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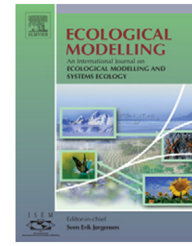

Design of a water quality monitoring network in a large river system using the genetic algorithm

Su-Young Park[a], *Jung Hyun Choi*[a], *Sookyun Wang*[b], *Seok Soon Park*[a,*]

[a] *Department of Environmental Science and Engineering, Ewha Womans University, Seoul 120-750, Korea*
[b] *Department of Environmental Exploration Engineering, Pukyong National University, Busan 608-737, Korea*

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ABSTRACT

Despite several decades of operations and the increasing importance of water quality monitoring networks, the authorities still rely on experiential insights and subjective judgments in siting water quality monitoring stations. This study proposes an integrated technique which uses a genetic algorithm (GA) and a geographic information system (GIS) for the design of an effective water quality monitoring network in a large river system. In order to develop a design scheme, planning objectives were identified for water quality monitoring networks and corresponding fitness functions were defined using linear combinations of five selection criteria that are critical for developing a monitoring system. The criteria include the representativeness of a river system, compliance with water quality standards, supervision of water use, surveillance of pollution sources and examination of water quality changes. The fitness levels were obtained through a series of calculations of the fitness functions using GIS data. A sensitivity analysis was performed for major parameters such as the numbers of generations, population sizes and probability of crossover and mutation, in order to determine a good fitness level and convergence for optimum solutions. The proposed methodology was applied to the design of water quality monitoring networks in the Nakdong River system, in Korea. The results showed that only 35 out of 110 stations currently in operation coincide with those in the new network design, therefore indicating that the effectiveness of the current monitoring network should be carefully re-examined. From this study, it was concluded that the proposed methodology could be a useful decision support tool for the optimized design of water quality monitoring networks.

1. Introduction

Modernized management of water resources requires a large amount of temporal and spatial information on variations in water quality and quantity, in order to protect communities from floods or drought, to support various types of water use and to control pollution in water bodies. Recently, as urbanization and industrialization have increased and water pollution has become a threat for more areas, both the general public and policy makers have called for improvements in the design and operation of monitoring networks in river systems. However, water quality monitoring networks have traditionally been designed on the basis of experience and intuition in keeping with increased management needs related to preventing water quality deterioration, rather than being based on a systematic design and specified monitoring objectives. In many developing countries, most of the existing monitoring networks exhibit deficiencies in terms of providing information required for integrated watershed management. Furthermore, complicated monitoring system require-

* *Corresponding author*. Tel.: +82 2 3277 3546; fax: +82 2 3277 3275.
E-mail address: ssp@ewha.ac.kr (S.S. Park).
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ments arising from new policies related to water management, such as the Total Maximum Daily Load (TMDL) program, integrated watershed management and information systems for water resources management, call for the development and operation of more systematic monitoring networks. The TMDL program, in particular, entails the quantitative estimation of pollution loads from each watershed unit and the use of results from appropriate water quality models. For this purpose, separately collected water quality and quantity parameters should be obtained simultaneously from an integrated monitoring system, and monitoring parameters and frequencies should also be rearranged to permit water quality modeling based on water and mass balance methods.

Water quality monitoring networks have been operated in Korea since the Environment Conservation Law was passed in 1977. Over the past several decades or so, water quality and/or quantity parameters have been measured regularly or irregularly through a variety of monitoring networks operated by a number of agencies, such as the Ministry of Environment, government public health and environment research institutes and the Korea Water Resources Corporation, to meet their own monitoring objectives. Lacking consistent principles, such diverse operations have created various challenges for the management of information on water quality parameters. Difficulties have also resulted from the ill-defined methodology used in siting monitoring stations in accordance with scientifically established planning objectives. The water quality monitoring networks are operated "in order to acquire fundamental information for understanding the current conditions and long- and short-term variations of water quality in nationwide rivers and lakes, for evaluating the effects of already enforced major policies for conservation of water quality and for establishing new policies" (Korea MOE, 2003). In order to meet the monitoring objectives, network planners select monitoring sites with a view to assessing water quality conditions for improvement, sustaining good water quality, tracking changes in water quality and pollution, studying inflowing pollutants and their effects on a water body and assessing pollution loading from freshwater flows in areas where mixing of freshwater and seawater occurs. However, the Korean DOE's approach to selecting monitoring sites is based solely on the basic objectives for water quality monitoring networks, and details of selection methodology are lacking.

The issues related to the optimal design of water quality monitoring networks and efficiency improvements have been the subject of research since 1970s (Ning and Chang, 2002). The basic principles of monitoring network design and site selection criteria for individual monitoring stations have been evaluated and applied (Skalski and Mackenzie, 1982; Lettenmaier et al., 1986; Smith and McBride, 1990; Loftis et al., 1991; Esterby et al., 1992). Later studies have focused greater attention on the effective design of water quality monitoring networks using various types of statistical and/or programming techniques, such as integer programming, multi-objective programming, kriging theory and optimization analysis (Hudak et al., 1995; Harmancioglu and Alpaslan, 1992; Cieniawski et al., 1995; Dixon and Chiswell, 1996; Timmerman et al., 1997; Dixon et al., 1999).

The aim of the present study was to develop a design framework for water quality monitoring networks in order to support newly introduced water management regulations and technologies as well as to satisfy the traditional network objectives of tracking water quality distribution and variations. A genetic algorithm was used in association with a GIS to derive an optimized design. The proposed framework was applied to the Nakdong River, the second largest river system in Korea, in order to devise an improved water quality monitoring scheme for the river.

2. Fundamentals of design methodology

2.1. *Planning objectives of water quality monitoring networks*

The design procedure for monitoring networks requires specific objectives for an efficient and effective monitoring system that will address sophisticated requirements related to water quality and quantity parameters. The monitoring objectives can be set based on operational and management requirements for monitoring programs and may include helping to establish water quality standards, determining water quality status and trends, identifying impaired waters, identifying the causes and sources of water quality problems, implementing water quality management programs and evaluating program effectiveness (U.S. EPA, 2003).

Both the traditional objectives of monitoring networks and the objectives required to support newly introduced water resource management programs have been considered in this study. Traditional objectives of water quality monitoring networks are listed below (Lettenmaier, 1979; Liebetrau, 1979):

Objective (1) To understand the long- and/or short-term trends of temporal variations in water quality parameters.
Objective (2) To monitor violations of the water quality standards specified for each watershed.
Objective (3) To identify external causes and sources affecting water quality changes.
Objective (4) To support utilization of water resources.
Objective (5) To examine short-term variations in water quality through a targeted investigation during a given period.

In addition, more recent policies and technologies such as TMDL and information systems for water resources management have created new management requirements, giving rise to additional objectives for monitoring networks, such as the following:

Objective (6) To estimate pollution loads from each watershed unit in order to perform TMDL analyses.
Objective (7) To use water quality modeling to support TMDL and scientific water quality management functions.
Objective (8) To establish information systems for water resources management.