EPA’s ECOLOGICAL MODELS FOR INTEGRATED WATERSHED MANAGEMENT

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ABSTRACT

As watershed management becomes more holistic and comprehensive, managers have become increasingly interested in the dynamics and functioning of the aquatic ecosystem and the relation of landscape processes to aquatic endpoints, such as fish and macroinvertebrates. The U.S. EPA has developed multiple tools to allow monitoring data to be used to support these more comprehensive questions: CADDIS is a decision-support tool for causal evaluations; BASS and AQUATOX are simulation models for aquatic systems. These EPA tools allow monitoring data to be integrated into analyses of the ecosystem effects of environmental change and alternative management scenarios.

Keywords: CADDIS, BASS, AQUATOX, ecological modeling, decision support

INTRODUCTION

Aquatic ecological populations and communities are affected by the nature and quality of the water in which they live. Specific factors that affect instream biota include chemical variables, biotic interactions, energy source, flow regime, and habitat structure (Karr and Chu, 1999). Novotny et al. (2005) described a hierarchical conceptual model for watersheds, where landscape and atmospheric stressors affect physical habitat and water and sediment quality, which in turn affect aquatic ecological endpoints, such as fish and benthic macroinvertebrates. As watershed management becomes more holistic and comprehensive, managers have become increasingly interested in the dynamics and functioning of the aquatic ecosystem and the relation of landscape processes to aquatic endpoints. The U.S. EPA has developed multiple modeling and decision support approaches to allow monitoring data to be used to support these more comprehensive questions. Three of these approaches – CADDIS, BASS, and AQUATOX – are most useful in integrated watershed management.

CADDIS

CADDIS (http://www.epa.gov/caddis) is an online decision support system that helps scientists and managers in the Regions, States and Tribes access, organize, and share information to
conduct causal assessments in aquatic systems. Current features of this site include: a step-by-step Guide for conducting a causal assessment, example worksheets, conceptual models for several commonly encountered candidate causes, source to effect conceptual models, advice on how to use specific methods for data analysis, general advice on data handling and analysis in a causal assessment, and downloadable data analysis tools. The website also includes related links, glossary and acronyms list, databases of stressor-response information and a reference section. The site also contains modules for deriving empirical stressor-response relationships from field data, stressor-specific tolerance values, and databases and syntheses of relevant literature on sediments and toxic metals. In the near future, more technical content will be added and more example case studies will be posted.

CADDIS is based on the U.S. Environmental Protection Agency Stressor Identification process (U.S. EPA, 2000), which is a formal method for identifying causes of impairments in aquatic systems. Defensible causal analysis that characterizes mechanisms and stressor-response relationships for specific stressors can support the formulation of appropriate management actions.

BASS

The Bioaccumulation and Aquatic System Simulator (BASS) is a computer model that simulates the population and bioaccumulation dynamics of age-structured fish communities (http://www.epa.gov/ceampubl/chain/bass/index.htm; Barber, 2004). Although BASS was specifically developed to simulate the bioaccumulation of chemical pollutants within a community or ecosystem context, it can also simulate population and community dynamics of fish assemblages that are exposed to a variety of non-chemical stressors such as altered thermal regimes associated with hydrological alterations or industrial activities, commercial or sports fisheries, and introductions of nonnative or exotic fish species.

Basic Model Structure

BASS’s model structure is generalized and flexible. Users can simulate both small, short-lived species (e.g., daces and minnows) and large, long-lived species (e.g., bass, perch, sunfishes, and trout) by specifying either monthly or yearly age classes for any given species. The community’s food web is defined by identifying one or more foraging classes for each fish species based on body weight, body length, or age. The dietary composition of each of these foraging classes is then specified as a combination of benthos, incidental terrestrial insects, periphyton/attached algae, phytoplankton, zooplankton, and/or other fish species including its own. There are no restrictions on the number of chemicals that can be simulated, the number of fish species that can be simulated, the number of cohorts or age classes that fish species may have, or the number of foraging classes that fish species may have.

Model Output

- Summaries of all model input parameters and simulation controls
- Tabulated annual summaries for the bioenergetics of individual fish by species and cohort
• Tabulated annual summaries for the chemical bioaccumulation within individual fish by species and cohort
• Tabulated annual summaries for community structure and function by species and cohort
• Plotted annual dynamics of selected model variables as a function of time and age or size class

**Significance for Watershed Management**

The ability to accurately predict the bioaccumulation of chemicals in fishes is an essential component in assessing the ecological and human health risks of chemical pollutants in watersheds. Accurate bioaccumulation estimates are needed not only to predict realistic dietary exposures to humans and fish-eating wildlife but also to more accurately assess potential ecological risks to fish assemblages themselves. Although the bioaccumulation of some chemicals can be predicted accurately using simple bioaccumulation factors and measured or predicted chemical water concentrations, such calculations frequently fail to accurately predict concentrations of extremely hydrophobic chemicals and metals such as mercury. Process-based models like BASS that simulate the toxicokinetic, physiological, and ecological processes of fishes provide scientifically defensible tools that can be used to overcome many of the limitations and uncertainties associated with the use of bioaccumulation factor approaches. Because BASS also simulates the growth and predatory-prey dynamics for individual fish and the productivity, recruitment/reproduction, and mortalities of their associated populations, BASS provides a tool that can be used to evaluate various dimensions of fish health associated with non-chemical stressors.

**Current Applications**

BASS is currently being used to investigate methyl mercury bioaccumulation in the Florida Everglades and to predict population and community dimensions of fish health for a regional analysis of the ecological sustainability of the Albemarle-Pamlico drainage basin in North Carolina and Virginia.

**AQUATOX**

AQUATOX (http://www.epa.gov/waterscience/models/aquatox/) is a simulation model for aquatic systems that predicts the fate of various pollutants and their effects on the ecosystem (EPA 2004a, b). AQUATOX has several potential applications to water management, including water quality criteria and standards, TMDLs (Total Maximum Daily Loads), and ecological risk assessments of aquatic systems. AQUATOX can be used to predict ecological responses to proposed management alternatives and it may help to assess the relative importance of multiple environmental stressors in a system. It has been applied in multiple countries in varied environmental settings (Park et al., 2008).

**Nutrient and TMDL applications**

AQUATOX is well suited for analysis of waterbodies under stress from nutrient enrichment, such as nuisance algal blooms. Potential applications would include development of water
quality criteria for nutrients, TMDLs, and analysis of management alternatives. AQUATOX simulates numerous inter-related variables important in nutrient and dissolved oxygen dynamics, and their effects on the resident aquatic life.

The following are simulated:

- Nitrogen (total, nitrate, ionized and un-ionized ammonia)
- Phosphorus (total, total soluble phosphate)
- Dissolved oxygen
- Algal biomass, chlorophyll a
- Attached algae biomass in streams
- Macrophytes
- Secchi depth (a measure of water clarity)

AQUATOX is applicable to vertically stratified lakes and reservoirs – it simulates stratification and differing conditions in each layer. It simulates how attached algae respond to nutrients, grazing, and flow. Multiple types of phytoplankton are simulated, so successive blooms can be represented. AQUATOX was successfully calibrated and validated against independent data in Walker Branch, Tennessee to simulate algal responses to nutrients, heavy grazing by snails, and variable flow. AQUATOX can be used to evaluate ecosystem responses to proposed control actions.

**Aquatic Life Effects**

Unlike most water quality models, AQUATOX treats the biota as integral to the chemical/physical system. It has potential applications in analyzing the cause and effect relationships between the chemical and physical environment and biological responses. AQUATOX represents several aspects of aquatic life:

- Simulates the trophic (feeding) relationships within the biological community
- Simulates the direct and indirect effects of stressors
- Articulates ecological linkages
- Calculates time varying ecological and biological processes
- Tests sensitivity of biological responses to individual stressors
- Analyzes contributions of multiple stressors

**Bioaccumulation in AQUATOX: Organic Toxicants**

AQUATOX has the ability to model bioaccumulation of organic toxicants, as well as their direct and indirect effects on the biota. Several processes are represented, including partitioning to water, sediments and biota; toxic organic chemical transformations; dietary uptake and food web biomagnifications; and toxic effects on biota, and subsequent effects on the food web.
DISCUSSION

The choice of an appropriate model or other tool depends upon the kinds of questions to be answered, the complexity of the situation, and the consequences of the outcome. CADDIS is best used for diagnosing causes of impairment in a stream or river, while AQUATOX and BASS can be used to simulate the aquatic system and examine effects of stressors. BASS has a particular strength in representing mercury. AQUATOX is particularly useful for modeling more complex systems, where ecological and biological processes are complex, indirect effects are important but difficult to monitor, and when one needs to articulate linkages between nutrients and the biotic community.

Taken together, these EPA modeling and decision support systems allow monitoring data to be integrated into analyses that evaluate ecosystem effects of environmental change and explore alternative management policy options. The combination of high-quality data and mechanistic models in all disciplines would be the ideal approach to forecasting ecological responses to land use and climate changes in watersheds (Nilsson et al., 2003).

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