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Evaluation of dams and weirs operating for water resource management of the Geum River

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HIGHLIGHTS

- We assessed the water supply capacity, energy generation and flow duration.
- We assessed the environmental management class of the changing riverine environment.
- We assessed to take countermeasures to mitigate resulting adverse environmental impacts.
- The presence of dam/weir controls optimizes the river flow for socioeconomic and the environment.

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ABSTRACT

As part of the Four Major Rivers Restoration Project, 16 multi-functional weirs have recently been constructed in each river system in Korea. The Project has pursued ecological approaches through constructing artificial weirs in waterways to ensure sufficient flow even in the dry seasons, improving agricultural reservoirs to supply environmental flow for the rivers, and thereby enhancing the water quality of the rivers. However, these anthropogenic activities have been accompanying a significant change in the riverine environment. In this study, the SSARR (Streamflow Synthesis and Reservoir Regulation) model was used to estimate natural flow in the 14 sub-basins of the Geum River. The natural flow determined by the SSARR model was used in estimation of environmental flow and input data of reservoir operation model. Hec-ResSim was used to assess runoff variations, water supply and energy generation based on the protocols for the associated operation of dams and multi-functional weirs. In addition to this, a method developed by the IWMI (International Water Management Institute) was also used to analyze the environmental flow, considering channels, water fronts and flow variations, and thereby assess the environmental management class of changing the riverine environment and to take countermeasures to mitigate the resulting adverse environmental impacts. It is hoped that the results of this study will provide basic data to establish policies for the effective operation and management of the existing dams and the newly constructed multi-functional weirs, and the effective monitoring and preservation of aquatic ecosystems in the Geum River basin.

1. Introduction

Water is one of the most important resources for the survival of all human beings. Experts who engage in water resources planning and management would be faced with problems on how to determine policy in accordance with a future climate change and how to evaluate environmental effect of that.

The fresh water available in lakes and rivers for human use accounts for only a fraction of all the water on the earth. According to UNICEF (United Nations Educational, Scientific and Cultural Organization) and WMO (World Meteorological Organization) publications, some 12% of the world's population does not have access to safe water. Korea has also been classified by the PAI (Population Action International) as one of the water-stressed countries; it is expected that it will require water resources equivalent to 1 billion m^3 in 2016. Currently, the country is undergoing a paradigm shift in water resource management, from being supply-driven to demand-driven. Since water resources are a key element of policies for the anthropogenic development of land, cities, houses, industries, etc., water demands become more concentrated in specific sectors on a large scale. This tendency is anticipated to continue in different consumption sectors thanks to the national pursuit of sustainable economic development and improvement of people's standards of living.

UNESCO (2003) projected that the amount of water available per person would decrease with time. This projection results from the expectation that water usage will increase more considerably than population growth although the availability of water resources is so limited.

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The 2007 Fourth Assessment Report of the IPCC (International Panel on Climate Change) reported that the observed evidence for global warming was apparent without doubt, which indicated that extreme events and disasters, such as sweltering heat and localized heavy rain, would occur with increasing frequency (IPCC, 2007). Therefore, since climate change is increasing the abnormal patterns of hydrological events, both structural and non-structural measures should be taken. Furthermore, the types of water demands change with time, with the range of water uses expanded from agricultural, municipal and industrial sectors to its use in the ecological environment. It is important to identify and define the nature and type of water uses because they are not only a starting point of developing systems and policies for water management in terms of their quantitative aspects, but also one of the key indicators used to estimate and allocate water requirements.

The conventional concept of environmental flow has concerned water only for use by human beings, rather than also including water needed for the riverine environment. However, as the importance of environmental ecology is widely recognized and people increasingly want to lead an environmentally rich and stable life, there have recently been many efforts to achieve effective water management in terms of quality and quantity, and thereby to preserve riverine ecosystems and restore the normal river functions, which, in turn, will help create a sound riverine environment.

This concept of environmental flow has appeared as a new paradigm for the preservation of water in the environment and aquatic ecosystems in the field of river basin management. As the precise estimation of hydrological water demands is one of the important goals at a national level, the estimation and allocation of the appropriate scale or volume of environmental flow requirements are required (Choi, 2007; The Nature Conservancy, 2006; Kashaigili et al., 2007). Although it may vary more or less within the literature, environmental flow generally concerns different types of flow regimes: IFRs (instream flow requirements), maintenance IFRs, dry IFRs and minimum flows (MOLIT of the ROK (Republic of Korea), 2007; Smakhtin and Anputhas, 2006). Estimating the environmental flow is deemed as a complex, difficult procedure (Hughes, 2001). This is because there is insufficient appropriate theoretical background or applicable data for a quantitative analysis of the impacts of a change in the flow regime on river ecosystems. Ko et al. (2009) reported that the evaluation of the eco-hydrological health of a river must be based on a wide range of hydraulic, hydrological and ecological data and analysis models.

Although it's legally mandatory that information about instream flows as part of the environmental flows should be announced by the relevant government authorities for river management so that it may be possible to maintain the normal functions and status of the flow regime in Korea, most of the information about estimated instream flows has been about mean dry streamflows. The former *Ministry of Land, Transportation and Maritime Affairs* (current MOLIT, 2000) developed a method to estimate instream flow based on the concept of the riverine environment. However, it has not yet been legally enforced.

With regard to the estimation of the environmental flow, one of the important hydrological characteristics attracting attention from experts in the field of ecology is flow variability (Bunn and Arthington, 2002). The IWMI (International Water Management Institute) has recently proposed a method or program to estimate environmental flow based on the behavioral characteristics of flow duration curves observed in a basin (Smakhtin and Eriyagama, 2008). Kim and Choi (2010) used the GEFC (Global Environmental Flow Calculator), a software program developed by the IWMI to estimate environmental flow, to apply the yearly mean runoff for each environmental management class to the Geum River basin in Korea, and thereby verify the compatibility of the results and findings of preceding studies (Jones, 2002; Tennant, 1976). Lee and Kim (2011) applied climate change scenarios provided by the GCMs to the tank model to estimate runoff in the Nakdong River, and then estimate environmental flow with the GEFC to analyze the impacts of climate change.

Table 1
Specifications for the Four Major Rivers Restoration Project.

Project	Scope	Effects
Flood control	Dredging: 450 million m^3 Detentions: 5 places Rehabilitating dilapidated levees: 784 km	Lowering flood water level (2–4 m)
Water security	Movable weirs: 16 Dams: 2 Elevating agricultural reservoir banks: 96	Securing 1.3 billion m^3 of water
Improvement of water quality	Sewage treatment plant: 1281 Total-phosphorus treatment facilities: 233	Swimmable water 76% → 86%
Ecological restoration	Ecological wetlands: 11.8 million m^3 Fish-ways: 33 sites	Improving natural ecology & promoting eco-tourism
Waterfront development	Bicycle paths: 1757 km Tourist attraction sites	Better quality of life

As part of the Four Major Rivers Restoration Project, 16 multi-functional weirs have recently been constructed in each river system in Korea, as shown in Table 1 and Fig. 1. The Project has pursued ecological approaches, through constructing artificial weirs in waterways to ensure sufficient flow even in the dry seasons, improving agricultural reservoirs to supply environmental flow for the rivers, and thereby enhancing their water quality. But these anthropogenic activities have been accompanying a significant change in the riverine environment.

The Project contains plans to construct 16 movable weirs, elevate existing agricultural reservoir banks, build small- to mid-sized dams, and thereby secure a sufficient amount of water totaling up to 1.3 billion m^3 to provide protection against water shortage. In particular, the weirs were designed to be movable to discharge silt deposited on riverbeds with time and to regulate the amount of water according to the weather conditions.

Together with climate localities, topographical characteristics and land uses, the important impacts of artificial intakes and other hydraulic structures constructed in a river include a change in the behavior of the flow duration. In this respect, interpreting flow duration curves and analyzing a change in the amount of flood and dry streamflow to identify flow duration variations and understand the sustainability of water flow are essential in terms of the reliability of water supply and flood control. This requires the proper assessment of environmental flow, considering the existing concept of water supply, and water abstraction should be determined in association with environmental flow, which, in turn, will enable sustainable river management. In addition, the environmental functions of a river must be considered in order to estimate and allocate the water supply.

In this study, the SSAR (Streamflow Synthesis and Reservoir Regulation) model was used to estimate natural flow in the 14 sub-basins of the Geum River, and thereby simulate the effects of river flow variations on aquatic ecosystems, which would help secure the effective use of limited water resources and pursue efficient basin development. Furthermore, Hec-ResSim was used to assess runoff variations, water supply and energy generation based on the protocols for the associated operation of dams and multi-functional weirs. In addition to this, the GEFC as developed by the IWMI was used to analyze the environmental flow while considering channels, water fronts and flow variations, and thereby assess the environmental management class of the changing riverine environment and to take countermeasures to mitigate resulting adverse environmental impacts.

2. Description of the study area

The catchment area of the Geum River is 9915 km^2, and the main stream of the river is 398 km long. The Geum River basin has benefited from the considerable effects of flow duration control through the