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An integrated measurement and modeling methodology for estuarine water quality management

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Abstract

This paper describes research undertaken by the authors to develop an integrated measurement and modeling methodology for water quality management of estuaries. The approach developed utilizes modeling and measurement results in a synergistic manner. Modeling results were initially used to inform the field campaign of appropriate sampling locations and times, and field data were used to develop accurate models. Remote sensing techniques were used to capture data for both model development and model validation. Field surveys were undertaken to provide model initial conditions through data assimilation and determine nutrient fluxes into the model domain. From field data, salinity relationships were developed with various water quality parameters, and relationships between chlorophyll a concentrations, transparency, and light attenuation were also developed. These relationships proved to be invaluable in model development, particularly in modeling the growth and decay of chlorophyll a. Cork Harbour, an estuary that regularly experiences summer algal blooms due to anthropogenic sources of nutrients, was used as a case study to develop the methodology. The integration of remote sensing, conventional fieldwork, and modeling is one of the novel aspects of this research and the approach developed has widespread applicability.

Keywords: Estuarine modeling; Hydrodynamics; Water quality management; Nutrients; Phytoplankton; Field measurements; Remote sensing

1. Introduction

Brackish waters are commonly characterized by high productivity due to frequent inputs of nutrients, notably nitrogen and phosphorous, from both freshwater and marine sources (Correll, 1978; Nixon, 1995). Significant settlement of particulate matter, sometimes rich in nutrients including organic carbon, often occurs in estuaries. These nutrients promote the growth of phytoplankton, and algal blooms may occur; high productivity, combined with alternating salinity and temperature conditions, can result in fluctuating oxygen levels. These disturbances and adverse environmental conditions often result in estuaries being characterized by a low biodiversity.

It is difficult to model the complex interaction of water quality processes in estuarine systems because of the large number of variables that can be critical to the onset of polluted conditions (Hines et al., 2012). These variables include (1) nutrient inputs from rivers, oceans, sediments, outfalls, and the atmosphere; (2) hydrodynamics of river flows, tidal dynamics, wind direction, and velocity; (3) shape and bathymetry of the estuary; (4) light available considering day-length, water transparency, temperature, and depth; and (5) distribution, composition, and abundance of natural fauna and flora. Water quality management issues in estuaries are receiving increasing regulatory attention from European Union (EU) directives (e.g. Birds and Habitats directives), and other initiatives such as the Oslo and Paris Commission (OSPAR). International research programs, notably the EU ELOISE (Estuarine Land−Ocean Interactions Studies) and its global counterpart LOICZ

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(Land–Ocean Interactions in the Coastal Zone) specialize in modeling nutrient dynamics in coastal and estuarine waters. In 1996, a workshop organized by the Environmental Assessment and Monitoring Committee (ASMO) of the OSPAR reviewed the available models and modeling activities used to assess eutrophication concerns in the North Sea and other Convention waters (Oursel et al., 2014). The only estuarine model included in the workshop was a one-dimensional (1-D) model called EcoWin. The report on the findings of the workshop (Oursel et al., 2014) lists a number of disadvantages associated with the model. For example, the model represented one spatial dimension; the model could only resolve parameters at a temporal scale of days and months; tides were not adequately resolved; and phytoplankton dynamics were not well represented. In the intervening period, models have been improved considerably: two-dimensional models are now commonly used and models tend to provide high temporal and spatial resolutions. Also, considerable detail can now be included regarding biochemical processes and interactions between various water quality parameters.

The present research was undertaken in order to develop a framework, using water quality modeling tools, for managing estuarine water quality in response to general issues arising pertaining to water quality management. Phytoplankton dynamic models require the inclusion of many parameters and processes such as oxygen and nutrient cycles, dissolved and particulate organic matter, sediment exchanges, algal species, light attenuation, temperature, hydrodynamics, water–atmosphere exchange processes, and respiration by fish, zooplankton, and other invertebrates (Allen et al., 1980; Runca et al., 1996). The number of water quality variables that numerical models require to fully describe the dynamics of algal blooms is often in the order of 50–60 (Hipsey et al., 2007). This poses severe constraints on computational requirements when high spatial and temporal resolutions are required. When large numbers of parameters are included in a model this also poses difficulties for data collection. To develop a consistent model, data should be provided for initial and boundary conditions for each parameter, along with values for kinetic rates and constants that govern physical and biochemical processes. If these data are not available then the model will not be fully prescribed.

This research focuses on the integration of a conventional field survey, remote sensing, and modeling, with one component being used to inform the other. Early-stage scenario modeling was undertaken to predict hydrodynamics and solute transport pathways. Modeling results informed the fieldwork program indicating the most appropriate locations for collecting water quality samples. Aircraft remote sensing has rarely been used to provide data for estuarine water quality models; this is a highly novel component of this research. Using specially developed sensors, water surface chlorophyll a levels were remotely sensed and integrated into the project. The remote sensing provided high-quality spatial data for model intercomparisons; this type of data is rare, but it is highly valuable for synoptic model validation. A further significant integration of modeling and measurements was the development of initial fields of water quality parameters; field data provided relationships between salinity and individual water quality parameters and model predictions of salinity distributions throughout the harbor allowed specification of initial fields of water quality parameters.

In the following sections water quality management issues are discussed and a methodology is proposed for assessing estuarine water quality using modeling and measurements. The modeling aspects are described in Nash et al. (2010). Details are presented here of the measurement aspects of the methodology, which was applied to an Irish estuary. Finally, conclusions are drawn from this research.

2. Methodology

In this research the number of variables included in the phytoplankton model was kept to a relatively small number. As can be seen from Fig. 1, the model was limited to the relationships between phytoplankton and the nitrogen, phosphorous, and dissolved oxygen cycles. The arrows represent processes which either increase or decrease the constituent concentrations, and arrows to shaded blocks indicate settlement to seabed. The philosophy underpinning the model is to

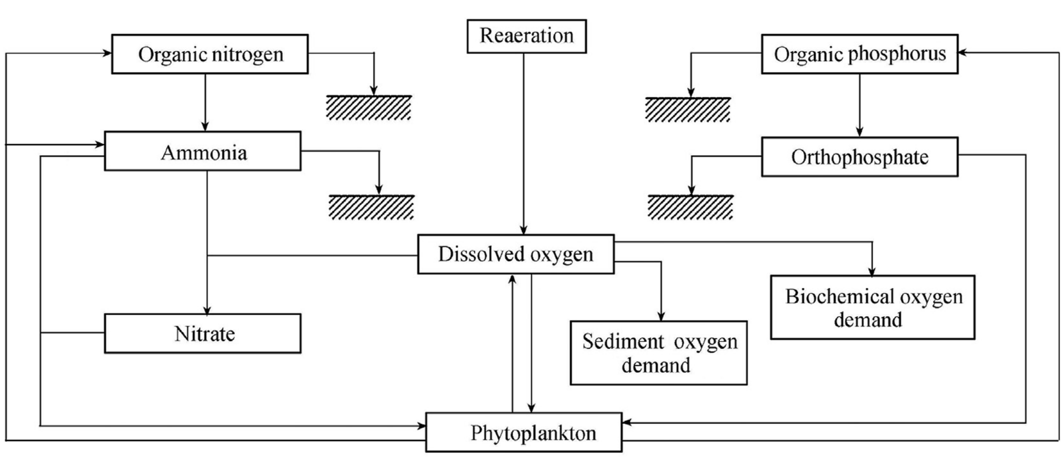

Fig. 1. Schematic diagram of phytoplankton model.