WATER RESOURCES RESEARCH GRANT PROPOSAL

Title: AMD Models for TMDL Development and Implementation

Focus Categories: WQL, M&P, LIP

Keywords: AMD, TMDL, water quality, GIS, environmental policy,

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(Total)

Non-Federal Funds Allocated:

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(Total)	(Direct)	(Indirect)

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Congressional District: Second (West Virginia)

Critical State Water Problems

Under section 303d of the Clean Water Act, states are required to identify streams in which water quality is impaired. To correct water quality deficiencies, Total Maximum Daily Loads (TMDL's) are developed to focus attention on improvements to overall stream quality by setting limits for pollutant loads (mass/unit time), by identifying load contributors, and setting load allocations. TMDL's will form the basis for developing plans for stream quality restoration and will play a key role in bringing partners together to develop remediation strategies. At all stages in the process it will be necessary to translate complex information into a coherent and clear package so that agencies and stakeholders will understand the issues and be able to evaluate remedial options.

The problems faced in developing TMDL's vary widely across water quality problems and issues. Many problems are somewhat ubiquitous and occur in many areas; others are more localized and create relatively unique problems unlike those in most areas. Acid

mine drainage (AMD), an environmental problem related to mining in identifiable geologic formations, is an example of such a localized issue. While a major environmental concern is those areas affected, such AMD affected areas are a relatively small proportion of streams in the U.S.; thus the problems related to AMD have not received the same degree of research and attention received by the more common issues. West Virginia currently needs to develop TMDL's for nearly a thousand AMD affected streams; efficient and equitable development of the required TMDL's requires a technical base and appropriate tools not currently available.

Results, Benefits, and/or Information Expected

This project brings together the research base on AMD issues developed at West Virginia University with the Geographic Information Systems (GIS) capabilities in the Natural Resource Analysis Center, Division of Resource Management, in a multidisciplinary approach that focuses on key issues which will be faced in implementing TMDL's on streams affected by AMD. It outlines a decision support framework for enhancing the TMDL decision making and implementation processes by combining technical information on in-stream water quality, pollutant sources, and current remediation options with economic factors on costs of alternative management scenarios. The GIS implementation extends the ability to understand and communicate complex environmental problems to the general public through maps and pictures. The goal is to develop tools that support and enlighten stakeholder input and, in the final analysis, lead to better informed and publicly acceptable management decisions.

This project, in combination with other ongoing efforts, will result in a practical approach to the development and implementation of TMDL's in West Virginia. While the initial focus is on the coal mining areas of West Virginia, the approach and methods will be applicable to other TMDL issues in the state as well as to acid mine drainage issues in other areas. The procedures developed will be assessed, and if successful, used by state and federal agencies to develop, implement, and monitor TMDL studies. Through the interaction with the Division of Environmental Protection, this project should directly affect the information used by the agency in the TMDL process in West Virginia.

Nature, Scope, and Objectives of Research

TMDL implementation includes both determining the loads for specific pollutants from each contributing source, both point and nonpoint, and distributing the allowable load for each pollutant among the various sources including a residual for the margin of safety. This project provides enhanced decision support for TMDL implementation by: 1) determining the pollution loads under different conditions, 2) developing efficient plans for allocating allowable loads among current contributors (including contributions from abandoned mine land and bond forfeiture sites under an array of remediation options) and

potential future permits, and 3) providing methods to choose among the set of efficient plans based on the priorities of all involved parties including direct and indirect estimates of costs. The implementation strategy chosen will be based on a variety of factors such as costs, technology constraints, availability of loadings that can be allocated to permits in the future for further development, site characteristics that constrain remediation options, operator availability (forfeited site or abandoned mine land), and so on; the weight given to each factor for a specific TMDL will depend on stakeholder input.

The component for determining pollution loads uses standard water quality models with specific components optimized for dynamic AMD processes. The component for distributing allowable loads uses a cost effectiveness criterion to allocate loadings subject to the allowable load established for the mouth of the watershed under alternative management scenarios. The final selection from among the set of cost efficient alternatives is based on a multiple criterion decision making approach. The modeling process and the outcomes developed for a particular TMDL situation will highlight areas of uncertainty where the potential contributions of additional data to improved allocation decisions may be highest, that is, areas where additional data is most likely to influence the final result. All components will be embedded in a Geographic Information System (GIS) to facilitate data storage and manipulation, spatial analysis, and presentation of the results in a readily understandable, graphical presentation with maps and other communication aids.

The project includes two primary objectives:

Develop improved models which can be used in a variety of environments which account for the acidity/alkalinity balance, pH, and metal precipitation issues indicative of AMD problems.

Develop a technical approach to TMDL development that seamlessly integrates all aspects of the TMDL analysis and implementation process within a GIS environment through extensions to the Watershed Characterization and Modeling System developed by the Natural Resource Analysis Center at WVU in conjunction with the West Virginia Division of Environmental Protection. The GIS consolidates data storage and presentation of detailed, site specific data and model results, both water quality and economic, for specified alternatives. To empower and facilitate stakeholder involvement, the system will include a user friendly interface that facilitates input from nontechnical users to guide the modeling and analysis components. This will allow stakeholders to compare and contrast the effects of alternative implementation and development strategies. That is, the platform will allow users to evaluate the downstream water quality effects and the economic consequences of adding or subtracting quantities of AMD related pollutants through alternative remediation strategies or new mine development.

The tasks necessary to meet these objectives are presented in additional detail below.

Methods, Procedures, and Facilities (including Related Research)

Water Quality Models

Background: Current Models

At the present time, the tool of choice for evaluating the impact of different point and nonpoint sources on the surface water in a watershed is the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) Version 2.0. From BASINS 2.0, two stream water quality models can be executed: QUAL2E and TOXIROUTE. Also incorporated in BASINS 2.0 is the Nonpoint Source Model (NPSM) which uses most of the simulation capabilities of the Hydrologic Simulation Program -- FORTRAN (HSPF) (Lahlou, Shoemaker, Choudhury, Elmer, Hu, Manguerra, Parker, 1998). Hydrologic Simulation Program – FORTRAN uses continuous rainfall and other meteorologic records to compute stream flow and water quality hydrographs. HSPF simulates the following hydrologic parameters (U.S. Geological Survey, 1998). The results of an HSPF simulation cannot be viewed with BASINS 2.0 (Lahlou, Shoemaker, Choudhury, Elmer, Hu, Manguerra, Parker, 1998).

- Interception Soil Moisture
- Surface Runoff
- Interflow
- Base Flow
- Snow Pack Depth and Water Content
- Snowmelt
- Evapotranspiration
- Ground Water Recharge

In addition to the above hydrologic parameters, HSPF also models the following water quality and sedimentation parameters (U.S. Geological Survey, 1998):

- Dissolved Oxygen
- Biochemical Oxygen Demand
- Temperature
- Pesticides

- Conservative Tracer(s)

- Fecal Coliforms

- Sediment Detachment and Transport

- pH

- Ammonia

- Nitrite-Nitrate

- Organic Nitrogen

- Orthophosphate

- Organic Phosphorus

- Phytoplankton

- Zooplankton

QUAL2E is a one-dimensional, steady-state stream water quality model which simulates the parameters listed below. Since QUAL2E is a steady-state model, the water quality boundary conditions must also remain constant in time. The results of QUAL2E can be viewed in BASINS 2.0 (Lahlou, Shoemaker, Choudhury, Elmer, Hu, Manguerra, Parker, 1998).

- Algal Nutrients

- Biochemical Oxygen Demand

- Dissolved Oxygen

- Temperature

- Algae

- Conservative Tracer(s)

- Nonconservative Tracer(s).

TOXIROUTE calculates the final and average concentrations of selected pollutants with the first order decay analytical solution under steady-state conditions. The effects of nutrient and other chemical reactions are not explicitly calculated by this model. The

results of a TOXIROUTE simulation can be viewed in BASINS 2.0 (Lahlou, Shoemaker, Choudhury, Elmer, Hu, Manguerra, Parker, 1998).

The present stream and nonpoint source models incorporated into BASINS 2.0 are of limited utility in modeling the water quality of mining-impacted watersheds for the following reasons:

- Both QUAL2E and TOXIROUTE are steady-state models and cannot simulate the transient effect of changes in source discharge and hydrologic conditions on stream water quality.

- Neither the nonpoint source and stream water quality models have the capability to simulate the effect of acid mine drainage (AMD) on water quality.

The BASINS 2.0 modeling system does not provide a mechanism for calculating the capital and operational costs of a particular treatment plan. Limited budgets for pollution mitigation require the establishment of treatment priorities. The proposed watershed water quality model will allow the user to develop a treatment plan that provides estimates of the expected improvement in stream quality for an array of project alternatives for a given funding level.

Methodology: Model Development

The process of modeling the water quality of a watershed with the proposed model will consist of the following steps:

- A first pre-processor will assemble the input data for the simulation of a particular watershed from existing databases containing observed and synthetic meteorologic, hydrologic, water quality and treatment cost data.

- A second pre-processor will allow the user to specify the water quality parameters to be modeled and the desired treatment options via a graphical user interface.

- A hydrologic model will simulate the runoff from storm events and route the runoff and base flow through the watershed. Stream stages will be calculated from existing or derived stage-discharge relationships.

- A water quality model will solve the governing equations for the desired water quality parameters from the results of the hydrologic model.

- A treatment cost model will calculate the capital and operational costs of the desired treatment options.

- A post-processor will display the results of the hydrologic, water quality and treatment cost models.

After the post-processor has displayed the results models, the user will be given the option of specifying another set of desired treatment options. This will permit the user to develop a near optimum treatment plan for the watershed.

The proposed water quality model will have the ability to simulate the watershed's stream dissolved oxygen concentrations and pH levels with transient boundary conditions. The user will have the option of specifying sources with point and nonpoint boundary conditions. The water quality parameters that will be simulated by the proposed model can be grouped into the following four categories. The user has the option of selecting which category(ies) of parameters to model.

- Temperature (required)

- Dissolved Oxygen

- Algal Nutrients

- Acid Mine Drainage

Because temperature affects the rate constants for all aqueous chemical and biological reactions, every simulation with the proposed model will include stream temperature. The other parameters are included to allow the user to calibrate the model with the results of tracer studies.

- Temperature

- One or more Conservative Tracers (optional)

- One or more Non-Conservative Tracers with First Order Decay (optional)

In order to simulate the effect of organic decay and aeration on the dissolved oxygen concentrations, the governing equations for the following water quality parameters will be solved by the model.

- Dissolved Oxygen

- Dissolved Organic Matter

- Suspended Organic Matter

The proposed water quality model will also simulate the runoff and stream transport of the following algal nutrients. Because of the complex nature of algae growth, the effect of algae on nutrient consumption and dissolved oxygen production will not be simulated by the initial version of the proposed water quality model.

- Phosphate
- Ammonia
- Nitrate
- Nitrite

The following water quality parameters are important to the production and treatment of AMD (Skousen and Ziemkiewicz, 1996). The pH of the stream will be calculated by the model by solving the governing equations for these parameters.

- Alkalinity
- Sulfide
- Sulfate
- Ferrous Iron
- Ferric Iron
- Aluminum
- Manganese
- Thiobacillus ferroxidans (optional)

Cost Analysis of Remediation Options

The water quality model provides the foundation for the analysis of alternative TMDL implementation strategies. Remediation technologies developed by the National Mine Lands Reclamation Center at West Virginia University provide a variety of technically feasible alternatives that can be utilized to reduce AMD pollutant loads from both point and nonpoint sources (Skousen and Ziemkiewicz, 1996). A series of theses (Zucker, 1992; Funk, 1993; Strager, 1995; Whetsel, 1997) and papers (Fletcher, Phipps, and Skousen, 1991; Strager, Fletcher, and Yuill, 1997; Strager, Fletcher, and Yuill, 1998; Strager et al. (in review); Zucker et al., 1992a; Zucker et al. 1992b) provide a foundation

for economic analysis of alternative remediation strategies within a watershed framework.

The set of applicable remediation alternatives for a specific AMD TMDL implementation depends on the physical characteristics of the watershed and the combination of specific concentrations of acid, metals, and other pollutants from the identified sources. Technical considerations thus dictate the set of feasible technologies available for AMD treatment for a specific TMDL. Selections from among the set of feasible alternatives is driven by cost effectiveness analyses which seek to meet the environmental goal at least cost subject to a variety of specified constraints and local acceptability of the alternatives by the affected communities. The alternatives are specified within a non-linear optimization (cost minimizing) framework (Funk, 1993). The constraints can include a variety of environmental, institutional, and site specific factors as well as the traditional technical constraints. Varying the constraints imposed provides an array of alternative options for TMDL implementation for a specific watershed. The primary outputs include a summary of the minimum costs of remediation for a specified management option or set of constraints and a summary of loadings for the watershed. A summary of the net allocable loadings that could be assigned to new permits can be developed as well.

Consider the following example. Suppose that a TMDL study identifies a variety of sources of AMD pollutants including abandoned mine lands, bond forfeiture sites, released sites, active mines, and, perhaps, other unidentified, nonpoint sources. Using information on the identified sources and loads developed for the initial TMDL study, supplemented with additional information obtained as part of the implementation effort, a range of remediation options, including costs, can be developed. Potential options include reducing loadings from active sites, developing remediation plans for abandoned and/or bond forfeiture sites, in-stream treatment, and so on. Any combination of the identified options could be included as well.

The objective is to develop a cost minimizing strategy for each scenario. Costs are calculated as the present value of all costs for an appropriate planning horizon (e.g., 20 years); they may be considered directly, presented as an initial cost with future obligations, or presented as an annual cost equivalent (i.e., an equivalent annual cost, the same for all years) for comparison with other budget items. Mathematically, the problem is to minimize the cost of treatment subject to a set of constraints that include the appropriate technical relationships between treatment and water quality and reflect any specific constraints applicable to a specified TMDL.

Implementation of TMDL's: Stakeholder Input and Choice

In nearly all cases, the final selection of a TMDL strategy will be affected by local environmental, political, social, and economic conditions. To enhance acceptability, stakeholder input must be solicited from the initial stages. Open analytical procedures subject to review and scrutiny will ultimately shorten the time for implementation and is expected to decrease total administrative and legal costs. After the water quality analysis and remediation options are completed and a set of cost efficient implementation plans

developed, stakeholder input must guide the final selection. The procedure to analyze and rank the implementation scenarios must take into account the multiple goals and objectives of the various stakeholders in the watershed as well as budgetary and regulatory constraints. Stakeholders include mining operators, state and federal resource management agencies.