Development of GIS-Based Decision-Making Support System for Water Resources Management and Planning

By Bahram Gharabaghi, Robin Bourke and Ramesh Rudra

Introduction

The public's need to protect source water is now of prime importance, particularly in light of the Walkerton tragedy. Source water protection is vital, especially in rural areas where it is the only protection available to the consumers. It is also recognized that agriculture can be a significant source of non-point pollution. Therefore, source water protection requires careful examination of agricultural land use plans and nutrient management practices in order to ensure that water quality objectives are met.

To achieve water quality targets for intended uses, information is required on sources of soil erosion, sediments, nutrients (phosphorous and nitrogen) and microbial loads associated with agricultural land use activities in the watershed. The Walkerton Inquiry Report has also recommended watershed-based management approaches for source water protection. Choices on Best Management Practices (BMPs) need to be made with the objective of meeting environmental sustainability and agricultural productivity.

Source water protection in Ontario has a long way to go. But the road may be a little smoother now that a University of Guelph research project has been chosen to receive funding, valued at $40,000 over two years, from the Consulting Engineers of Ontario (CEO). This commitment confirms the respect that the industry has for the University of Guelph and its pioneering work in this area. The proposed research program will focus on developing a GIS-based Decision-Making Support System for watershed management to help quantify the health status of water bodies in southern Ontario and plan for economically feasible, environmentally sustainable and socially acceptable strategies to improve that status.

Background

Contamination of Ontario's surface water by pathogens, nutrients, pesticides, and sediments is a serious concern. In order to ensure a safe and clean water supply for aquatic ecosystems and humans alike, it is necessary to assess source water conditions and identify contaminant sources.

Agricultural practices have a significant impact on surface and ground water quality in Ontario. Intensive livestock operations as well as the land application of chemicals including organocarbons, manure, and wastewater treatment plant sludge are practices that can potentially damage the quality of our water sources. In addition, road salt, septic system effluent, and municipal waste disposal provide valid concerns for water quality specialists. It is evident that land-based activities have a large impact on aquatic environments and downstream water quality.

The United States Environmental Protection Agency (EPA) has recently established Total Maximum Daily Loads (TMDL) for several chemicals entering water bodies. This approach establishes the maximum amount of pollutant that can enter a water body each day while maintaining the overall pollutant concentration within water quality standards. In Ontario, Conservation Authorities have shown interest in the TMDL approach, though under a different name, by determining the Natural Assimilative Capacity of the system. Further development of this approach will enable watershed managers to evaluate the health of the ecosystem and water bodies within the watershed.

As with any physical system, watersheds have spatial and temporal complexities. The landscape and soil type are among many variables. In addition, climatic conditions, which give Canadians four distinct seasons to look forward to, offer extremes of

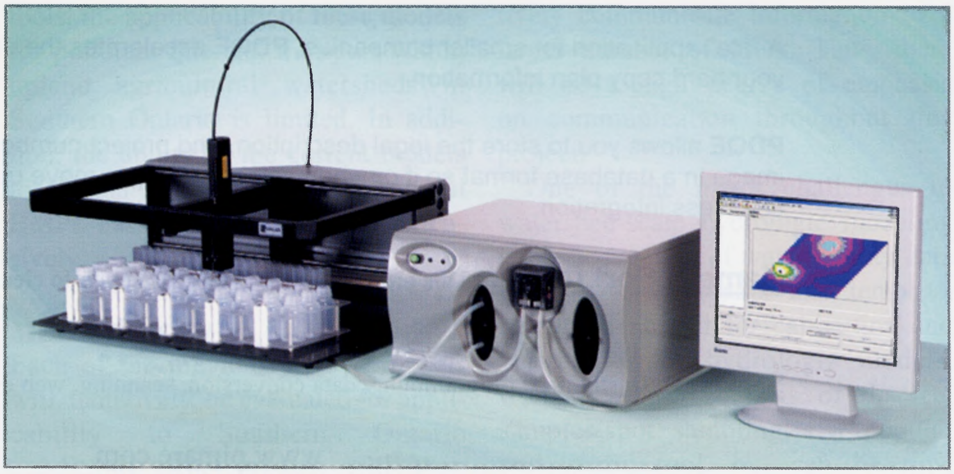

FIGURE 1
Skalar-LDI Fluo-Imager™ was used for multi-wavelength spectral fluorescence analysis of collected water quality samples, which was essential for calibration of LIF measurements of DOM, and oil products in water.

temperature and precipitation. It is therefore necessary when developing watershed management scenarios to consider the water quality parameters and targets, the spatial location of the parameter data sources in the watershed, the pathways of pollution, the linkage between target and sources, the distribution of parameter loads to point and non-point sources, the development and evaluation of management strategies to meet targets, an economic evaluation of management strategies, and, finally, the impact of changes in climate characteristics.

Objectives

The main objective of the proposed research is to develop a GIS-Based Decision-Making Support System for watershed management, which is based on water availability versus demand as well as pollutant loadings and water quality information on a watershed-scale. The approach will have a capacity to assess the health of water bodies in the watershed and the loadings of various pollutants to identify sources and their contributions to loadings and to develop best management practices to improve impaired water bodies. The initial focus of this project will be to evaluate the effect of land use activities on sediment and nutrient (phosphorus) loadings. Later on the approach will be extended to nitrogen, bacteria (fecal coliforms, total coliforms and E. coli) and pesticides to the receiving waters.

Computer Modeling of Watershed Systems

The increasing number of large-scale livestock operations and the vulnerability of water sources as demonstrated at Walkerton have raised public concerns over drinking water sources. Currently, monitoring and modeling are the two main approaches used to quantify the impacts of agricultural activities on surface water and ground water. Monitoring, in the form of spot sampling, relies entirely on taking field measurements, and is fairly accurate but requires a long sample time and is generally expensive. Advancements in remote sensing are occurring rapidly, however, and an interesting new technology from Laser Diagnostics Instruments International Inc. (LDI3), a Canadian company, will be described later in this article.

In addition, new software is making watershed systems modeling an excellent option for watershed management. There are several different watershed-modeling packages on the market right now, including AGNPS, ANSWERS, AVGWLF, HSPF, and SWAT. Although these are generally useful tools, the applicability of these models for pollutant fate and transport within upland agricultural watersheds in Southern Ontario is limited. In addition, the ability of the current models to simulate site-specific agricultural BMPs has not been validated extensively.

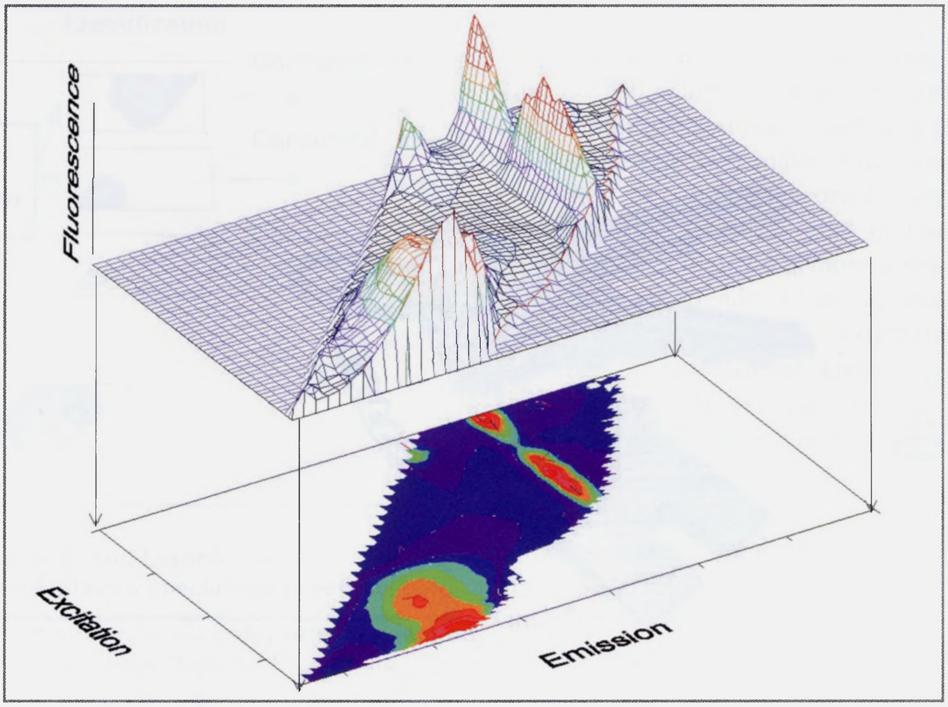

FIGURE 2
Spectral Fluorescence Signature (SFS) technique comprises analysis of the set of induced fluorescence spectra at different excitation wavelengths.

Methodology

Each of the previously listed models will, tentatively, be evaluated for applicability to Southern Ontario conditions. The project will then switch into production mode, focusing on developing a new and improved system to integrate existing data sources with models used for the TMDL approach. Two of the biggest problems with current models are the level of expertise needed to navigate through the massive output information and the complexity of data interpretation. The models are designed for users with a high level of expertise and are therefore inaccessible to many who would benefit from them. To overcome this challenge, one of the project goals will be to create a user-friendly interface based on GIS software. This highly visual method of data representation will more effectively communicate information to a larger number of users. Thus, there will be a high degree of emphasis on communication throughout this project.

One of the major challenges to watershed-scale hydrologic modeling is the acquisition of water quality data with sufficient spatial and temporal resolution needed for calibration and verification of hydrologic models. Collection and analysis of discrete samples-spot sampling-is a popular and useful tool, but can be time consuming and expensive, as well as being prone to spatial and temporal discontinuities. How, then, can land

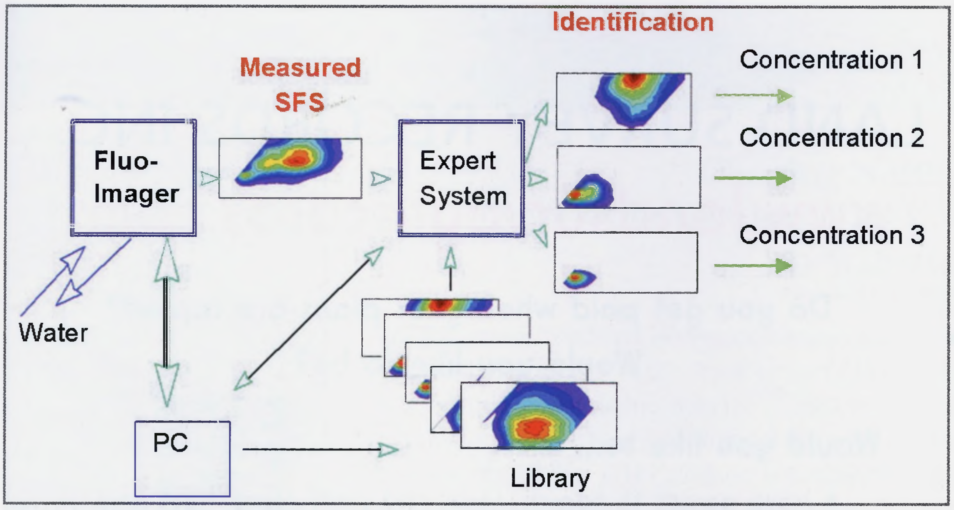

FIGURE 3
Real-Time Spectral Fluorescence Signature (SFS) and Laser-Induced Fluorescence (LIF) analysis software, which deploys a specialized expert system.

information professionals collect enough water quality data at reasonable cost to develop useful watershed-scale hydrologic models?

Laser Diagnostics Instruments International Inc. (LDI3) is an Ottawa-based company that, among other industrial applications, specializes in remote measurement of organics in water. In late 2003, LDI3 partnered with the Grand River Conservation Authority as well as Environment Canada, the Ontario Ministry of the Environment, and several private sector companies to demonstrate their novel Light Detection and Ranging (LiDAR) Spectrometer. The LiDAR unit was installed in a small airplane and taken for a 12-hour data collection survey of areas of Lake Ontario, Lake Simcoe, Lake Huron, and Lake Erie, and several rivers including the Grand, the Saugeen, and the Maitland. The data collected from the laser spectrometer was calibrated with simultaneous gathering and analysis of physical samples from along the flight path. Water transparency, dissolved organic matter (DOM), concentrations of certain organic chemical constituents, and various oil fractions were measured in the study.

In addition, Spectral Fluorescence Signature (SFS) analysis was carried out on collected grab samples to determine the accuracy of this method. This device as shown in Figure 1, uses multi-wavelength spectral fluorescence to determine DOM and oil products in the water. Laser-Induced Fluorescence (LIF) analyzers are based on capture and analysis of spectrum of fluorescent response, induced in the target object by illuminating it with monochromatic laser emission at one or more wavelengths. LIF reading is a composite of fluorescent responses of individual compounds present in the target object. Such molecular responses (e.g. shown in Figure 2) are deterministic for many compounds, and depend on their concentration in the sample. As a result, many objects of study have a specific shape of fluorescence spectra, which can be used to remotely identify and characterize them (Figure 3).

In the 12 hours that the LiDAR unit was airborne for the 2003 test, there were 45,000 samples taken to a spatial resolution of 30 meters. The measurements taken are presented in GIS-based format. This highly visual and accessible information format would fit in nicely with our project at the University of Guelph, and so we are excited about the prospect of working with LDI3 technology as we develop watershed management tools for Southern Ontario.

Conclusion

Source water protection in Ontario has a long way to go. The new partnership between the Consulting Engineers of Ontario and the University of Guelph confirms that protection of our surface water and groundwater sources is a necessary and important undertaking. The new technologies available to land information professionals, such as the LiDAR system, will make watershed modeling a more accurate and powerful tool. It is our goal in this project to make these tools more accessible and user-friendly to ensure that we can draw on a more extensive reservoir of professional knowledge and information in our quest for clean and safe drinking water.

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Alexandre I. Vorobiev, Project Manager, LDI3, provided the images and a report on LIF/SFS technology. vorobiev@ldi3.com

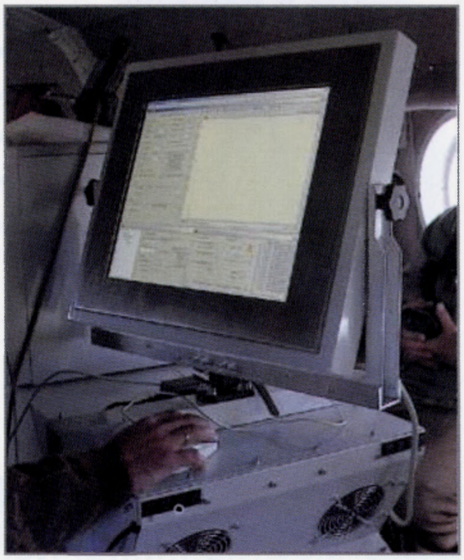

FIGURE 4
The Light Detection And Ranging (LiDAR) system installed on board a twin-engine aircraft.