Assessment of Long-term Groundwater Use Increase and Forest Growth Impact on Watershed Hydrology

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Abstract
Geum River basin is currently suffering from stream drying which is caused by various reasons. Among many reasons, the expansion of groundwater use and forest growth which are known to pose an influence on stream drying have significantly developed over the past 40 years in Geum River basin. Therefore, the periodic change of two factors were reflected to SWAT to figure out their influences on watershed hydrology and stream drying. The periodic change was considered by using 10-year period data from the 1980s (1976–1985) to the 2010s (2006–2015), and applying the condition to SWAT. The model was calibrated based on observed data of streamflow, evapotranspiration, at monitoring points including dam, weir, flux tower, and soil moisture sensor. The calibration result showed satisfactory result evaluated by coefficient of determination ($R^2$), Nash–Sutcliffe Efficiency (NSE), scatter index (SI), and percent bias (PBIAS). The impact of groundwater use and forest growth was evaluated by hydrologic responses obtained by differentiating and comparing their conditions by period while settling weather conditions. As a result, the increase of groundwater use lowered groundwater recharge and groundwater flow while forest growth led to the rise of evapotranspiration which lessened surface runoff and the infiltration to soil layer. These two series of processes reduced total runoff showing decreased value of 2.7%, 6.3%, and 8.9% in 1990s, 2000s, and 2010s compared to 1980s.

Keywords Stream drying · Groundwater use · Forest growth · SWAT

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1 Introduction

Stream drying phenomena, which are often defined as long-term declines in water levels caused by sustained factors, are key issues associated with groundwater use, and they define the reduction in streamflow rates caused by various factors that are hydraulically related to a given stream. With watershed development and increasing groundwater use, studies evaluating these phenomena have recently gained interest (Messager et al. 2021; Price et al. 2021; Shanafield et al. 2021). However, there are many difficulties in investigating continuous stream drying and studying the phenomena from a quantitative perspective. The difficulties come from complex factors that are not clearly understood or defined (Jung et al. 2003) and the lack of hydrological data in small rivers where stream drying usually occurs. Jung et al. (2019) considered stream drying phenomena by applying five different factors, groundwater use, afforestation, watershed development, road development, and soil erosion, and ranked their contribution rates to the loss of runoff. The results demonstrated that increase of groundwater use and forest growth had a relatively higher influence on stream drying than did other factors.

Increased population numbers and increased amounts of harvest trigger increases in water demand. Although the demand can be fulfilled using surface water sources such as lakes, rivers, and reservoirs, heavy rain in South Korea is concentrated in Summer; thus, the water demand in other seasons cannot be met from surface water stored in the sources. Therefore, groundwater is often used solely or with surface water to satisfy insufficient surface water supplies. However, when groundwater use exceeds groundwater recharge for a long time, groundwater depletion can occur (Gleeson et al. 2010; Park et al. 2016, 2021; Warix et al. 2021), and the lowering of groundwater levels can result in serious effects on natural streamflow and related ecosystems (Kirk and Herbert 2002). Many studies have tried to determine the hydrological impacts of groundwater use. Wen and Chen (2006) explored the spatial distribution of streamflow trends for and climatic impacts on the watershed and concentrated on the analysis of streamflow residuals from gauging stations to determine the decrease in baseflow caused by groundwater withdrawals. Kim et al. (2012) quantified the streamflow depletion from groundwater pumping for the target watershed. Jung and Kim (2017) identified stream drying by tracing the flow decrease from cell-based hydrological routing under different land use and groundwater use conditions. These studies commonly explained that groundwater use is highly associated with streamflow condition and should be considered when studying stream drying phenomena.

Forest growth changes the net loading of streamflow by intercepting precipitation, controlling the rate of evapotranspiration, and extracting groundwater from vegetation roots. Thus, quantifying the influences of forest growth on watershed hydrology is crucial for planning forest or land management and adaptation strategies for watershed ecosystem sustainability. The relationship between forest growth and water cycle in watersheds has been studied for a long time, and several studies have demonstrated that forest changes can significantly affect streamflow and watershed hydrology by altering its pattern, magnitude, frequency, and quality. Mackay and Band (1997) showed that the canopy distribution has significant effects on simulated hydrological outputs where evaporative demand exceeds available water. Birkinshaw et al. (2014) made full use of the unique 45-year dataset over the entire cycle from the original upland grassland vegetation through plowing the catchment and through forest growth up to mature trees. The results showed clear changes in the nonstationary nature of the catchment, with an annual increase in intercepted evaporation and a decrease in discharge as the trees grew. Yue and Hashino (2005) assessed the impact
of forest growth on the streamflow of the basin using statistical trend analysis, and sug-
gested that forest growth is responsible for the decrease in all regimes and that the increase
in evapotranspiration due to the growth resulted in the change of total runoff. The studies
proved forest growth has an influence on watershed hydrology, and supported the reason
why it should be regarded as one of stream drying factors.

The main objective of this study was to figure out the impact of long-term variation of
groundwater use and forest growth on watershed hydrology and how they caused stream
drying. It is believed that considering the two factors and defining their relative contribu-
tions to watershed hydrology will improve previous studies that did not quantified the influ-
ence of stream drying factors and did not evaluated the impact of factors over time. The
evaluation was performed using SWAT which is commonly used to simulate watershed
scale hydrology and has been proven around the world (Shi et al. 2011; Zhang et al. 2011;
Luo et al. 2012; Lee et al. 2014; Woo et al. 2019; Bal et al. 2021). When SWAT is used as
hydrology model, it is available to simulate unobserved past flow and understand progress
of stream drying according to the variation of different stream drying factors.

2 Data and Methods

2.1 Study Area

Geum River basin is a complex land-use basin located in the Midwest part of South Korea.
When the basin is divided into river system, subbasins can be classified into few groups
under similar land-use condition. Yongdam Dam, the downstream basin of Yongdam Dam,
and Chogang basin are forest dominated basin where more than 70% of total area is cov-
ered by forests. Gapcheon basin is an urban basin that occupies a relatively high urban
ratio of 14.6% compared to the average urban ratio, 5.3%. Agricultural activities are mainly
focused on downstream basin of Geum River including Mihocheon, Nonsancheon, estuary
bank, and Bojeongcheon.

Geum River originates from southwestern part of South Korea, where Yongdam Dam
(YDD) is located. It passes through Daecheong Dam (DCD), Sejong Weir (SJW), Gongju
Weir (GJW) and Baekjae Weir (BJW) and discharges into the West Sea. The five hydraulic
structures support people living in the region and are crucial since most hydrologic inflows
arriving during the flood season are stored in the facilities and used throughout the dry
season.

Geum River is an important supply line of domestical, industrial, and agricultural water
use for 5.1 million civilians, and the river is responsible for more than 90% of water sup-
plied to residents. Therefore, the importance of river maintenance and water resource man-
agement is being emphasized recently. However, the maintenance is currently exposed to
danger due to stream drying phenomena. River system of South Korea is classified into
three groups: river of state, local level 1, and local level 2, considering contributing area,
contributing population, and the influence on hydraulic structures. In case of Geum River,
there are 11 rivers of state (397.79 km), 20 rivers of local level 1 (358.70 km), and 460 riv-
ers of local level 2 (3000.87 km). By the way, among 460 rivers of local level 2, 39 rivers
are drying and their total length exceeds 25 km. Stream drying, which is still underway,
poses a threat to river and water management in Geum River basin, so it is necessary to
define stream drying factors and build specific mitigation plan for the phenomena (Fig. 1).
2.2 Soil and Water Assessment Tool (SWAT)

SWAT is a watershed hydrology model developed to quantify the impact of land management practices. The model operates by dividing the watershed into subbasins, with each subbasins being connected to stream channels. Subbasins are further divided into hydrological response units (HRUs), which are portions of a subbasin that possess unique land use, management, and soil attributes. The simulation of the hydrological cycle is based on the water balance equation:

\[
SW_i = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{qw})_i
\]

(1)

The water balance for dams or floodgates considers inflow, outflow, precipitation, evapotranspiration, and seepage. The equation is expressed as follows:

\[
V = V_{stored} + V_{flowin} - V_{flowout} + V_{pcp} - V_{evap} - V_{seep}
\]

(2)

where \( V \) is the water storage in the reservoir at the end of each day; \( V_{stored} \) is the volume of water stored in the reservoir at the beginning of a day; \( V_{flowin} \) and \( V_{flowout} \) are the volumes of water entering and flowing out of the reservoir throughout a day, respectively; and \( V_{pcp}, V_{evap}, \) and \( V_{seep} \) are the volumes of precipitation falling into the reservoir, the water removed by evaporation and the water lost by seepage, respectively.

2.2.1 Groundwater Use

Consumptive water use is a management tool equipped in SWAT. The tool helps user to remove water from reach, pond, shallow aquifer, and deep aquifer. Water removal can be applied from month to month in a sub-basin unit and removed water is designed to be lost from system (Neitsch et al. 2005). In this study, monthly groundwater use were removed from a shall aquifer because the aquifer, soil layer distributed throughout South
Korea, is mainly used as a major source of groundwater due to its good porosity and adequate nutrients for cultivation.

National Groundwater Information Center updates annual groundwater use report of South Korea that provides groundwater use information in the unit of administrative district. Based on the report, the annual groundwater use data in Geum River basin from 1976 to 2015 were collected and averaged in 10-year period (1980s;1976 ~ 1985, 1990s; 1986 ~ 1995, 2000s; 1996 ~ 2005, 2010s;2006 ~ 2015). By the way, since the watershed delineation using SWAT was carried out in standard area unit, groundwater use data were recalculated into the unit using areal average method and used as an input data.

Groundwater use in Geum River basin has gradually increased since the 1980s (Fig. 2). The average groundwater use of each period is 2.22 \(10^8\) ton/year in the 1980s, 2.63 \(10^8\) ton/year in the 1990s, 3.55 \(10^8\) ton/year in the 2000s, 4.63 \(10^8\) ton/year in the 2010s. By month, more than 50% of annual groundwater use is focused on Summer, flood season in South Korea, and close to 50% of groundwater is used even in the dry season. The increase in water use occurred in the entire period and it was relatively larger in the flood season than in the dry season.

### 2.2.2 Forest Growth

In the initial period of plant growth, canopy height and leaf area development are controlled by the optimal leaf area development curve:

\[
f_{r\text{LAI}_{\text{max}}} = \frac{f_{r\text{PHU}}}{f_{r\text{PHU}} + \exp(l_1 - l_2 \cdot f_{r\text{PHU}})}
\]

where \(f_{r\text{LAI}_{\text{max}}}\) is the fraction of the plant’s maximum leaf area index (LAI) corresponding to a given fraction of potential heat units for the plant, \(f_{r\text{PHU}}\) is the fraction of potential heat units accumulated for the plant on a given day in the growing season, and \(l_1\) and \(l_2\) are shape coefficients.

The shape coefficients are calculated by solving Eqs. (4) and (5) using two known points \((f_{r\text{LAI},1}, f_{r\text{PHU},1})\) and \((f_{r\text{LAI},2}, f_{r\text{PHU},2})\):

![Fig. 2 The annual use of groundwater in the study area corresponding to the four decades](image)
where $l_1$ is the first shape coefficient, $l_2$ is the second shape coefficient, $fr_{PHU,1}$ is the fraction of the growing season corresponding to the 1\textsuperscript{st} point on the optimal leaf area development curve, $fr_{LAI,1}$ is the fraction of the maximum plant LAI corresponding to the 1\textsuperscript{st} point on the optimal leaf area development curve, $fr_{PHU,2}$ is the fraction of the growing season corresponding to the 2\textsuperscript{nd} point on the optimal leaf area development curve, and $fr_{LAI,2}$ is the fraction of the maximum plant LAI corresponding to the 2\textsuperscript{nd} point on the optimal leaf area development curve.

For tree stands, the canopy height varies from year to year rather than from day to day:

$$h_c = h_{c,\text{max}} \cdot \left( \frac{yr_{\text{car}}}{yr_{\text{fulldev}}} \right)$$

where $h_c$ is the canopy height for a given day (m), $h_{c,\text{max}}$ is the plant’s maximum canopy height (m), $yr_{\text{car}}$ is the age of the tree (years), and $yr_{\text{fulldev}}$ is the number of years for the tree species to reach full development (years). Once plant growth reaches the maximum canopy height, $h_c$ remains the same until the plant is killed. However, the kill operation of tree is not activated in the model, and forest height will maintain its maximum value when forest growth stops (Neitsch et al. 2005).

In this study, LAI and forest height were used to represent forest growth condition of each decade. Korea Forest Service provides forest type map of South Korea which has forest related information including forest height, type, diameter of breast height, and so on. There are five provisions of forest type map from 1\textsuperscript{st} to 5\textsuperscript{th} survey according to their production period. By matching map production and study period, maps representing each period were determined and average forest height of each decade was estimated based on them.

LAI data were retrieved from the Land Processes Distributed Active Archive Center (LP DAAC) which supports monthly LAI (MOD15A2) measured at a 1,000 m spatial resolution. However, the retrieval has a limitation that LAI measurement has started from 2000. Therefore, LAI data from 1976 to 1999 were estimating using the regression between forest height and LAI. The regression was performed using power function which showed the most appropriate curve fitting between two factors (Yongwei et al. 2013). Using observed and estimated LAI, periodical LAI were determined. Average LAI showed the value of 0.7, 1.5, 2.7, 3.7 in the 1980s, 1990s, 2000s, and 2010s, respectively. The average value of forest height showed the value of 4.4 m, 6.3 m, 8.5 m, and 9.9 m in the 1980s, 1990s, 2000s, and 2010s, respectively.

The leaf area development curve (Fig. 3a) and canopy height development curve (Fig. 3b) are determined by six parameters, two known points on the optimal leaf area development curve ($fr_{LAI}, fr_{PHU}$), maximum LAI (BLAI), the fraction of growing season at which senescence becomes the dominant growth process (DLAI), maximum canopy height (CHTMX), and the number of years for the tree species to reach full development ($yr_{\text{fulldev}}$). Since average values of LAI and forest height were estimated and should be
applied to SWAT, the development curve for two factors was designed to maintain average value for each period during growing season while simulating watershed hydrology.

3 Results

3.1 SWAT Calibration

SWAT was calibrated to verify its applicability of simulating the watershed hydrology of the Geum River basin. Three hydrologic factors including evapotranspiration, soil moisture, and streamflow were calibrated using observed data and simulated result in daily time steps. The monitoring points are one flux tower (DU) for evapotranspiration, two TDR (Time Domain Reflectometry) points (CC, GB) for soil moisture, and five hydraulic structures including two multipurpose dams (YDD, DCD) and three multifunction weirs (SJW, GJW, BJW) for streamflow. While 4 years (2002 ~ 2005) were used as a warm-up period, the calibration was performed from 2006 to 2015. The calibration period for each component was settled based on the operation period and the quality of observation data which led to the year of 2006 ~ 2015 for streamflow at multipurpose dams, 2012 ~ 2015 for streamflow at multifunction weirs, 2011 ~ 2015 for evapotranspiration and soil moisture.

SWAT parameters adjusted to calibrate the model are the SCS curve number, Manning’s “n” value, soil evaporation compensation factor, groundwater delay time, threshold depth for the return flow in the shallow aquifer, baseflow recession constant, saturated hydraulic conductivity, snowfall temperature, snow melt base temperature, and hydraulic structure sources (Table 1). Default value was used for other parameters that are not mentioned in Table 1.

The model performance for streamflow was evaluated by coefficient of determination ($R^2$), Nash–Sutcliffe efficiency (NSE), scatter index (SI), and percent bias (PBIAS). The calibration at two dams and three weirs achieved the average $R^2$ value of 0.82, 0.78, 0.83, 0.81, 0.79, NSE value of 0.72, 0.68, 0.74, 0.76, 0.76, SI value of 0.17, 0.33, 0.28, 0.22, 0.15, and PBIAS value of –4.56%, –9.12%, –7.34%, –4.20%, +0.80% for YDD, DCD, SJW, GJW, and BJW, respectively. Table 2 presented the statistical summary of streamflow calibration at five monitoring points. On the other hand, the model performance for evapotranspiration and soil moisture was evaluated by coefficient of determination ($R^2$). The calibration result of evapotranspiration and soil moisture achieved average $R^2$ value of 0.67 and

![Fig. 3](image_url) a LAI and b canopy height development curve during growing period corresponding to the four periods

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### Table 1  The introduction of SWAT parameters adjusted for the calibration

| Parameter      | Unit | Definition                                                                 | Range | Value |
|----------------|------|---------------------------------------------------------------------------|-------|-------|
|                |      |                                                                           | LB    | UB    | YDD  | DCD  | SJW  | GJW  | BJW  |
| CN2            |      | Initial SCS runoff curve number for moisture condition II                 | 35    | 98    | 57   | 59   | 54   | 63   | 57   |
| CH_N(2)        |      | Manning’s “n” value for the main channel                                  | 0     | 0.95  | 0.3  | 0.95 | 0.95 | 0.95 | 0.95 |
| ESCO           |      | Soil evaporation compensation factor                                      | 0     | 0.01  | 0.3  | 0.04 | 0.04 | 0.04 | 0.04 |
| GW_DELAY       | days | Groundwater delay time                                                    | 0     | 500   | 180  | 200  | 100  | 100  | 100  |
| GWQMN          | mm H₂O | Threshold depth of water in the shallow aquifer required for return flow to occur | 0     | 5000  | 400  | 400  | 500  | 500  | 500  |
| ALPHA_BF       | 1/days | Baseflow alpha factor                                                     | 0     | 1     | 0.7  | 1    | 0.3  | 0.3  | 0.3  |
| SOL_K          | mm/hr | Saturated hydraulic conductivity                                           | 0     | 2000  | 40.5 | 45.4 | 39.6 | 60.9 | 60.3 |
| SOL_AWC        | mm³ cm⁻¹ | Available water capacity of the soil layer                               | 0.13  | 0.14  | 0.14 | 0.13 | 0.13 | 0.06 |
| SFTMP          | °C    | Snowfall temperature                                                      | −5    | 5     | −1   |      |      |      |      |
| SMTMP          | °C    | Snow melt base temperature                                                | −5    | 5     | 0    |      |      |      |      |
| RES_ESA        | ha    | Reservoir surface area when the reservoir is filled to the emergency spillway | -     | -     | 3700 | 7420 | 350  | 350  | 350  |
| RES_EVOL       | 10⁴ m³ | Volume of water needed to fill the reservoir to the emergency spillway     | -     | -     | 81500| 149000| 560  | 1550 | 2470 |
| RES_PSA        | ha    | Reservoir surface area when the reservoir is filled to the principal spillway | -     | -     | 3390 | 6750 | 350  | 300  | 300  |
| RES_PVOL       | 10⁴ m³ | Volume of water needed to fill the reservoir to the principal spillway     | -     | -     | 74250| 124160| 560  | 1554 | 2471 |
| RES_VOL        | 10⁴ m³ | Initial reservoir volume                                                  | -     | -     | 61200| 76900| 560  | 1550 | 2471 |
0.51, respectively. Graphical comparison of streamflow, evapotranspiration, and soil moisture between observed data and calibrated result is shown in Fig. 4.

### 3.2 Hydrologic Responses

Calibrated model ran 10-year hydrology of the target watershed. The decadal watershed hydrology was explained by hydrological components including evapotranspiration (ET), surface runoff (SR), lateral flow (LF), groundwater flow (GF), percolation (PE), and groundwater recharge (GWR).

Watershed hydrology of the 1980s under corresponding groundwater use (GU) and forest growth (FG) condition was used as a standard to quantify hydrologic responses caused by two changes. In this study, there are three scenarios that are designed to understand how GU and FG change separately and concurrently affected watershed hydrology. GU scenario considered decadal change of groundwater use, FG scenario dealt with change of forest growth condition, and stream drying (SD) scenario reflected periodical variation of both groundwater use and forest growth simultaneously. However, weather condition was fixed to the 2010s while operating three scenarios so that the impact of GU and FG change on watershed hydrology can be observed.

On the other hand, flow-duration analysis for three scenarios was performed to understand the impact of GU and FG change on the annual streamflow. Using descending order of simulated streamflow, flow rate corresponding to the time duration of 95, 185, 275, 355 day was extracted. The time duration of 95, 185, 275, 355 day stands for wet season, normal season, dry season, and drought season frequently used to represent the streamflow condition in South Korea.

#### 3.2.1 Hydrologic Responses to Groundwater Use Increase

Groundwater recharge and groundwater flow were affected when groundwater use has increased. Two factors decreased as groundwater use increased, and showed monotonous decreasing trend in terms of period. Compared to the 1980s, GWR decreased by 7.6% (14.3 mm/year), 19.1% (35.7 mm/year), 27.9% (52.2 mm/year), and GF by 7.6% (13.6 mm/year), 19.0% (34.2 mm/year), 27.7% (49.9 mm/year) in GU1990s, GU2000s, and GU2010s, respectively. The response led to the decrease of TR, and it showed a decrease value of 1.9% (13.6 mm/year), 4.8% (34.2 mm/year), 7.0% (49.9 mm/year) in GU1990s, GU2000s, and GU2010s (Table 3).

Figure 5 displays flow-duration curve of study area in the 1980s and GU2010s. Streamflow decreased in all four time durations including wet season (Q95), normal

| Index    | Monitoring Points | R²   | NSE  | SI   | PBIAS (%) |
|----------|-------------------|------|------|------|-----------|
| Streamflow| YDD              | +0.82| +0.72| +0.17| −4.56     |
|          | DCD              | +0.78| +0.68| +0.33| −9.12     |
|          | SJW              | +0.83| +0.74| +0.28| −7.34     |
|          | GJW              | +0.81| +0.76| +0.22| −4.20     |
|          | BJW              | +0.79| +0.76| +0.15| +0.80     |
Fig. 4 The graphical comparison between observed and simulated data at a YDD, b DCD, c SJW, d GJW, e BJW, f DU, g CC, and h GB for streamflow, evapotranspiration, and soil moisture
season (Q185), dry season (Q275), and drought season (Q355). Quantitatively, the degree of decrease sequentially increased from Q355 to Q95. When observed in ratio, Q275 showed the biggest decrease (12.97%) followed by Q185 (11.48%), Q355 (10.81%), and Q95 (8.03%) in sequence.

### 3.2.2 Hydrologic Responses to Forest Growth

The most notable response to forest growth was the increase in ET. As forest grew, it increased by 1.3% (6.6 mm/year), 2.9% (14.3 mm/year), and 3.7% (18.8 mm/year) in FG1990s, FG 2000s, and FG 2010s, respectively. Every other hydrological component showed decreasing pattern, and total runoff resulting decreased by 0.8% (5.6 mm/year), 1.7% (11.9 mm/year), and 2.2% (15.5 mm/year) in FG1990s, FG 2000s, and FG 2010s (Table 4).

Flow-duration curves for the 1980s and FG 2010s are illustrated in Fig. 6. The decreased amount of streamflow was successively increased from Q355 to Q95 as same as GU scenario, but the decrease ratio showed the highest value in Q185 (3.45%), followed by Q95 (2.45%), Q275 (2.36%), and Q355 (1.89%).

![Flow-duration curve of 1980s and GU2010s](Image)

**Fig. 5** Flow-duration curve of 1980s and GU2010s

| Scenario  | TR (mm/year) | ET (mm/year) | SR (mm/year) | LF (mm/year) | GF (mm/year) | PE (mm/year) | GWR (mm/year) |
|-----------|--------------|--------------|--------------|--------------|--------------|--------------|---------------|
| 1980s     | 687.5        | 501.7        | 181.6        | 353.4        | 180.0        | 186.5        | 186.9         |
| GU1990s   | 674.8        | 501.7        | 181.6        | 353.4        | 166.4        | 186.5        | 172.6         |
| GU1990s   | (–1.9%)      | (0.0%)       | (0.0%)       | (0.0%)       | (–7.6%)      | (0.0%)       | (–7.6%)       |
| GU2000s   | 654.9        | 501.7        | 181.6        | 353.4        | 145.8        | 186.5        | 151.2         |
| GU2000s   | (–4.7%)      | (0.0%)       | (0.0%)       | (0.0%)       | (–19.0%)     | (0.0%)       | (–19.1%)      |
| GU2010s   | 640.7        | 501.7        | 181.6        | 353.4        | 130.1        | 186.5        | 134.7         |
| GU2010s   | (–6.8%)      | (0.0%)       | (0.0%)       | (0.0%)       | (–27.7%)     | (0.0%)       | (–27.9%)      |
Hydrologic Responses to Groundwater Use Increase and Forest Growth

Hydrologic response to groundwater use increase and forest growth showed decreasing trend for SR, LF, GF, PE, and GWR while ET had increasing pattern. In a series of processes, TR was decreased by 2.7% (19.0 mm/year), 6.3% (45.1 mm/year), and 8.9% (63.4 mm/year) in SD1990s, SD 2000s, and SD2010s compared to the 1980s. Among all hydrological components, the most vulnerable component was GWR which is decreased by 8.7% (16.3 mm/year), 21.1% (39.4 mm/year), and 30.1% (56.3 mm/year) in SD1990s, SD2000s, and SD2010s, respectively (Table 5).

Figure 7 illustrated flow-duration curve for two scenarios, the 1980s and SD2010s. Periodic change of groundwater use and forest growth condition imposed flow reduction on all time durations and the amount of reduction gradually increased from Q355 to Q95 like other scenarios. In case of decrease ratio, the most vulnerable season to two stream drying factors is dry season (Q275) which appeared to decline by 14.61%. Excluding dry season, the flow rate decreased in the order of Q185 (13.62%), Q355 (12.11%), and Q95 (–9.93%).

Spatial Evaluation of Total Runoff Loss

The evaluation of total runoff loss has spatially performed to identify which basin is suffering from stream drying due to the change of groundwater use and forest growth. The
unit of basin is standard basin, and the decreased rate of total runoff in three scenarios, including GU, FG, and SD scenario, compared to the 1980s was estimated for every subbasin.

### 3.3.1 Spatial Evaluation Under Groundwater Use Increase

The result evaluated the spatial impact of groundwater use increase on total runoff loss is illustrated in Fig. 8. The gradually worsening of stream drying can be observed for every subbasin. Especially, Nonsancheon, estuary bank, Mihocheon, and Bojeongcheon basin showed relatively higher drying than other basins. The most significantly suffered basin is Nonsancheon basin where the decrease rate is 2.8% in GU1990s, 7.5% in GU2000s, and 10.7% in GU2010s.

### 3.3.2 Spatial Evaluation Under Forest Growth

Figure 9 displayed the spatial decrease of total runoff caused by forest growth. The average rate of total runoff decrease increased by period showing 0.79% in FG1990s, 1.70% in FG2000s, and 2.21% in FG2010s. Spatially, the basins with a large decrease in total runoff are Chogang, Dacheong Dam, and Mihocheon basin. Among them, Chongang
3.3.3 Spatial Evaluation Under Stream Drying

When periodic condition of groundwater use and forest growth influenced total runoff concurrently, the runoff has decreased by 2.68% in SD1990s, 6.37% in SD2000s, and 8.96% in SD2010s on average. The impact of two stream drying factors on total runoff loss is resulting heavier on Chogang, estuary bank, and Mihocheon while the most influenced basin is Nonsancheon where total runoff has decreased by 3.2% in SD1990s, 8.2% in SD2000s, and 11.5% in SD2010s (Fig. 10).

Fig. 8 Spatial evaluation of total runoff loss under groundwater use increase in a GU1990s, b GU2000s, and c GU2010s

Fig. 9 Spatial evaluation of total runoff loss under groundwater use increase in a FG1990s, b FG2000s, and c FG2010s
Discussion

The long-term variation of groundwater use and forest growth clearly affected watershed hydrology in Geum River basin and aggravated stream drying over time. The two factors showed different ways of influence on watershed hydrology. Increase of groundwater use extracted more water from shallow aquifer over time and accelerated deficiency in groundwater recharge and groundwater flow (Cosgrove and Johnson 2005; Mukherjee et al. 2018; Ostad-Ali-Askari and Shayannejad 2021). In the aspect of forest growth, the growth triggered to increase evapotranspiration which is an starting point of hydrologic response to forest growth. The rise of evapotranspiration lessened surface runoff and the mass of water infiltrated into soil layer (Yue and Hashino 2005). As less water infiltrates into soil layer, water quantity of underground components including lateral flow, percolation, groundwater flow, and groundwater recharge were dried (Warix et al. 2021; Wang et al. 2022). These series of hydrologic procedure diminished total runoff in the study area.

The influence of groundwater use increase and forest growth was also differed by month and season (Fig. 11). The expansion of groundwater use was more dangerous in Q275 (dry season) which is Winter in South Korea. The dramatic decrease in dry season can be explained by the development of facility cultivation which has gradually expanded since 1980s. The cultivation under structure extracts a lot of water from underground from October to March to maintain temperature inside structure and to protect products because there are not enough surface water during the period (Chung and Chang 2016). As a result, groundwater, which is slowly recharged from Summer rain, gradually consumed by water demand from facility cultivation, and the consumption triggered relative deficiency of total runoff to the past over time. In case of forest growth, its influence on stream drying was highest in Q185 (normal season) although it is not the least rained season. The result is related with a growing period of forest which is reproduced by the development curve of LAI in SWAT. The development changes greatly from Spring to Autumn, and its degree becomes bigger when forest grows. The periodic change resultingly brings out the rise of evapotranspiration during growing period, and normal season which relatively rains less showed higher intensity of stream drying. The second most vulnerable time duration due

![Fig. 10](image-url)
to forest growth was Q275 (dry season). It is because grown branches and residues made more evaporation while extended roots transpired more water from underground (Mackay and Band 1997; Hou et al. 2018).

Hydrologic responses to groundwater use increase and forest growth were estimated by averaging annual results of 10 years. In order to analyse the influence of the two factors according to annual precipitation condition, the decrease rate of flow rate with GU and FG scenario were annually evaluated (Fig. 12). When groundwater use increase is considered, inversely proportional relationship between the decrease rate of flow and the amount of precipitation was observed which suggests that the increase in groundwater use can cause bigger reduction of flow rate in drought years. On the other hand, FG scenario showed an inversely proportional relationship as did GU scenario, but the reduction of flow rate showed strong sensitivity to consecutive droughts. Successive droughts occurred twice from 2008 to 2009 and from 2014 to 2015. Although the droughts differ in precipitation patterns because the former (2008–2009) has less precipitation in the first year while the
latter (2014–2015) has less precipitation in the second year, the decrease rate of flow was higher in the second year for both cases. This cannot be fully explained by evaporation because it is a proportional factor to rainfall. However, successive drought lowers groundwater recharge and level (Komasi et al. 2021) while increased amount of transpiration by plant growth keeps accelerate the reduction of percolation and groundwater flow. This synergy effect forced a greater rate of flow reduction during consecutive drought.

From spatial analysis of stream drying by long-term variation of groundwater use and forest growth, GU scenario showed well-matched result with the distribution of groundwater use change, and FG scenario fitted well with the distribution of forested area, proving that model simulation made a good agreement with the spatial. By the way, since the decrease in total runoff according to unit use or growth can be varied by subbasin, the vulnerability to the reduction of flow rate by subbasin was estimated in consideration of groundwater use and forest growth. Figure 13 illustrated box plots of total runoff loss per unit groundwater use and forest growth for 78 subbasins in Geum River basin. The box plots of GU scenario shows a large variation by subbasin suggesting that the influence of groundwater use varies depending on basin characteristics. In addition, the decreasing pattern of average value over time is also observed which demonstrates
that the influence of unit groundwater use increase has decreased over time. The periodically decreased influence is because SWAT calculates groundwater flow using exponent coefficient (Wang et al. 2019) and the calculation result is proportional to the amount of soil water content which has decreased by increasing groundwater use. By the way, total runoff loss per unit forest growth showed small range of variation by subbasin with almost consistent average value for each period explaining that forest growth is rather affected by climate and forest condition than geographical characteristics.

Fig. 13 The boxplots of total runoff loss per a unit groundwater use and b unit forest growth for 78 subbasins in Geum River basin
5 Conclusions

The impact of long-term variation of groundwater use and forest growth on watershed hydrology in Geum River basin was evaluated under three scenarios. In GU scenario, the increase of groundwater use affected groundwater recharge and groundwater flow which resulting decreased total runoff of the study area. The decrease showed the value of 1.9%, 4.7%, and 6.8% in GU1990s, GU2000s, and GU2010s, respectively. When forest growth has reflected, the growth brought the rise of evapotranspiration which diminished surface runoff and the infiltration into soil layer. These series of process reduced total runoff and showed the decrease value of 0.9%, 1.8%, and 2.4% in FG1990s, FG2000s, and FG2010s. Finally, groundwater use and forest growth condition varied, and total runoff decreased to a large extent influenced by both factors. The lessened amount is 2.7%, 6.3%, and 8.9% in SD1990s, SD2000s, and SD2010s. In conclusion, long-term variation of groundwater use and forest growth influenced watershed hydrology in a different way while groundwater use showed higher contribution to the decrease of total runoff than forest growth. When observed the relative contribution of groundwater use and forest growth on watershed hydrology by season and year, groundwater use tended to maximize flow reduction in less rainy season, Winter, and drought years, while forest growth was most influential in moderate rainy season, Spring and Fall, and consecutive drought. This finding can help prepare a plan to secure flow rate in terms of water management by basin, because every basin experiences different kind of stream drying pattern.

In this study, groundwater use increase and forest growth were considered as stream drying factors that possibly influence the watershed hydrology and accelerate stream drying. The overall result showed that they have clear impact on the water cycle and the decrease of streamflow. However, there are still many factors that are expected to affect watershed hydrology such as land use, road network, and soil erosion. These factors also have changed in time, and should be considered in further studies so that we can understand stream drying comprehensively and design water resource management appropriately.

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Data Availability The data and materials that support the findings of this study are available on request from the corresponding author.

Declarations

Ethical Approval Not applicable, because this article does not contain any studies with human or animal subjects.

Consent to Participate Informed consent was obtained from all individual participants included in the study.
Consent to Publish  All the authors give the Publisher the permission of the authors to publish the research work.

Conflicts of Interest  The authors have no conflicts of interest to declare.

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