). ((**a**) Monthly mean flow (m^3/s); (**b**) Monthly mean precipitation (mm); (**c**) Monthly mean temperature (°C); (**d**) Annual mean discharge (m^3/s) (dams)).

2.2. Description of HSPF Model

The HSPF model was developed by the United States Environmental Protection Agency (U.S. EPA) and has been widely used for simulation of hydrology and water quality in various watersheds [38]. The HSPF model can be applied to runoff simulations in urban and rural watersheds based on the water balance equation. In HSPF, Watershed Data Management (WDM) input/output data are managed through separate software, WDMUtil, and long-term simulations of extensive hydrology and water quality are possible [38]. The HSPF model comprises application and utility modules that support the application module [39]. The application module can simulate runoff in urban and rural areas and comprises the PERLND module (which simulates the water quantity and water quality in the previous land), the IMPLND module (which simulates the impervious land), and the RCHRES module (which simulates the water body). Each module is independent of the others, and simultaneously interacts and performs simulations [40]. Time-series data, such as rainfall and temperature, are required as input data to simulate the water quantity and quality in the watershed (Table 1). In this study, to apply the HSPF model, we used the 10 m × 10 m Digital Elevation Model (DEM) provided by the National Geographic Information Institute [41], and the 2017 land use map and Korean Reach File (KRF) v3.0 use map provided by the Environment Geospatial Information Service [42,43]. The sub-classified 2017 land cover map provided by the Environmental Geospatial Information Service [42] was used for land use (Figure 4). Data constructed by the Water Resources Management Information System [44] were used for the daily dam discharge. Weather data (2006–2017) such as precipitation (mm), temperature (°C), wind speed (km/h), solar radiation (MJ/m^2), dew point temperature (°C), and total cloud amount (tenth conversion) were provided by the Meteorological Agency and constructed as a WDM file (.wdm format) using WDMUtil for input to the HSPF model simulation. The weather data time series are stored in the WDM file, and with the watershed data constructed from BASINS, they become inputs to the HSPF model. Table 1 shows the data necessary for HSPF modeling.



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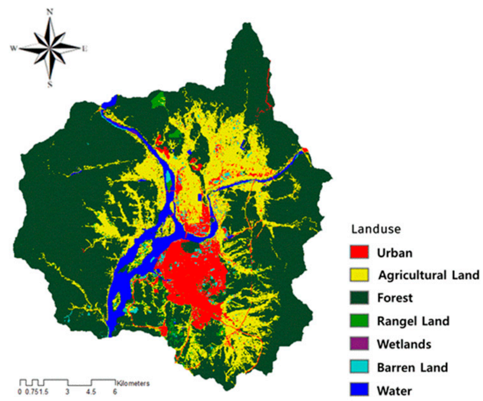


(**b**)

Figure 4. Input data for the HSPF of the Uiam watershed (DEM provided by the National Geographic Information Institute and 2017 land cover map provided by the Environmental Geospatial Information Service). ((**a**) DEM (**b**) Land use).

Table 1. Data necessary for HSPF modeling.

Model Data	Content	Years	Sources
Terrain data	Digital elevation model	2014	National Geographic Information Institute
Land use	Land use spatial distribution	2017	Environmental Geospatial Information Service
Meteorological data	Precipitation Evaporation Temperature Wind speed Solar radiation Evapotranspiration Dew point temperature Cloud cover	2006–2017	Meteorological Agency
Hydrological data	Runoff (KRF 3.0)	2015	Environmental Geospatial Information Service

2.3. Estimation of the Effective Parameters Based on Soil Properties and Scenario Analysis

Among the parameters used in the HSPF model, Upper Zone Storage Nominal (UZSN), Lower Zone Storage Nominal (LZSN), Infiltration (INFILT), and Ground Recession Rate (AGWRC) have influence on the flow simulation [45]. The LZSN parameter was found to have the most influence on runoff [36]. Therefore, for accurate runoff and infiltration analysis, it is important to estimate the LZSN parameter well to reflect the soil characteristics across the watershed.

There are various practical difficulties in estimating parameters directly from measured information in hydrological models. Therefore, it is essential to calibrate and appropriately calculate parameter values using available information [46]. Many studies have been conducted to investigate the uncertainty of the flow simulated in the hydrologic model as well as the calibrations of the simulation results and to evaluate the reliability of the model [47,48]. Additionally, in hydrological models, various factors and methods of estimating parameters can be considered. In this study, the LZSN parameter was calculated using the soil layer depth and effective moisture content data based on characteristics of the soil profiles. To reflect the characteristics of the soil, information on soil type and its properties was used based on the soil map for each sub-watershed. As the LZSN parameter means the storage nominal, so AWC and depth information for each soil type were important factors. To consider the depth of the soil and the soil properties for each layer, the value of the LZSN parameter was calculated by adding the values obtained by multiplying the layer depth and the AWC for the soil types. The Available Water Content (AWC) is the effective moisture content of each soil layer and refers to the value obtained by subtracting the moisture content at the permanent wilting point from the field capacity. The LZSN parameter is related to the amount that can be stored in the lower layer of the soil. A smaller value means less water storage, and a larger value means more water storage. In this study, total storage was calculated based on the soil type data, and the upper 10 cm was assumed to be UZSN.

Two scenarios were constructed to compare and analyze the proportions of the hydrological components. Through the simulation and results analysis of the two scenarios, it is possible to numerically determine how the parameters reflecting the soil characteristics represent the differences in the flow and water balance analysis results. Scenario 1 applies the soil parameters (LZSN) calculated by the existing method, and Scenario 2 applies the effective soil parameters reflecting the soil characteristics of each layer as the newly calculated LZSN parameters. Water balance analysis was performed for the two scenarios to analyze the difference between hydrological components with and without soil characteristic consideration with the LZSN parameter in HSPF. In addition, to evaluate the impact of the effective LZSN parameter on the baseflow, the Baseflow Index (BFI) was calculated using BFLOW [14,24] and WHAT [49,50], which are the baseflow separation models. The BFI was compared with the baseflow ratio calculated using the measured flow for the two scenarios. Figure 5 presents the overall outline of this study.

The hydrological components were divided into direct runoff and baseflow, intermediate outflow, infiltration, and evapotranspiration. The analysis was conducted by dividing the total flow obtained from the simulation into Surface Outflow (SURO), Active Groundwater Outflow (AGWO), Intermediate Outflow (IFWO), Total Simulated Evapotranspiration (TAET), and Inflow to Inactive Groundwater (IGWI). Water balance analysis was performed per land use by dividing flow into SURO, TAET, and IGWI. The infiltration was calculated as the sum of the baseflow, intermediate outflow, and infiltration.

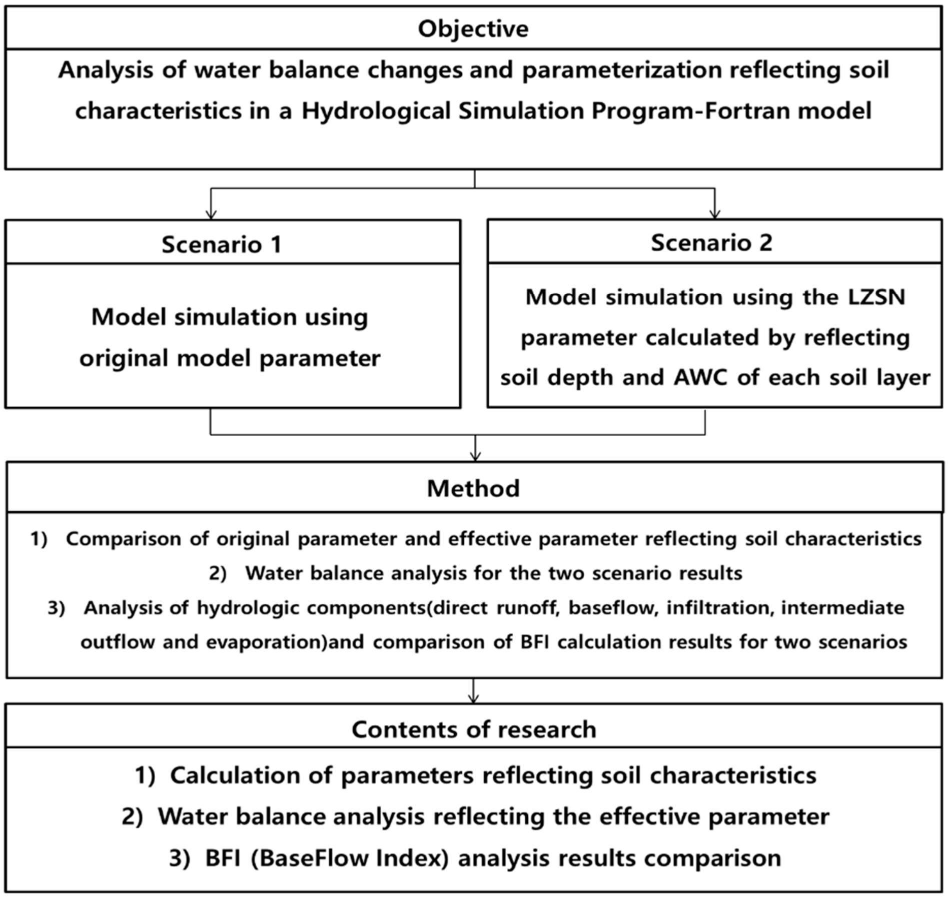


Figure 5. Flowchart of the study design.

2.4. Baseflow Analysis Using Baseflow Separation Programs (WHAT, BFLOW)

The WHAT system is a web-based tool developed to estimate the baseflow separately from the streamflow data, and has been used in various studies for baseflow simulation and analysis in rivers [26,48,51]. A baseflow filter program (BFLOW) is one method that has been widely used to separate the baseflow from streamflow data. BFLOW separates the baseflow using digital filtering and provides the amount of baseflow to the total flow as a ratio.

Separation Methods (WHAT, BFLOW)

The WHAT can separate the baseflow by three methods. First, the Local Minimum Method (LMM) separates the baseflow by connecting the points where the river flow comprises only the baseflow, by decreasing the direct flow at the recession part of the flow hydrograph. The second method is the one-parameter digital filter method, which separates the baseflow ratio based on the method used in signal processing research to separate high and low frequencies. Third, the Eckhardt filter method uses a variable called the maximum value of BFI, which is the ratio of the baseflow to the total river flow [52]. The method is like the BFLOW filter method but has the advantage of considering the characteristics of the aquifer in the watershed. Therefore, in this study, the Eckhardt filter method in Equation (1) was used, which considers the maximum value of the ratio of baseflow to total flow:

$$b_t = \frac{(1 - BFI_{max})\alpha + b_{t-1} + BFI_{max}Q_t}{1 - \alpha BFI_{max}} \quad (1)$$

where b_t is the baseflow separated at time t (m^3/s), b_{t-1} is the baseflow separated at time $t-1$ (m^3/s), Q_t is the total stream flow during time t (m^3/s), α is the filter parameter constant, and BFI_{max} refers to the maximum value of the baseflow ratio to total flow.

In this study, the value of BFI was calculated using the WHAT system. To accurately calculate the baseflow ratio using WHAT, the BFI_{max} value suitable for the aquifer characteristics of the target watershed must be calculated. Eckhardt [52] proposed maximum values for each representative aquifer: 0.8 for the porous aquifer of perennial streams, 0.5 for ephemeral streams, and 0.25 for a stream that temporarily flows.

With the measured flow of Gangchon Bridge at the end of the Uiam Dam basin, the target area of this study, the smallest daily flow was 2.73 m^3/s in 2013, 2.55 m^3/s in 2014, 4.04 m^3/s in 2015, 6.11 m^3/s in 2016, and 17.78 m^3/s in 2017. Most of the target river always flows over 10 m^3/s for 5 years, so BFI_{max} used in the WHAT simulation was applied as 0.8 in this study.

In BFLOW, the digital filtering method was used to separate high and low frequencies in signal processing research. The baseflow separation method was applied to separate the high-frequency signals. The digital filter method does not consider the physical characteristics of direct runoff and baseflow, but it can be calculated quickly and reproduced consistently [53]. The method of separating the baseflow from the hydrograph is shown in Equation (2) below:

$$\begin{gathered} f_t = a \cdot f_{t-1} + \tfrac{1+a}{2}(y_t - y_{t-1}) \\ b_t = y_t - f_t,\ 0 \le b_t \le y_t \end{gathered} \quad (2)$$

where y_t is average daily flow, f_t is direct flow, b_t is baseflow, and a is filter parameter.

The BFLOW program uses daily flow data and a one-parameter filter [54] to calculate the baseflow. The user calculates the baseflow as the amount passing the filter at the first, second, and third passes. The user can select from the filtered results and use those suitable for the characteristics of the target watershed [43,53]. The first to third passes can calculate the baseflow ratio as the amount passing the filter for stream flow data. In particular, with the third pass, the contribution to the baseflow is relatively small, and the result of separation of the first and second passes is generally used [55]. Besides improving the accessibility of the existing BFLOW system, it also evaluated the contribution to the river by quantifying the direct and baseflow through the BFI and Coefficient of Variation (CV). The results demonstrated that BFLOW would be helpful for evaluating river flow characteristics for water resource and flood risk management.

The minimum and maximum number of days of rainfall duration for calculating the recession coefficient must be entered as the input data to BFLOW. However, with the Uiam Dam basin, it is difficult to calculate such specific values. Thus, in this study, the BFI value was calculated by using the minimum value of 2 and the maximum value of 100, which are the default values provided by BFLOW. Therefore, the results of the baseflow analysis using the BFLOW model can differ from the actual baseflow ratio of the streamflow. In addition, the results of the BFLOW model are presented as first, second, and third passes. It can be seen that the base outflow ratio decreases from the first pass to the second and third passes. Therefore, because Arnold and Allen [14,24] suggested that the first pass result and the baseflow ratio classified manually are similar, this study calculated the average baseflow ratio for five years using the first pass result and compared it with the baseflow ratio calculated using the measured flow ratio.

2.5. Evaluation Method

In the hydrological model, to remove uncertainty, reliable results are derived by calibrating the characteristics of the watershed and the dynamics of the runoff process based on the measured data [23,56]. The HSPF model also needs to be corrected for the target watershed based on the measured values. The accuracy of each element of the hydrological model must be evaluated to analyze the water balance according to the parameter changes. Heo et al. [57] suggested the importance of evaluating each hydrological element when calibrating hydrological models. The inflow into the Uiam Dam collected through the

National Water Resources Management Information System was used as the measured data to evaluate the accuracy of the model [37,44]. After comparing the model-predicted daily flow with the measured value, the simulation results were evaluated by the coefficients of determination R^2, Nash–Sutcliffe Efficiency (NSE), and % difference, respectively, as shown in Equations (3)–(5). The accuracy of the model was evaluated based on the results of Morioasi et al. [58]. According to the presented criteria, the result was classified as very good, good, satisfactory, or unsatisfactory (Table 2).

$$R^2 = \left(\sum_{i=1}^{n}(O_i - \overline{O_i})(P_i - \overline{P_i})\right)^2 / \sum_{i=1}^{n}(O_i - \overline{O_i})^2 \sum_{i=1}^{n}(P_i - \overline{P_i})^2 \quad (3)$$

$$\mathrm{NSE} = 1 - \sum_{i=1}^{n}(O_i - P_i)^2 / \sum_{i=1}^{n}(O_i - \overline{O_i})^2 \quad (4)$$

$$\%\ \mathrm{difference} = \frac{\sum_{i=o}^{n} O - \sum_{i=0}^{n} P}{\sum_{i=o}^{n} O} \times 100 \quad (5)$$

where P_i is the simulated value, O_i is the observed value, n is the total number of data, $\overline{P_i}$ is the mean of the simulated value, and $\overline{O_i}$ is mean of the observed value. The closer R^2 and NSE are to 1 and % difference is to 0, the better the model's simulated value predicts the measured value, increasing the model efficiency [17,40].

Table 2. Evaluation criteria for flow simulation result of the HSPF model [58].

Evaluation	Very Good	Good	Satisfactory	Unsatisfactory
% Difference	<10	10–15	15–25	25<
R^2	>0.8	0.7–0.8	0.6–0.7	0.6>
NSE	>0.8	0.7–0.8	0.5–0.7	0.5>

3. Results and Discussion

3.1. Parameter (LZSN) Calculation Considering Soil Characteristics

The LZSN parameter for each soil profile in the study watershed was calculated using the AWC and depth of each soil layer. In Table 3, the default parameter is the value estimated by the built-in functions in the HSPF model, and the estimated parameter is the value calculated using soil properties. The estimated parameter varied according to the characteristics of the sub-watershed and soil types. It might be difficult to compare the parameter values due to regional variability of each study area. However, in this study the validity of the parameter estimation through comparison with the simulated and measured flow was shown. The LZSN of Scenario 1, the default value of the model, was 0.051 m for all land uses except for forest (0.099 m). However, in Scenario 2 the values of LZSN were calculated and applied according to the land use and soil types and ranged from 0.01 m to 0.67 m. The LZSN for the forest (which occupies the largest area) was applied as 0.1 m in Scenario 1, and in Scenario 2 it was calculated to be 0.19 m downstream of Chuncheon Dam, 0.04 m downstream of the Soyang River Dam, 0.16 m for the Gongjicheon Stream, and 0.21 m for the Uiam Dam. Thus, there were differences compared to the original parameter value for the forest area in the HSPF model (0.1 m).

In this study, Scenario 1 showed high NSE and R^2 without additional calibration, so it might not represent the physical properties of the watershed well. Scenario 2, reflecting the watershed characteristics, showed better results (e.g., water balance) than Scenario 1. Therefore, it is possible to consider the effect of hydrological components for each sub-watershed in Scenario 1 using default values and in Scenario 2 using the parameters calculated by considering soil characteristics. In addition, although the simulated flow at the end of the watershed numerically matched the actual flow well, this illustrates the importance of a reasonable prediction of the hydrological component for each land use while considering the watershed characteristics.

Table 3. Default and estimated parameters (LZSN) for each land use in sub-watersheds.

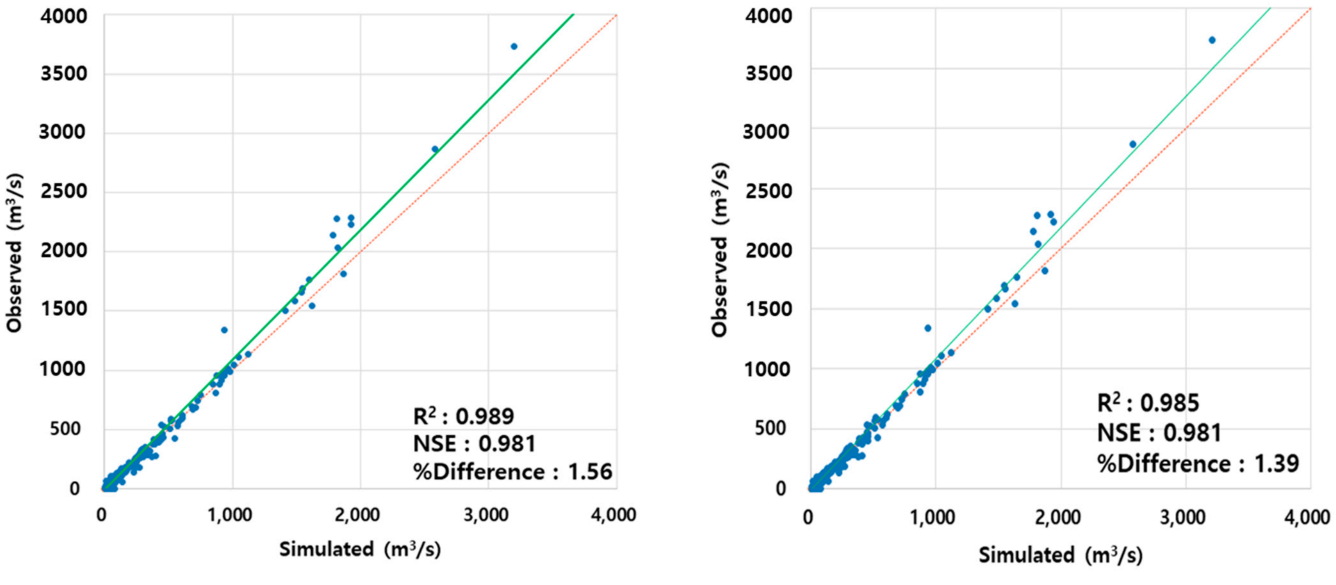
Land Use	Estimated Parameter				Default Parameter
	Chuncheon Dam—Downstream	Soyanggang Dam—Downstream	Gonggi Stream	Uiam Dam	
Urban	0.35	7.81	12.06	10.5	2
Agricultural Land	12.34	12.33	10.08	6.61	
Range Land	6.43	6.52	7.79	9.98	
Wetlands	15.93	5.66	26.28	7.66	
Barren Land	8.19	6.08	11.38	6.61	
Water	2.9	4.9	4.9	4.9	
Forest Land	7.54	10.4	6.44	8.26	3.9

In Table 3, the default parameter was the same value calculated for four sub-watersheds and land use by the built-in functions in the HSPF model. The estimated parameter was calculated by considering the soil properties. In the case of the forest, it was calculated as 3.9 for all sub-watersheds. However, with the estimated parameter, different values were calculated for each sub-watershed and land use. With urban areas, the default parameters were given as 2, but estimated parameters 0.35, 7.81, 12.06, and 10.50 were calculated in each sub-watershed. (In this study, the difference is minimum 82% and maximum 700% across the entire land use of sub-watersheds.)

As the estimated parameters were calculated by considering the properties of each soil layer, the values are different even for the same land use. The LZSN parameter shows that, the lower the zone nominal storage and larger the value, the larger the water storage space in the soil layer is. The proportion of soil properties is different for each sub-watershed, 'Mn' soil properties took the largest proportion in the sub-watersheds of Chuncheon Dam—downstream, Soyanggang Dam—downstream, and Uiam Dam. In the Gongjicheon sub-watershed, 'Re' soil properties took the largest proportion.

3.2. Water Balance Analysis for Scenarios 1 and 2

The runoffs according to the application of Scenarios 1 and 2 and the hydrological components of each land use in the sub-watersheds were compared. R^2, NSE, and % difference indicators were used to evaluate the accuracy of the simulation by comparing the observed Uiam Dam inflow. Even though R^2 and NSE were very good or better, there may be differences in hydrological components by land use in the sub-watersheds. Therefore, in this study, even if the simulation matched well with the observation at the end of the watershed, the parameter calculation reflecting the soil characteristics and the difference in the proportion occupied by hydrological components were analyzed. Data from 2013 to 2017 were used for the model–scenario calibration period. The validation period of the model is 2008–2012. In Figure 6, the observed values from 2013 to 2017 and the simulated results for each scenario are plotted. The data used for the calibration are the inflow of the Uiam Dam located downstream of the target area, and the data were provided with daily data observed by the Water Resources Management Information System (WAMIS) [44]. In the simulation for Scenario 1, R^2 was 0.99, NSE was 0.98, and the % difference was 1.56. In Scenario 2, R^2 was 0.99, NSE was 0.98, and the % difference was 1.39 (Figure 6). The closer R^2 and NSE are to 1, the better the measured value that is simulated, and the closer to zero the % difference, the better the simulation [17]. Even though the modeling results from Scenario 1 showed high NSE and R^2 without additional calibration, it might not represent the physical properties of the watershed well. Scenario 2, reflecting the watershed characteristics, showed better results (e.g., water balance) than Scenario 1. Additionally, with the study watershed, the discharge of the two upstream dams accounted for 55% and 40% of the inflow of the Uiam Dam, so it was not significantly affected by the hydrological parameters in the study watershed.



(**a**) Scenario 1: Simulated vs. Observed Flow (**b**) Scenario 2: Simulated vs. Observed Flow

Figure 6. Comparison of simulated and observed flow (calibration period: 2013–2017, simulated value: simulation results of two scenarios, observed value: observed value of Uiam Dam inflow located downstream of the watershed). ((**a**) Scenario 1: Simulated vs. Observed Flow; (**b**) Scenario 2: Simulated vs. Observed Flow).

This study does not discuss the correctness of the model but presents the differences in hydrological components for each sub-watershed when the soil characteristics within the watershed were considered. The aim is to demonstrate why it is necessary to consider soil characteristics when calibrating the HSPF model. Thus, the simulated value at the end of the basin reflected the measured value well, but this was not a problem even if the soil characteristics were not reflected in the model. However, to evaluate the effect of water pollution on land use in sub-watersheds, the spatial characteristics must be reflected in the model. When applying a Best Management Practices (BMPs) scenario within a watershed, the effect of reducing pollution by sub-watersheds will appear differently, so it is important to simulate the spatial characteristics of each land use/soil within the target area.

Tables 4 and 5 show the results of the water balance analysis by sub-watershed for each scenario. Looking at the results of Scenario 1, the proportion of direct runoff by each sub-watershed ranged from 14% to 27%, with an average of 19%; with baseflow, from 21% to 25%, with an average of 24%; and with intermediate outflow, from 12% to 14%, with an average of 13%. The percentage of evapotranspiration was 41% on average, ranging from 36% to 43%, and penetration was found to account for 3% on average, ranging from 2% to 3%. Looking at the results of Scenario 2, the percentage of direct outflow by sub-watershed ranged from 13% to 27%, with an average of 17%; baseflow averaged 26%, ranging from 23% to 27% with median outflow ranging from 12% to 14%; and intermediate outflow ranged from 12% to 14%, with an average of 13%. The percentage of evapotranspiration averaged 41%, ranging from 36% to 43%, and the penetration was 3% on average.

Figure 7 shows the results for each scenario. The proportion of direct runoff was larger in Scenario 1, and the proportion of baseflow was larger in Scenario 2. The proportion of intermediate runoff was greater in Scenario 1, and the proportions of evapotranspiration and infiltration were greater in Scenario 2. Therefore, although the total flow for each sub-watershed was similar in the two scenarios, the proportion of each hydrological component could be different. This means that even if the total flow was the same at the outlet of the watershed, the ratios of each hydrological component differ when the parameters reflecting the soil characteristics are applied.

Table 4. Hydrologic components for each sub-watershed from Scenario 1.

Sub-Basins	Chuncheon Dam—Downstream		Soyanggang Dam—Downstream		Gongji Stream		Uiam Dam	
	mm	%	mm	%	mm	%	mm	%
SURO	200.1	14.4	238.7	16.8	443.3	27.2	224.8	15.9
AGWO	347.3	25.1	346.6	24.3	345.4	21.2	345.7	24.5
IFWO	206.8	14.9	207.8	14.6	210.5	12.9	208.4	14.8
TAET	591.4	42.7	591.2	41.5	590.8	36.3	591.0	41.9
IGWI	39.8	2.9	39.7	2.8	39.6	2.4	39.6	2.9
SUM	1385.5	100.0	1424.1	100.0	1629.6	100.0	1409.5	100.0

(SURO, Surface Outflow; AGWO, Active Groundwater Outflow; IFWO, Intermediate Outflow; TAET, Total Simulated Evapotranspiration; IGWI, Inflow to Inactive Groundwater).

Table 5. Hydrologic components for each sub-watershed from Scenario 2.

Sub-Basins	Chuncheon Dam—Downstream		Soyanggang Dam—Downstream		Gongji Stream		Uiam Dam	
	mm	%	mm	%	mm	%	mm	%
SURO	185.7	13.4	222.0	15.6	432.9	26.5	210.6	14.9
AGWO	370.9	26.8	374.5	26.3	370.3	22.7	369.6	26.2
IFWO	190.8	13.8	189.8	13.3	192.0	11.8	192.7	13.7
TAET	594.5	42.9	594.6	41.8	594.4	36.4	594.6	42.2
IGWI	42.6	3.1	42.8	3.0	42.4	2.6	42.3	3.0
SUM	1384.4	100.0	1423.8	100.0	1631.9	100.0	1409.9	100.0

(SURO, Surface Outflow; AGWO, Active Groundwater Outflow; IFWO, Intermediate Outflow; TAET, Total Simulated Evapotranspiration; IGWI, Inflow to Inactive Groundwater).

In this study, the water balance analysis (Tables 6 and 7) was performed by land use, by dividing the total flow obtained from the simulation into SURO, TAET, and IGWI. The parameter values can be entered in the HSPF model according to the characteristics of the sub-watershed and land use, but the LZSN value in Scenario 1 was applied equally as 0.051 m for other land uses, excluding forest areas. The results of the water balance analysis for Scenario 1 confirmed that the same results were obtained for land uses with the same LZSN value. In Scenario 2, the effective parameter values (recalculated LZSN, which reflected the depth of each layer and effective moisture) were entered.

In Scenario 1, the results of the water balance analysis were the same according to the parameter values for each land use. In Scenario 2, the result of the water balance analysis also differed according to land use and soil characteristics. The method of performing water balance analysis differs depending on the purpose of the study.

In previous studies, a method of water balance analysis using MODSIM and a water balance analysis for agricultural return flow analysis were performed [59,60]. A study model using the linked HSPF-MASA-CREAMS-PADDY model and a study suggesting the circulation rate in agricultural watershed were conducted [61,62]. In this study, to analyze differences according to the input parameters, water balance analysis was performed by land use and sub-watersheds. Water infiltration is the most important hydrological parameter for the evaluation and diagnosis of the soil and water balance [63]. In this study, the differences between hydrological components appear according to parameters. However, a more in-depth analysis will be possible through the parameter calculation method, analysis of differences that occur depending on the soil factor being considered, and linkage with other models in future studies.

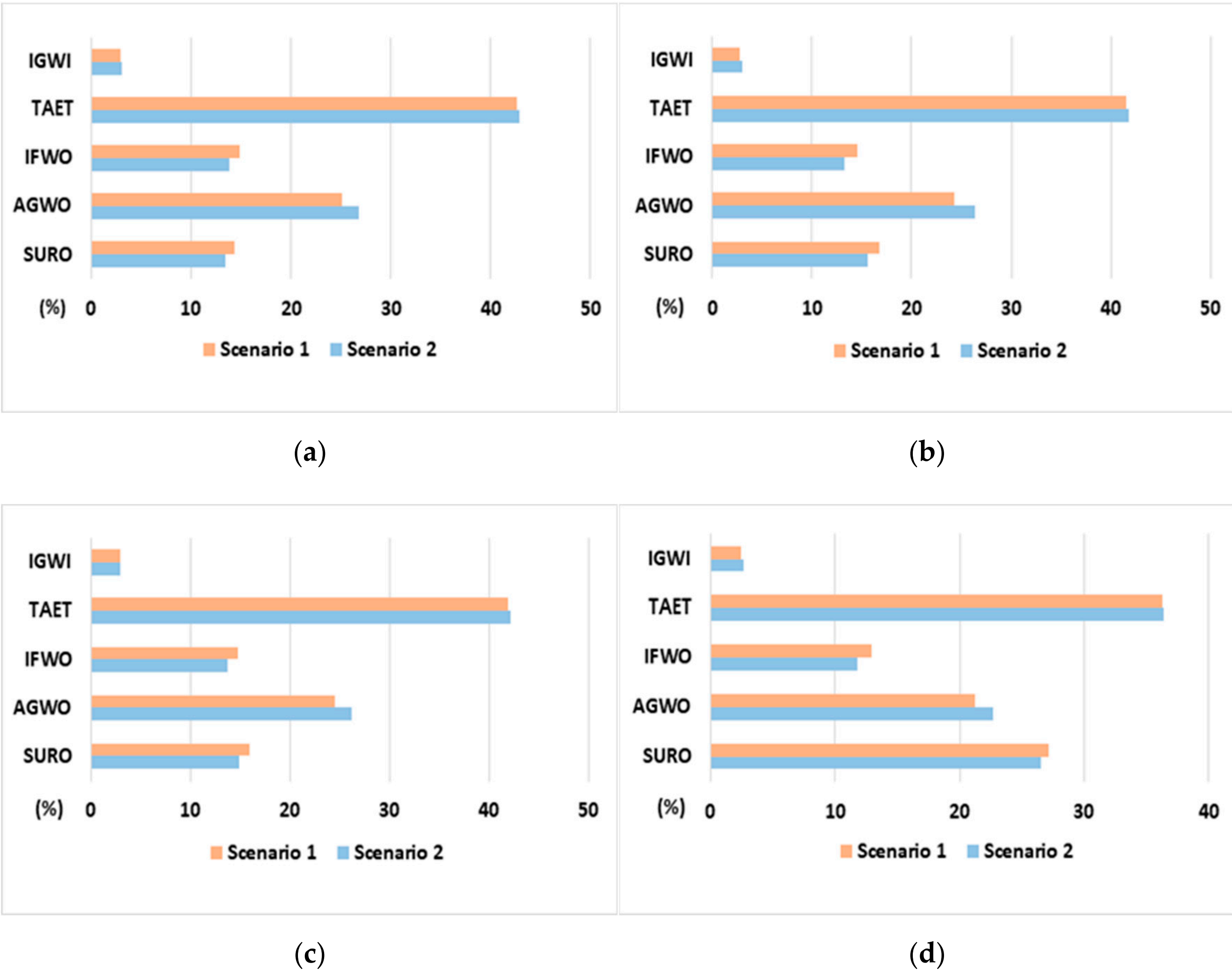


Figure 7. Comparison of hydrologic components of four sub-watersheds from two scenarios. (IGWI, Inflow to Inactive Groundwater; TAET, Total Simulated Evapotranspiration; IFWO, Intermediate Outflow; AGWO, Active Groundwater Outflow; SURO, Surface Outflow.) ((**a**) Chuncheon Dam—downstream; (**b**) Soyanggang Dam—downstream; (**c**) Uiam Dam; (**d**) Gongji Stream).

Table 6. Hydrologic components for each land use from Scenario 1.

Land Use	SURO		TAET		IGWI		SUM	
	mm	%	mm	%	mm	%	mm	%
Urban	284.8	13.3	927.6	43.3	928.4	43.4	2140.7	100.0
Agricultural Land	24.4	13.3	79.3	43.3	79.4	43.4	183.0	100.0
Forest	1026.6	12.2	3675.3	43.7	3701.4	44.1	8403.3	100.0
Range Land	40.3	13.3	131.4	43.3	131.5	43.4	303.2	100.0
Wetlands	319.5	13.3	1040.9	43.3	1041.8	43.4	2402.1	100.0
Barren Land	16.9	13.3	55.1	43.3	55.2	43.4	127.2	100.0
Water	658.0	100.0	0.0	0.0	0.0	0.0	658.0	100.0

Table 7. Hydrologic components for each land use from Scenario 2.

Land Use	SURO		TAET		IGWI		SUM	
	mm	%	mm	%	mm	%	mm	%
Urban	236.3	11.6	890.2	43.9	903.4	44.5	2029.9	100.0
Agricultural Land	19.6	11.3	76.1	43.9	77.7	44.8	173.4	100.0
Forest	911.8	11.5	3495.0	43.9	3558.9	44.7	7965.7	100.0
Range Land	33.1	11.5	126.1	43.9	128.3	44.6	287.5	100.0
Wetlands	266.7	11.7	998.7	43.8	1012.5	44.5	2277.9	100.0
Barren Land	14.4	11.9	52.8	43.8	53.6	44.3	120.6	100.0
Water	624.0	100.0	0.0	0.0	0.0	0.0	624.0	100.0

3.3. Baseflow Separation Result for Scenarios 1 and 2

In this study, WHAT was used to separate the direct and base outflows, and the average annual flow and BFI were estimated. Average flow refers to the annual average flow for five years, from 2013 to 2017. Due to separating the baseflow from the observed flow using WHAT, the BFI was 0.61, the baseflow ratio in Scenario 1 was 0.65, and that in Scenario 2 was 0.61 (Table 8).

Due to the separation of the baseflow from the observed flow using BFLOW, the results of the first pass, second pass, and third pass were analyzed, and the BFI value calculated using the first pass was 0.65. The BFI analysis result of Scenario 1 was 0.69 and that of Scenario 2 was 0.63 (Table 9). Therefore, the result of Scenario 2 was more similar to the result of the baseflow separated by using the measured flow ratio, compared to the result of Scenario 1. The difference between hydrological components was analyzed through the water balance analysis, and comparison with the measured and simulated values was performed through the baseflow separation result. Accurate hydrological analysis and comparison are possible through baseflow separation.

Table 8. A portion of average direct runoff and baseflow from streamflow in Uiam Dam (unit: CMS).

	Average Streamflow	Average Direct Runoff	Average Baseflow
Uiam Dam	3.18 (100)	1.23 (38.7)	1.95 (61.3)
Scenario 1	3.12 (100)	1.09 (35.0)	2.03 (65.0)
Scenario 2	3.13 (100)	1.21 (38.7)	1.92 (61.3)

Numbers in parentheses mean a portion (%) of streamflow.

Table 9. A result of baseflow separation (BFI) using BFLOW program.

	Annual Average Baseflow Index (BFI)
Observed	0.65
Scenario 1	0.69
Scenario 2	0.63

4. Conclusions

The LZSN parameter was estimated for the Uiam Dam basin based on characteristics of each soil layer, including depth and AWC. Through the HSPF simulation, the water balance and baseflow were analyzed using the LZSN parameter and the baseflow separation program. The results and discussion were as follows:

(1) With the forest, which occupies the largest area in all sub-watersheds, in Scenario 1 an LZSN value of 0.1 m was applied throughout all sub-watersheds. In Scenario 2, the values of LZSN were 0.16–0.26 m (for each sub-watersheds). For all other land uses, in Scenario 1 an LZSN value of 2 m was applied throughout all sub-watersheds;

in Scenario 2 the depth and water capacity of the soil were calculated and applied differently to obtain LZSN for each sub-watershed. In this study, only soil depth and AWC were used as watershed characteristics in calculating the LZSN parameter. However, future studies related to LZSN parameter calculation that reflect more soil properties such as soil adsorption and detachment should be conducted.

(2) Water balance analyses by sub-watershed and land use were performed for two scenarios before and after the application of the parameters (LZSN) reflecting soil characteristics. In Scenario 1, the same LZSN value was applied to all land uses except forests, and the water balance analysis showed similar results. In Scenario 2, different LZSN values (reflecting the characteristics of the soil) were applied, and the water balance results differed according to the land use in the sub-watershed. Therefore, even if the total flow was the same, the ratio of each hydrological component varied according to the LZSN value reflecting the soil characteristics.

(3) Due to separating the baseflow using WHAT, the BFI for the measured value was 0.61. BFIs for Scenario 1 and Scenario 2 were 0.65 and 0.61, respectively; the results of Scenario 2 were like the actual measurements. The first pass of BFI by year using BFLOW gave a BFI of 0.65, and the BFIs for Scenarios 1 and 2 were 0.69 and 0.63, respectively. This could be because the BFI was also calculated (using the WHAT system) through analysis of the flow during the dry season because the default value of the model was used, not the value reflecting the runoff characteristics in the BFLOW simulation.

In this study, the parameters reflecting soil characteristics were calculated to overcome limitations of previous hydrological simulations in HSPF, which does not consider varying soil characteristics. This study confirmed that even though the simulated and measured flows were similar at the outlet of the watershed, the ratio of each hydrological component could be significantly different. In addition, the simulation accuracy of the direct runoff and baseflow runoff was improved in comparison with the measured values. The LZSN parameter values based on the soil characteristics can be applied in the HSPF according to the land use and area of the target watershed.

The HSPF model was also used to apply a BMP scenario and analyze the reduction in water pollution. In both scenarios, R^2 and NSE at the watershed outlet were very good, but there were differences in the LZSN parameter estimates, reflecting the soil characteristics and the proportion of each hydrological component. In this study, the simulation and analysis were performed on the target area where the observation values and simulated values were well matched, which is a possible limitation. Therefore, additional research on parameters that reflect watershed characteristics in various target areas are needed.

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