United States Environmental Protection Agency | Office of Research and Development

National Exposure Research Laboratory
Research Abstract

Government Performance Results Act (GPRA) Goal 4
Annual Performance Measure 235

Significant Research Findings:

Watershed Mercury Simulation Software for TMDL Assessments

Scientific Problem and Policy Issues

Mercury (Hg) has been declared a primary pollutant by the U.S. Environmental Protection Agency (USEPA), the United Nations Environmental Science Committee (UNESCO), the United Nations Environmental Council of Europe (UNECE), and the trilateral Council of North American Environment Ministers. Human and wildlife exposure to mercury is primarily due to the consumption of contaminated fish. Out of 189 compounds identified as hazardous air pollutants in the 1990 Clean Air Act, mercury was singled out for separate study to examine anthropogenic (human-caused) emission and to define thresholds at which mercury affects human health and the environment.

Most mercury in the atmosphere is the gaseous element, Hg^0, which can be oxidized to divalent mercury, Hg(II) and then deposited to receptor sites. Hg(II) depositing from the atmosphere onto terrestrial components of the watershed may accumulate in soils, where a fraction is reduced and re-emitted back to the atmosphere as gaseous Hg^0. A small but significant, fraction of the deposited mercury is delivered to the surface water network via runoff and erosion. Total Hg(II) loading to surface water bodies includes, therefore, direct atmospheric deposition and indirect atmospheric deposition; that is, fluxes depositing first onto the land and then washing into an adjacent water body. Within some soils, wetlands, and water bodies, Hg(II) can be methylated to organic forms, primarily monomethylmercury, CH_3Hg^+ (here designated MeHg), which is the most toxic of the mercury species and strongly bioaccumulates.

States or EPA Regions are responsible for setting Total Maximum Daily Loads (TMDL) for water bodies adversely affected by high mercury levels. TMDL analyses must determine the present indirect contributions of atmospheric mercury deposition to the watershed, in order to predict water body mercury levels under regulatory control strategies. Watershed mercury loading estimates must account for atmospheric deposition directly to the aquatic systems and elements of the terrestrial watershed, transport and transformation through biota and soils in the watershed, delivery to the tributary network, and transport and transformation through the network and the main water body. A complete description of these fluxes in a watershed must be inferred from a judicious combination of measurements and calculations, because mercury cycling in watersheds is complex and incompletely understood. To support defensible mercury TMDLs, a convenient watershed characterization and modeling framework is needed to help users integrate watershed transport and mercury cycling processes described in the literature with site-specific watershed and water body data. This product uses Geographic Information System (GIS) technology to link terrestrial and aquatic simulation models along with atmospheric mercury deposition data on a watershed scale to quantify the direct and indirect atmospheric mercury sources to the terrestrial and aquatic components of a selected watershed, providing the states and regions a model capable of supporting a TMDL assessment of methylmercury levels in fish resulting from atmospheric deposition, point sources, and internal watershed processes.

Research Approach

The objective of this research was to produce and demonstrate practical, second-generation mercury watershed simulation technology that can be applied at basin scales to investigate proposed remediation and load reduction options. The approach was to assimilate present scientific knowledge of hydrology, sediment transport, and mercury cycling into descriptive modules linked by recently developed GIS watershed software and supporting databases. This technology takes advantage of the recently-released ArcGIS 9 to implement watershed calculations on a grid rather than a sub-watershed basis. The software was produced by combining new hydrology, sediment, and mercury fate modules with components of the GIS- based Watershed Characterization System (WCS) (Greenfield et al., 2002) which calculates soil mercury concentrations and loadings from pervious and impervious surfaces in individual sub-basins. The software has been peer reviewed and tested on two watersheds in Georgia, where it was used to calculate mercury TMDLs.

Results and Impact

A distributed grid-based watershed mercury loading model was developed to characterize spatial and temporal dynamics of mercury from both point and non-point sources. The model simulates flow, sediment transport, and mercury dynamics on a daily time-step across a diverse landscape. The model is composed of six major components: (1) an ArcGIS interface for processing spatial input data; (2) a basic hydrological module; (3) a sediment transport module; (4) a mercury transport and transformation module; (5) a spreadsheet-based model post-processor; and (6) links to other models such as WASP and WhAEM 2000 developed by EPA. The model fully uses the grid processing capacity of the latest ArcGIS technology. The water balance, sediment generation and transport, and mercury dynamics are calculated for every grid within a watershed. Water and pollutants are routed daily throughout the watershed based on a unique and flexible algorithm that characterizes a watershed into many runoff travel-time zones. The mercury transport and transformation module simulates the following key processes: (1) mercury input from atmospheric deposition; (2) mercury assimilation and accumulation in forest canopy and release from forest litter; (3) mercury input from bedrock weathering; (4) mercury transformation in soils; (5) mercury transformation in lakes and wetlands including reduction and net methylation; (6) mercury transport through sediment and runoff; and (7) mercury transport in stream channels. By using the grid-based technology, flow and mercury dynamics can be examined at any of several points in the watershed. The model is capable of supporting large-scale watershed modeling with high-resolution raster datasets. The model is programmed in Visual Basic and requires two ArcGIS (version 9.0) components—ArcView 9 and the Spatial Analyst extension.

Research Collaboration and Research Products

This software was produced under contract with Tetra Tech, Inc. Along with the software, a document is available describing the conceptual design and modeling procedures.

Publications from this study include:

Tetra Tech, Inc., "Development of Second Generation Mercury Watershed Simulation Technology - Technical Document," U.S. EPA, National Exposure Research Laboratory, Athens, GA, 2004.

Ting Dai, Ambrose, R. B., Alvi1, K., Wool, T.A., Manguerra, H., Chokshi, M., Yang, H., and Kraemer, S. "Characterizing Spatial and Temporal Dynamics: Development of a Grid-Based Watershed Mercury Loading Model," to be presented at the American Society of Civil Engineers, Environmental and Water Resources Institute 2005 Watershed Management Conference, Williamsburg, VA, July, 2005.

Future Research

EPA and other governmental and private organizations are supporting research to better understand mercury transport and transformation processes in watersheds and water bodies. METAALICUS is a particularly notable collaborative effort investigating the cycling of historical versus newly deposited mercury in an experimental lake in Ontario, Canada. We plan to incorporate new research findings from this and other ongoing research into future versions of the mercury TMDL software.

Contacts for Additional Information

Questions and inquiries can be directed to:

Robert B. Ambrose, Jr., P.E.
U.S. EPA, Office of Research and Development
National Exposure Research Laboratory
960 College Station Road, Athens, GA 30605-2700
Phone: 706-355-8334
E-mail: ambrose.robert@epa.gov

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