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THE VALUE OF MASS BALANCE MODELING IN FORMULATING A PTS REDUCTION STRATEGY FOR THE GREAT LAKES

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Background

The value of mass balance models for both research and management purposes has long been recognized in the Great Lakes community. From chlorides to nutrients/eutrophication and more recently for toxic substances, mass balance models have served Great Lakes managers for almost thirty years with an aid to making informed decisions regarding regulation and remediation by providing a tool to simulate the concentration of important materials in various compartments of the aquatic ecosystem as a function of the loadings of those materials to the system. For example, in the 1970s mass balance models were instrumental in setting phosphorus target loads for each of the Great Lakes. Today, these same conservation of mass principles are being used to evaluate remediation alternatives for areas impacted by toxic substances, to help understand the relationship between fish productivity and nutrient loadings and fish stocking practices, and to integrate what we know about the ecological impacts of exotic species like zebra mussels within the Great Lakes ecosystem. With respect to PTS, a mass balance model can quantitatively relate the external sources of a chemical of concern (i.e., loadings) to the temporal and spatial concentrations of that chemical in each environmental compartment of interest (atmosphere, water, sediments, biota). These concentration profiles can then be input to risk assessment models to assess human and ecological health risks, thus providing a quantitative relationship between risk and the loading history for the system of interest. One can then forecast future trends in human and ecological risks as a function of a range of load reduction scenarios represented by the future implementation of alternative load reduction strategies. Appropriate use of the model can also provide a quantification of the mass transfer rates among compartments and between spatial segments of the system; in other words, these models can help quantify the relative exposure pathways connecting sources and receptors for a given system.

Despite their capability to produce mass budgets, mass balance models should not be confused with contaminant input-output budgets based strictly on field data. An input-output chemical budget merely relates a measurement of the chemical output flux to its measured input flux for the time interval over which the measurements were made. It has no predictive value and does not provide information on the quantitative transport and fate of the chemical within the system. Data from a chemical budget are, of course, a necessary part of the monitoring program required for the calibration and confirmation of a mass balance model; but, in general, a more comprehensive data acquisition and experimentation program is necessary to obtain the additional benefits derivable from the mass balance model.

Utility of Mass Balance Models

Because mass balance models of chemicals of concern can quantify the relationship between external sources and the concentration in water, sediments and biota and can also quantify the relative importance of various pathways of exposure within the system, they have value in addressing many policy and management questions of concern. Generally, the type of analyses that these models can address include:

1. Models can quantify the linkage between loadings and in-situ concentrations of chemicals of concern, thereby providing a rational basis for regulatory and remedial actions such as establishment of a load reduction and allocation strategy to achieve a target chemical concentration within a key component of the system (e.g., chemical body burden in top predator sport fish);
2. Models can help design of more effective and efficient monitoring and surveillance programs aimed at documenting the success of regulatory/remediation efforts;
3. Models can provide a reference point to define the notions of ecosystem health/integrity, restoration goals, and sustainable development;
4. Models can aid assessments for which there is not actual environmental experience, such as assessing the relative risks of chemicals of emerging concern or the impact of exogenous environmental stressors (e.g., exotic species invasions, major storm events, climate change) on risks from chemical loadings;
5. Models can help evaluate and measure the success of management programs by providing a reference state by forecasting the ramifications of no action and by providing a means to explain or normalize the small scale, stochastic variability so often present in monitoring data so that longer term, system-wide trends can be seen.

An example of the management value of mass balance models can be seen in both the Lake Michigan and Lake Ontario mass balance modeling efforts. In both of these lakes, the models explained that the current rate of reduction of banned and restricted chemicals (historical legacy chemicals like PCBs) in open lake water and in lake trout is being controlled by surface sediment feedback through resuspension processes (because chemicals in the surface mixed layer of sediments have much longer residence times than water) rather than watershed or atmospheric load reductions. That is why these reduction rates appear to be quite slow and not affected by external load reductions. As the surface sediment concentrations get closer to being at steady-state with loads, the whole lake response will indeed become more controlled by the external load reductions that have been taking place. So, programs should continue to strive for load reductions but we should not expect to see the fruits of these reductions on a lakewide basis for some time (15 – 30 years, depending on lake and amount of reduction).

Ongoing Chemical Mass Balance Modeling in the Great Lakes

The development of chemical mass balance models in the Great Lakes began in the early 1980s. Examples of early chemical mass balance modeling efforts include: the development of MICHRIV by studying the transport and fate of heavy metals in the Flint River (Delos, et al. 1984) and the early analysis of solids dynamics and PCBs fate and transport in the Great Lakes (Thomann and Di Toro, 1983). A seminal effort in determining the feasibility and utility of using mass balance modeling in large lakes involved an IJC supported project in 1987 in which three different modeling teams built models for PCBs in Lake Ontario based only on existing data. These three models were vetted at a workshop and the resulting report concluded that mass balance modeling of toxics in the Great Lakes not only was feasible but had potential great management value (IJC Task Force on Chemical Loadings, 1988). Encouraged by this project, the USEPA Great Lakes National Program Office initiated the first major mass balance modeling pilot study in the Great Lakes, the Green Bay/Fox River Mass Balance Study (Bierman, et al.

1992; DePinto, et al. 1994; Beltran and Richardson, http://www.epa.gov/grtlakes/gbmb/Greenba1.htm). The GBMBS was instrumental in expanding our knowledge of the sources, internal cycling, and exposure pathways of hydrophobic chemicals in the Great Lakes. Using the knowledge gained from the Green Bay study, GLNPO moved to a full lake mass balance study, using Lake Michigan as the whole lake study system and including atrazine, mercury, and PCBs among the chemicals investigated (GLNPO, http://www.epa.gov/glnpo/lmmb/index.html). A mass balance model has also been used to support the Lake Ontario LaMP in its efforts to develop a load reduction strategy for priority pollutants in that system (DePinto, J.V. et al. 2004). The ARCS program (Assessment and Remediation of Contaminated Sediments) also embraced the use of mass balance models to inform the development of remedial action plans in Great Lakes Areas of Concern (e.g., DePinto, et al. 1995). Now models are being used throughout the basin to support contaminated sediment assessments and development of remediation actions. Finally, the Great Lakes Initiative used many of the findings associated with the research and model development in the Great Lakes to establish point source loading guidelines for the bioaccumulative chemicals of concern that were identified in the Initiative. Also, the ongoing work of the Binational Toxics Strategy program is being informed by the analysis of mass balance models.

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