Journal of Hydrology 406 (2011) 129–135

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Optimal design of river nutrient monitoring points based on an export coefficient model

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ARTICLE INFO

Article history:
Received 19 March 2011
Received in revised form 13 June 2011
Accepted 16 June 2011
Available online 28 June 2011
This manuscript was handled by G. Syme, Editor-in-Chief

Keywords:
Nutrient export coefficient
River monitoring
Nutrient load
Non-point source assessment
Feitsui reservoir
Monitoring network

SUMMARY

Nutrient concentration is an important factor in identifying the quality of water sources and the likelihood of eutrophication. A nutrient monitoring network is an important information source that provides data on the nutrient pollution status of rivers. Export coefficient models have been widely used to study non-point source pollution. However, there has been little discussion about applying non-point source pollution and export coefficient modeling to design sampling points for monitoring. In this study, a new procedure providing a comprehensive solution was proposed to design nutrient monitoring points, from identifying pollution sources to designing sampling points and frequencies. Application of this procedure to design nutrient monitoring points upstream from the Feitsui reservoirs, Taipei, Taiwan, indicated that agriculture occupied only 7.24% of the area, but it released 45,795 kg/yr, or 41%, of the total nutrient load from non-point sources. Additionally, the optimization conditions defined four sampling points as well as the frequency of sampling at those points in the study area.

1. Introduction

Nutrient loading into rivers is one of the major concerns in river water quality management (Shrestha et al., 2008). Overloading of nutrients causes eutrophication problems. Eutrophication affects water quality and aquatic life in rivers and increases the costs of water treatment. Nutrient concentration is an important factor in identifying the quality of water sources and the likelihood of eutrophication. A nutrient monitoring network is an important source of information about the nutrient pollution status of rivers. Data from monitoring can help river basin managers make decisions about the usage of water sources and about human activities along rivers. The location of nutrient sampling points is the most critical design factor in a monitoring network. If the locations are not representative, the data collected become inconsequential (Sanders et al., 1983). To design a nutrient monitoring network, it is necessary to identify the pollution sources that release pollutants into rivers.

The use of applied export coefficients in determining pollution from non-point sources is a well-developed method that has been successfully applied in environmental studies (Kay et al., 2008; Khadam and Kaluarachchi, 2006; Townsend and Douglas, 2000). The advantages of the export coefficient model include the simplicity of the model format and its spreadsheet-based mode of operation (Johnes, 1996). Export coefficients have been combined efficiently with Geographic Information Systems (GIS) to study non-point source pollution, owing to the compatibility, integration capability and easy implementation of this method (Gurel et al., 2011; Liu et al., 2008; Mattikalli and Richards, 1996). In previous studies, the results produced for non-point source pollution have been used widely to identify critical pollution regions (Erturk et al., 2006; Johnes, 1996; Liu et al., 2009; Worrall and Burt, 1999). However, there has been little discussion about applying non-point source pollution and export coefficient modeling to design sampling points for monitoring.

Sharp's procedure and Sanders' application were used in some studies for locating representative sampling points (Chilundo et al., 2008; Park et al., 2006; Strobl and Robillard, 2008). The advantage of this method was to specify sampling station locations systematically, based on the number of contributing tributaries (Sanders et al., 1983). Sharp's procedure for selection of sampling sites based on indicators of stream use treated the number of outfalls (point sources) as if they were tributaries to design sampling points. However, there has been little discussion about applying non-point source pollution to design sampling points.

To fill this gap in our current knowledge, a combination of a nutrient export coefficient model and Sharp's algorithm was implemented to design a nutrient monitoring network. The objectives of this study were to (1) apply nutrient export coefficients to determine the sources of nutrient into rivers; (2) design nutrient monitoring points based on nutrient load results; and (3) optimize sampling points and recommend sampling frequencies.

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doi:10.1016/j.jhydrol.2011.06.012

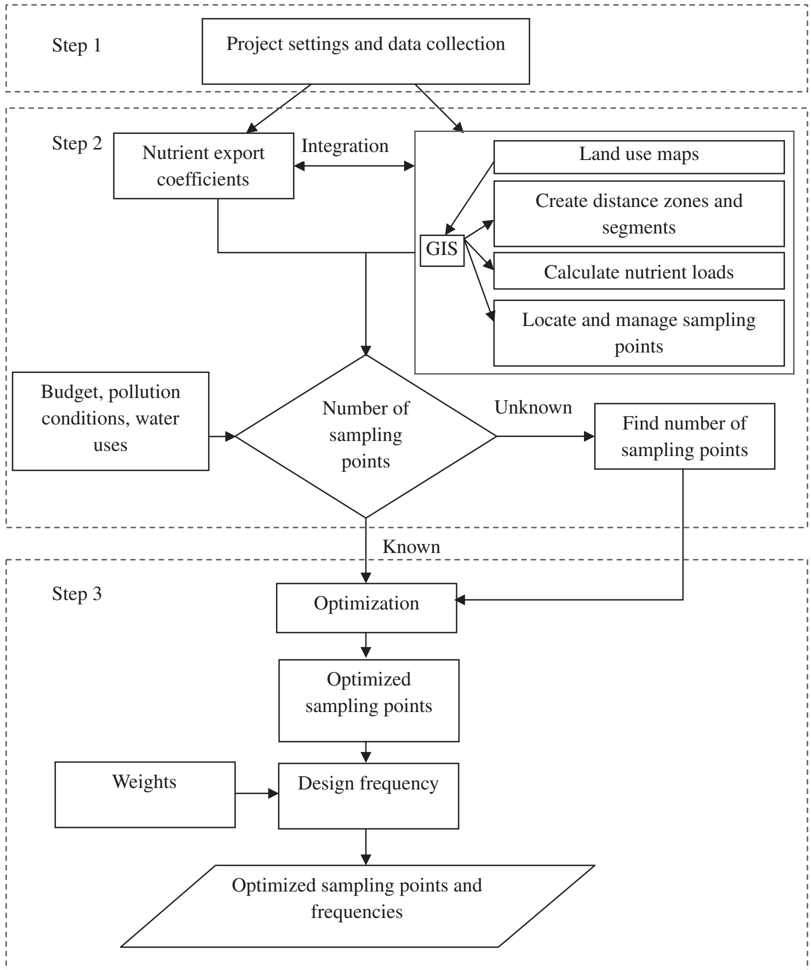

Fig. 1. Research framework.

2. Materials and methods

2.1. Research framework

A research framework was proposed for this study. Three steps were applied to design nutrient sampling points in this research, including (1) data collection; (2) integration of export coefficients and GIS tools; and (3) optimization and calculation of sampling frequencies (Fig. 1).

2.2. Nutrient loads from diffuse sources

The river system addressed in this study was the main water source of the Feitsui reservoir, which provides water for Taipei city, Taiwan. The research area was located in Pinglin and Toucheng, upstream of the reservoir (Fig. 2). The farms in this study area used fertilizer on their green tea crops. In an area of this type, unabsorbed fertilizer and nutrients from daily human activities would be released into rivers. Nutrient overloading would affect river water quality and would become an urgent problem for water treatment plants. It is therefore necessary to identify the sources that furnish the nutrient load to the rivers and to install a nutrient monitoring network.

To determine the critical nutrient sources, nutrient loads from diffuse sources were estimated based on the export coefficient model. This model has been widely applied in many environmental studies (Ding et al., 2010; Liu et al., 2008; Winter and Duthie, 2000; Zobrist and Reichert, 2006):

$$N = \sum_{i=1}^{n} A_i E_i \quad (1)$$

where N is the nutrient load (kg/yr); A_i the area of land-use class i (ha); and E_i is the export coefficient for land-use class i (kg/ha/yr).

GIS software (ArcInfo 9.2) was used in this study to process the database and map layers. A land-use map layer was divided into different categories: Agriculture, Forest, Urban, Grassland, and Watershed. This classification helped in determining the specific sources of pollution. Each category had an export coefficient value obtained from a previous study (Wen et al., 2001). Values for the export coefficient fields were then added in the land-use map layer.

2.3. Nutrient loads from point sources

A wastewater treatment plant is located in the study area. The Pinglin wastewater treatment plant treats an average of 3300 m^3/day. The quantities of nutrients released into the river are 602 kg/yr total phosphorus (TP) and 12,045 kg/yr total nitrogen (TN) (Fig. 2).

2.4. Selection of representative sampling points

The river network was systematically subdivided into portions in Sharp's procedure for locating sampling points. Each portion