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Peer Review of the Acid Mine Drainage Module of the Watershed Analysis Risk Management Framework (WARMF)

An evaluation of WARMF/AMD using USEPA Guidelines

Technical Report

Peer Review of the Acid Mine Drainage Module of the Watershed Analysis Risk Management Framework (WARMF)

An Evaluation of WARMF/AMD Using USEPA Guidelines

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Final Report, October 2001

EPRI Project Manager
Robert A. Goldstein

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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Donald Bren School of Environmental Science and Management
University of California
Santa Barbara, California 93106

Principal Investigator
A. Keller

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REPORT SUMMARY

This report contains results of a peer review, using USEPA guidelines, for national application of the Acid Mine Drainage (AMD) Module of EPRI's Watershed Analysis Risk Management Framework (WARMF) to total maximum daily load (TMDL) issues. The report will be valuable to industry, agriculture, environmentalists, and government agencies involved in management and protection of watershed resources and compliance with water quality criteria.

Background

The United States Environmental Protection Agency (USEPA) is promoting adoption of a new water resource management approach that uses watershed analysis and stakeholder consensus building in lieu of command and control. This approach incorporates consideration of all point and nonpoint sources within a watershed and the determination of TMDLs of various pollutants for water quality limited sections (WLS). EPRI has sponsored development and testing of WARMF to support the watershed approach and TMDL calculation and allocation. In cooperation with EPRI members, WARMF has been tested on the Catawba River (Duke Energy), Cheat River (AEP and Allegheny Power), Chartiers River (PA power companies) and Oostanaula River (TVA) basins. In addition, WARMF is being tested in cooperation with government agencies and other stakeholders in the Truckee River (CA), Mica Creek (ID), and Blue River (CO) watersheds. An earlier peer review of WARMF without the AMD module was conducted in 2000 and published as EPRI report 1000252.

Objective

To peer review—using USEPA guidelines and independent experts—the AMD module of WARMF for national application to watersheds where acid mine drainage is an important issue.

Approach

The peer review process followed USEPA guidelines, based on the *Guidance for Conducting External Peer Review of Environmental Regulatory Models* (EPA 100-B-94-001). The review considered the following: purpose and objectives, major defining and limiting considerations, theoretical basis, key assumptions, parameter value estimation, data quality and quantity needs, performance measures, TMDL and consensus processes, and documentation and user's guide. Reviewers provided a critical assessment in their areas of expertise and raised valid concerns or comments in other areas as warranted. Reviewer's comments are documented in their entirety to avoid misrepresentation. The developer of WARMF responds to reviewer comments in Chapter 5.

Results

The majority of reviewers felt that WARMF is suitable for addressing AMD in the context of developing TMDLs. The key assumptions and processes considered by the model are adequate for modeling AMD. The improved graphical user interface and statistical analysis tools are an important improvement over the previous versions of WARMF. The main concerns expressed with the framework are common to watershed-scale models; for example, large-scale averaging of processes and necessary simplification of mathematical formulations to reduce data needs. Another concern is difficulty in determining chemical load from each land use. Other important issues include gaps in model documentation. WARMF has since been modified to make loading by land use a standard output. In addition, the gaps in documentation have been addressed in a new EPRI publication (1005181) that will be published this year.

EPRI Perspective

WARMF helps watershed and government agencies prepare for two significant changes in water resource management policy: (1) use of watershed TMDLs and (2) stakeholder consensus decision making. For the next twenty years, TMDLs will be a major factor determining water resource management policy. TMDLs also will affect air quality management since atmospheric deposition is a significant nonpoint source in many watersheds. Stakeholder consensus decision making creates opportunities for effluent trading and ecological resource management (for example, ecosystem restoration, banking, and mitigation). Both effluent trading and ecological asset management are active areas of research at EPRI and provide opportunities for their practitioners to develop new revenues. In the future, it is likely that these two activities will be an integral part of business plans for many organizations. More information about WARMF can be found in EPRI Report TR-110709, *Watershed Analysis Risk Management Framework*; 1000729, *Watershed Analysis Risk Management Framework (WARMF) User's Guide*; 1000252, *Peer Review of the Watershed Analysis Risk Management Framework (WARMF)*; and, 1005181, *Watershed Analysis Risk Management Framework, Update One*.

Keywords

Watershed analysis risk management framework (WARMF)
Total maximum daily load (TMDL)
Watershed management
Water resources
Atmospheric deposition
Nonpoint source pollution

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OBJECTIVE OF THE PEER REVIEW

This peer review of the new Acid Mine Drainage Module of the Watershed Analysis Risk Management Framework (WARMF) model, developed by Systech Engineering for the Electric Power Research Institute (EPRI), is to determine the applicability of WARMF/AMD to develop Total Maximum Daily Loads (TMDLs) for pollutants that impact the acidity of waterbodies, in accordance with Section 303(d) of the Clean Water Act (40 CFR Part 130). The model's application niche is surface water quality, which depends on inputs from point and non-point sources, atmospheric deposition, watershed processes and groundwater-borne pollutants into the receiving water bodies. This particular module increases the applicability of WARMF to watersheds where AMD is a major issue, such as the Cheat River in West Virginia, USA.

The peer review panel was tasked with evaluating the conceptual model for AMD in WARMF, the mathematical formulation of the AMD conceptual model, the numerical solution, the methods used to estimate parameter values, the process for calibrating the model, and the performance of the model with respect to observed data. The reviewers were also asked to evaluate the major assumptions, the model strength's and weaknesses, the limitations of the model, the robustness of the model predictions, the basis for calculating TMDLs, the confidence level for calculating TMDLs, and any specific areas where additional research or model development would result in significant improvements.

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PEER REVIEW PROCESS

The Peer Review Guidelines were prepared based on the USEPA "Guidance for Conducting External Peer Review of Environmental Regulatory Models" (EPA 100-B-94-001), with additional questions to address TMDL development in the case of Acid Mine Drainage. All the reviewers received a CD-ROM with the WARMF model, Cheat River application, as well as copies of the WARMF model documentation and user guide. The reviewers were asked to load and run the model as soon as possible, and to provide comments or ask questions to Systech Engineering as needed. Reviewers were asked to provide their expert opinion on those areas with which they are most familiar, not necessarily on each and every question included in the guidelines.

As a note to the reader, the peer review process is not intended to provide a unified response, since different reviewers have different values and levels of expertise. Rather, the intent is to provide expert opinions on the various issues involved with the use of the WARMF/AMD model, highlighting both the advantages and disadvantages. The reader of this report can then determine whether this is an appropriate model for the intended application, and understand the limitations of the model. The peer review process is not intended to be an endorsement of the model, or of the results produced by the model, nor is it intended to be a specific comparison of the model with respect to other existing watershed models.

As the Peer Review process was being concluded, one of the reviewers (Evan Hansen) indicated that a new model (Mining Data Analysis System (MDAS)) has just become available from TetraTech to study and model AMD at the watershed scale. However, the MDAS model was not available to the reviewers during the process, so it was not possible to make a comparison between these two models, which apparently are similar but with some differences, as pointed out by one of the reviewers. Thus, wherever a reviewer indicates that there are no comparable models it should be understood that at the time of the review there were no such models available to most of us, and that the MDAS model has not yet been released for general evaluation.

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COMPOSITION OF THE PEER REVIEW PANEL

Dr. Arturo Keller, from the University of California at Santa Barbara, was asked by Dr. Robert Goldstein from the Electric Power Research Institute to organize the review of WARMF by a group of experts. The following individuals were asked to provide their comments and critical assessment, based on their expertise in AMD at the watershed scale, as discussed briefly here:

Mary F. Beck (Beck.mary@epa.gov) is a registered PE working for USEPA - Region III. Ms. Beck transferred from the USDA - Soil Conservation Service to the Resource Conservation and Recovery Act (RCRA) program, EPA, Region III, in September 1984, were the water quality issue was contamination of groundwater from hazardous waste. In June 1998 transferred to the Water Protection Division, TMDL Management and Support Unit, where responsibilities include assisting states in developing TMDLs, reviewing states' TMDL development methodologies, reviewing state-submitted TMDLs, reviewing states' section 303(d) listing methodologies, and responding to related TMDL and listing issues. While working for a consultant prior to joining the federal government, Ms. Beck was responsible for all hydrology/hydraulics analysis under four dam safety inspection contracts with the Corps of Engineers, performed dam-break studies using the NWS dam-break computer program, and prepared sedimentation and erosion control plans. Ms. Beck holds a BSCE (Civil Engineering) from Drexel Institute of Technology; a MSCE (Geotechnical Engineering) from Drexel University; and a MSCE (Water Resources) from Villanova University.

Jan E. Groenenberg (J.E.Groenenberg@alterra.wag-ur.nl) has more than 10 years experience in the modeling of chemical processes in soils, especially in processes related to acidification from pyrite oxidation and atmospheric deposition and heavy metal behavior. He has contributed to the development of several models of which one model SMASS was developed to simulate the physical and chemical processes in acid sulfate soils. Furthermore Mr. Groenenberg has experience in the modeling of phosphate and nitrate leaching from soils. Mr. Groenenberg studied environmental sciences at Wageningen with specialization in soil and colloid chemistry. Since 1989 he works as a scientific researcher at the DLO-Winand Staring Centre for integrated land in water research, which since the beginning of 2000 merged into Alterra.

Professor Nicholas Gray, (nfgray@tcd.ie) BSc (microbiology and biochemistry), MSc (environmental management), PhD (environmental engineering), DSc, is a senior member of the Department of Civil, Structural and Environmental Engineering. A former Director of the postgraduate teaching and research Environmental Sciences Unit at Trinity College, University of Dublin, he teaches in the area of water technology and pollution control, with extensive research expertise in wastewater treatment and freshwater pollution control. Some recent publications in AMD:

- Gray, N.F. (1998) Practical assessment techniques for the impact of acid mine drainage on riverine systems. CSIR Indian Journal of Engineering and Materials Sciences, 5, (4), 147-161.
- Gray, N.F. (1998) Acid mine drainage composition and the implications for its impact on lotic systems. Water Research, 32, (7), 2122-2134.
- Gray, N.F. (1997) Environmental impact and remediation of acid mine drainage: a management problem. Environmental Geology, 30, 62-71.

Evan Hansen (ehansen@downstreamstrategies.com), works as an independent consultant for watershed groups, environmental organizations, consulting companies, and government agencies. Through Downstream Strategies, his work focuses on four areas: TMDLs, water resources and water quality, agriculture and the environment, and energy and greenhouse gases. In his TMDL work, Mr. Hansen primarily works for stakeholder groups and environmental organizations to assess the data and models used to develop TMDLs, and to help incorporate local information into TMDL models to improve their results. From 1988-95, while employed at Tellus Institute/Stockholm Environment Institute-Boston, Mr. Hansen designed and developed WEAP, a water-planning tool that provides a comprehensive framework for water resource assessment. He applied WEAP to model water supply and demand in the tributaries to Central Asia's Aral Sea to predict future water level decline, and he provided support for the application of WEAP by the U.S. Army Corps of Engineers. He also designed, developed, applied, and provided training on other resource and environmental computer models. From 1995-97, Mr. Hansen was employed at the Natural Heritage Institute in San Francisco, where he worked on issues related to water resources allocation and consensus building among stakeholders. Mr. Hansen holds a B.S. in Computer Science and Engineering from M.I.T. in 1988, and an M.S. in Energy and Resources from University of California-Berkeley in 1997.

David M. Hyman (David.Hyman@netl.doe.gov), is a registered Professional Geologist with B.S. Geological Sciences and M.S. Geology from Lehigh University. After a tour of active duty in US Army, most of which was spent at the Waterways Experiment Station in Vicksburg Mississippi doing remote sensing and hydrologic research, Dave joined the US Bureau of Mines to manage a computer-based mapping program and a mineral industry database. In 1980, David joined the US Bureau of Mines Pittsburgh Research Center. For about 5 years, his health and safety-oriented research activities were primarily concentrated on the occurrences, prediction, and control of underground mine gases, primarily methane, in both coal and hardrock mines. Other projects included subsidence and ground control in underground coalmines. Some of the results of his work contributed to significant revisions of Federal mining law in gassy hardrock mines. During the next 11 years, Dave's research efforts were in the prediction, treatment, and control of contaminated mineral wastes and mine drainages. These efforts were applied to both coal and hardrock mines and mills. Research results in passive treatment technologies earned several awards. Currently, Dave is a Project Manager and consulting environmental geologist with the US Department of Energy's National Energy Technology Laboratory where he manages contract research projects and consults on various energy and mining related environmental issues.

Richard P. Bush (bush@netl.doe.gov), has over 15 years experience in mining and metallurgy research, including several years in acid mine drainage research. He has studied gold heap leaching and cyanide recovery, copper heap and dump leaching and sulfide oxidation chemistry,

clay ion exchange capacities, gangue mineral activities, and prediction, treatment and control of acid mine drainage. He is currently a project manager in DOE's Environmental Management program. He has a B.S. degree in Chemical Engineering and an M.S. degree in Environmental Engineering, both from the University of Nevada, Reno. As well, he has attended a number of continuing education courses in groundwater modeling and geochemistry, mineralogy and hydrometallurgy.

Arturo Keller, (keller@bren.ucsb.edu), is an Assistant Professor of Biogeochemistry at the Bren School of Environmental Science and Management, UC Santa Barbara. Keller's research interests are in the fate and transport of chemical in the environment, and the effects of management practices on fate and transport. Most recently he led the production of a report by a group of UC investigators on the "Health and Environmental Assessment of MTBE" for the State of California. He has also done work with global carbon models, and experimental and modeling work with the fate and transport of chlorinated organic contaminants in groundwater systems. His research group involves a combination of experimentalists and numerical modelers. Keller teaches courses in Biogeochemistry, Fate and Transport of Pollutants, Soil and Water Quality Management, Air Quality Management, Advances in Pollution Prevention, and most recently Watershed Quality Management. Keller is also involved in the research group that recently received a Long-Term Ecological Research (LTER) award from NSF, and will be implementing a watershed model to understand and characterize the chemical loads that discharge into the coastal ecosystems in Mediterranean climates such as those present in Southern California. Keller holds a PhD in Civil (Environmental) Engineering from Stanford University, an M.S. in Civil (Environmental) Engineering from Stanford University, and a B.S. in Chemical Engineering and a B.A. in Chemistry from Cornell University.

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ELEMENTS OF THE MODEL ADDRESSED BY THE PEER REVIEW PANEL

This section presents the answers from the reviewers to specific questions. Some reviewers provided their answers question by question, while others opted for providing an answer for the entire section, based on the specific questions. Specific answers follow the questions, while general section answers are at the end of each section. The reviewers are identified in bold. The questions are identified in italics.

General Comments from Peer Reviewers

Beck: While this present and previous reviews of WARMF indicate that the program does an adequate job of determining the TMDL that an impaired waterbody may receive and still meet water quality standards, allocating the TMDL has not been discussed. In both the Cheat watershed, West Virginia, and the Chartiers watershed, Pennsylvania, Systech Engineering, Inc. was tasked with developing and calibrating WARMF to the watershed. The Cheat model was turned over to the Environmental Protection Agency (EPA), and other stakeholders to actually develop and allocate the TMDL. In the case of the Chartiers watershed, Systech is still developing the watershed model which will be turned over to the Pennsylvania Department of Environmental Protection for development and allocation of the TMDL.

The TMDL is defined as the sum of the individual wasteload allocations (WLAs), load allocations (LAs), and the margin of safety (MOS). The WLA is the portion of a receiving waters loading capacity that is allocated to one of its existing or future point sources of pollution. The LA is the portion of a receiving waters loading capacity that is allocated to one of its existing or future nonpoint sources of pollution or to natural background pollution. The MOS takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality. The TMDL also needs to consider critical conditions for stream flow, loading, and water quality parameters.

The WLAs historically have been to industrial or municipal wastewater treatment systems, point sources permitted under the national pollution discharge elimination system, NPDES. Usually, each point source within a watershed receives its own allocation expressed as mass per time, *e.g.,* pounds per day or kilograms per year. After the TMDL has been approved by EPA, the re-issuance of a NPDES permit or issuance of a any new NPDES must conform to the approved TMDL.

The LAs are allocations to nonpoint sources which are defined as a pollution source that is not a point source. Nonpoint sources include naturally occurring background sources such naturally occurring metals in soils, pollutants washed into waterbodies by rainfall runoff such as metals from mining spoil piles, and nutrients, pesticides, sediment from agriculture lands. The LAs are usually allocated to land use types, *e.g.,* a nutrient TMDL

may call for a reduction of nitrogen loads from row crops, a smaller reduction from pastures, and no reduction from forested land. The Clean Water Act and the approval of the TMDL does not provide any regulatory authority to enforce the reductions of nonpoint source loads, instead, any existing local or state authorities and/or voluntary or incentive programs are used.

In practice, the term "point source" has become shorthand for a pollutant source subject to NPDES permitting.

WARMF models the process of AMD generation. The watershed models estimates the amount of rainfall infiltration and AMD generation and transport through soil and deep mine tunnels to waterbodies based on, among other parameters, land use. While WARMF calculates the metal loading from the strip or surface mine land use and combines it with metal loads from other land uses such a forest, urban, and agriculture, WARMF does not provide the individual land use loadings to the user.[1] For the AMD TMDLs the loads from the strip mines must be estimated outside WARMF. For agriculture-caused impairments, the loads from individual land use is even more important.[2] At present the only way a user can estimate the load from a land use is to change the land use and re-run WARMF for that catchment area. Apparently it would not be a trivial undertaking to reprogram WARMF to print out loads by land use type.

In addition to coal mining, other land uses can contribute metals and low-pH water. Urban areas are likely contributors of metals, and depending on soil characteristics, agriculture and forest lands, especially logging, may contribute metal loads. Therefore, knowing the loads from different land uses is important in the allocation process.

In the case of strip mines and permitted/nonpermitted discharges, the application of WARMF is even more difficult. Except for the T&T Mine, neither surface mines nor deep mines are explicitly modeled. The T&T Mine was the only mine which had adequate data available.

Most of the permitted mines in the Cheat watershed have technology-based standards, that is, limits for metals concentrations up to a specified storm level, *e.g.,* two-year storm, with no limits for flow. A few permits have water quality-based standards, *e.g.,* end-of-pipe concentrations must meet water-quality standards, no limit for flow.

Based on data available from the West Virginia Office of Mining and Reclamation (OMR) in October 2000, there are 309 mining permits in the Cheat watershed. Of these permits, 113 represent new, renewed, revoked, or inactive mines. The remaining 196 permits represent mines with a released performance bond (either Phase I, Phase II, or completely released).[3] The 309 permits represent coal underground mines, coal surface

[1]It should be noted that the HSPF, Hydrologic Simulation Program-Fortran, program commonly used for TMDL development can printout the loads from each land use, e.g., average annual load, average load by month, or as a time series, determined as a function of land use and meteorological data.

[2]At present WARMF lumps all agriculture land into grassland/pasture. In the Chartiers watershed, some impairments are sediment and nutrients where the required reductions will be greater from row cropland than from pastures or forests.

[3]The Surface Mining Control and Reclamation Act (SMCRA) of 1977 establishes a permitting framework and requirements for surface coal mining and reclamation operations. Section 509 requires an applicant to file a bond for performance that will be sufficient to ensure the completion of the reclamation plan.

mines, quarries, prospects, and a number of additional categories. According to OMR, approximately 50% of the coal underground mines contribute continuously to waterbodies while the remaining are precipitation-driven. All of the permitted mines with water quality-based standards are underground coal mines that discharge continuously. A required element of a TMDL is "reasonable assurance." The required load reductions specified to meet a TMDL are meaningless if they cannot be achieved. WARMF's TMDL module determines the TMDL by lowering either point loads or nonpoint loads until water quality standards are met. The user can specify a load reduction in the load-type being held constant. For example, a user may specify that point source loads are held at some fraction (0 to 1) of their load and the TMDL is determined by reducing nonpoint loads until water quality standards are met in the waterbody. WARMF will indicate if water quality standards cannot be met while reducing all nonpoint loads with the specified point source loading. If a TMDL is achievable, the user does not know if a particular land use could supply all of the required reduction. For example, either with or without a point source, a user requests a TMDL from a catchment area which is predominately forested, with some agriculture, say row crops which highly disturb the soil, and some surface mines. It is unknown whether or not the required reduction can be achieved from the surface mines or if loading from row crop land is also required. As another example, consider a catchment with surface and deep mines, both modeled as nonpoint sources. The user does not know the loading from the deep mine and if treating the only deep mine is sufficient to meet the TMDL (deep mine discharge is more likely to be a concentrated flow and more easily captured for treatment).

Originally, Systech recommended changing land uses and rerunning WARMF in order to estimate loads from various land uses. However, considering that the Cheat watershed has 55 section 303(d) listed4 segments for four pollutants, that suggestion quickly becomes cumbersome. The Chartiers watershed in Pennsylvania has even more combinations of waterbodies and pollutants.

In January 2001 Systech Engineering made a preliminary modification to WARMF to enable the user to make a distinction between permitted and unpermitted surface and deep mines and to see the portion of the loading from each. It is anticipated that WARMF will be further modified to enable the user to be able to see the load contribution from all land uses and to be able to specifies load reductions from specific land uses.

At the same time the Cheat River watershed TMDLs were developed, 54 TMDLs for the Tygart Valley River watershed were developed. EPA's contractor, Tetra Tech, Inc., modified HSPF (Hydrological Simulation Program - Fortran), a dynamic watershed model, to MDAS (Mining Data Analysis System) and included a graphical interface, data storage and management system, and a data analysis/post-processing system. Originally, the Cheat TMDLs would have been established using MDAS, and EPA had the option of using MDAS instead of WARMF up until a few months before the due date for establishing the Cheat River watershed TMDLs. I have just started looking at the latest

[4]Section 303(d) of the Clean Water Act requires states to "list" their impaired waterbodies.

version of WARMF and it appears that Systech's modifications will improve the allocation process.

In summary, WARMF, with output modifications, could be used to allocated the calculated TMDL load among various point and nonpoint sources, although, as a proprietary program, there will be users who are troubled, to a greater or lesser degree, by the "black box" nature of the program.

[Editor's note: see the response at the end of this document, in which Systech addresses these concerns and presents the recent modifications implemented in April 2001 to provide a solution to these issues.]

Gray: I am extremely impressed by the procedures employed for the evaluation of this model. Due to the limited time available l felt that it was important that l should get back to you as soon as possible. For that reason my evaluation of the model has been limited and l have concentrated on its conceptual design. I have made comments below based on the key elements listed in the guidelines. I have not been able to comment on all the issues raised within the guidelines, but have, l hope, given you some ideas from a European context.

Hyman: Due to schedule constraints, I was not able to do as in-depth of a review as I would have liked, but I believe that the review I was able to do captured some rather significant points that should be considered if this is to be a more viable and useful tool to model AMD-impacted watersheds. I did not get a chance to run the actual model on computer (various computer problems and time), so my review was limited to the report "Adaptation of WARMF to calculate TMDLs for Acid Mine Impaired Cheat River, West Virginia".

As a general note, I would like to suggest that AMD be changed to CMD (Contaminated Mine Drainage). I have seen almost as many circumneutral metal bearing mine and mine waste drainages and I have of the more traditional acidic varieties. In fact, quite often the circumneutral-contaminated drainages are just as deleterious to aquatic life, particularly in metal mining districts, as their acidic cousins.

A. Model Purpose/Objectives

The first step in evaluating a model used for environmental regulatory purposes is to clearly understand the broad context in which a model is intended to be used.

i. Does the WARMF/AMD model fit within the regulatory context for which it is intended, and does it answer the scientific questions that are required?

Groenenberg: As far as I can judge the WARMF AMD model fits in the regulatory context for which it is intended. In general it answers the scientific questions that are required.

Hyman: The model addresses some major ions, such as Fe, SO_4, Al, Mn, and Zn. It also addresses pH, alkalinity and Ca.

Bush: The purpose of the WARMF system is to assist in the development of load allocations based upon water quality criteria or standards. As such it generally is successful in addressing the constituents of concern. Apparently the new module handles the typical AMD contaminants.

ii. What are the AMD model's strengths and weaknesses?

Groenenberg: The strength of the model is that it can be used to evaluate the water quality for a whole watershed with still quite a relatively detailed (process based) modeling approach. The detailed modeling on the other hand contributes also to the weakness of the model that it needs a large amount of input data. However this does not need to be a great disadvantage if the model is parameterized for a watershed by experts.

Hyman: The model captures many of important AMD reactions. It does not capture the concept of acidity, which can be readily calculated, nor does it consider the hydrolysis reactions that Fe^{+2}, Fe^{+3}, and Al^{+3} generally undergo in AMD systems. The model does not appear to consider sorption of metals on hydrous iron hydroxides, an important component of AMD systems and significant contributor to sediments in receiving drainages and reservoirs. Acidity is considered a pollutant loading in many AMD systems and should at least be evaluated for applicability in the Cheat.

Bush: Judging from the documentation alone, some important aspects of the chemistry involved seem to have been glossed over or not included. The Cheat AMD report includes some reference to the difficulty in obtaining proper balances for iron when assuming that all iron is from pyrite and reacts stoichiometrically to produce two moles of sulfate per mole of iron. However, this assumes that all iron remains soluble and is not precipitated as an oxy-hydroxide, which is not a likely event. It is more likely that the highly pH-dependent hydrolysis and oxidation of iron occurs, producing a mixture of ferrous and ferric oxy-hydroxides, leaving the sulfate in solution. Depending upon what other mineral species are present, this may also be an over simplification, as arsenic is known to form an iron arsenate compound that then absorbs dissolved cations in solution. Iron oxy-hydroxides also are known to co-precipitate many metal cations from solution. There is some discussion of this problem on page 2-9 of the report. There is also some discussion of low ferric concentrations predicted by WARMF in stream segments with pH of 6. Again, the pH dependence of both solubilities and reduction/ oxidation reactions must be accounted for in the model in order for it to be accurate in predicting metals concentrations. The discussion at the bottom of page 2-9 seems to address this at least for ferrous iron oxidation.

There is some discussion of alkalinity on page 2-10 that seems a bit lacking in that the model apparently calculates alkalinity based solely on a cation/ anion balance. This assumes that all ions have been captured in the analysis, and that there are no significant errors. This becomes a problem of scale when you look at higher concentrations, for example. Analytical error can be either constant or proportional, so a small percentage error for a high concentration ion such as Ca or SO_4 would result in significant error in this calculation of alkalinity. If some ion is not captured in the analysis, there is even more room for error. I believe this is why many of the pH calculations are far off in the Cheat runs. Also contributing to this is the lack of consideration for hydrolysis reactions. Additionally, many of the equations used to calculate pH or metals concentrations

inherently assume that the system is at equilibrium, which is rarely the case with AMD waters. The contaminated water is perhaps in some degree in equilibrium with the rock from whence it came, but not with the new condition of being open to the atmosphere in a receiving water.

One other problem identified in page 4-45 involves the discrepancy between storm events and runoff. It indicates that some large events resulted in low stream flow and some small events led to large flows. This may be explained by understanding the runoff process. If the soil is initially fairly moist, a large amount of rain will infiltrate shortly after a storm event, but if it is initially dry, as in late summer, it may not allow much infiltration at all. If the discrepancies of high rain/ low flow occurred during wet months and the opposite occurred during dry months, it might be possible to predict and compensate for this problem. If there seems to be no correlation with season, then something else is happening that I can't identify.

Another model limitation is the interbasin transfer of water. This may be a larger issue in other watersheds, but after discussion of the problem, I see no practical way to adequately address this. The data required are simply lacking and not easily obtainable. It should be stated clearly that this is a simplifying assumption in order to make it clear that this was considered in model development.

One last comment on the model limitations is that it is all based upon a particular 8 year snap shot in time. This may be adequate in the east, where a drought is declared after more than 20 days without rain. However, in the west, there was recently a 7-year period of drought where some years the precipitation was 30% of normal. Obviously, if the model used 8 years including 4 or 5 of these 50% or less years, it would bear little resemblance to typical years in terms of flow or water quality. The resulting load allocations may then become unrealistically low due to the higher flow since they are based on contaminant concentrations. The normal higher flow may bring a lower concentration, but the load may be so much above the allocation that even best management practices could never achieve the mandated TMDL. The current approach may indeed be the best that can be used, but its limitations need to be recognized by the stakeholders and regulatory agencies.

iii. How well does the AMD model fit its intended application niche compared to existing models?

Groenenberg: The model fits good into a niche because as far as I know no AMD models exist which can be applied at the watershed scale.

Hyman: There are some existing models from the USGS and EPA which address the aqueous geochemistry of minerals and the compositions of resultant waters. MINTEQA2 and variants of PHREEQC and NETPATH are good examples. These could be added to WARMF to make it a more complete model applicable to AMD-impacted watersheds as the watershed model presented appears to lack many important geochemical considerations that these models address. This comment is tempered with my not being aware of any better AMD-impacted watershed models available in the public domain.

Bush: To my knowledge there is no model currently available that combines surface and groundwater hydrology with mine drainage geochemistry. MinteqA2 calculates mineral equilibria and indicates the degree of saturation similar to Phreeque, while Netpath and some others attempt to define reactive transport in a geologic setting. In short, WARMF

is a fairly impressive tool that suits its intended use well. It may benefit from incorporation of some of these existing models to more accurately calculate pH and metals concentrations.

Keller: The WARMF/AMD model is an appropriate tool for the intended application, namely developing TMDLs for AMD impacted watersheds. It is to my knowledge the only model that addresses AMD at the watershed scale. Given the scale, the chemistry is simplified, but appears to capture the main processes occurring within the watershed. The advantages and disadvantages that were identified by the peer review of the WARMF model (EPRI TR-1000252) are valid for this new module.

Gray:

- This is an excellent model and quite the best l have seen. It is easy to install and operate. From a North American perspective the acquisition of catchment frameworks and data is easy and impressive, making it the most accurate and user-friendly model of its type. It has the potential to revolutionize catchment management.
- In Europe the New EU Water Framework Directive replaces much of the existing EU water legislation with what could be described as a WARMF approach. This new Directive is to be adopted throughout Europe as soon as possible. However, in practice we lack a cohesive management framework on which to operate the water basin management system. The modelers should take the initiative to see how this model could be used to help implement this Directive.
- The AMD model works well in predicting water quality parameters, yet does not address the more complex issue of multi-factor impacts. This is considered in more detail below.

Hansen: WARMF is specifically designed to calculate TMDLs. For a variety of pollutants, including those associated with AMD, WARMF provides answers to the questions: what is the TMDL for a portion of a water body, and by how much must current loads be reduced to meet this TMDL.

Two other watershed scale models have been used, or are currently being used, to develop AMD TMDLs in West Virginia. HSPF was used to develop TMDLs for the Buckhannon River and Ten Mile Creek in 1998. A new model called the Mining Data Analysis System (MDAS) is currently being developed by Tetra Tech, Inc. through EPA funding for the development of AMD TMDLs in the Tygart River Basin. The Tygart TMDLs will be finalized in early 2001.

MDAS is a generic, watershed-scale model that can be applied to any river basin. MDAS runs on a PC, and like WARMF, incorporates basic GIS functions into an excellent graphical user interface. MDAS models both point and nonpoint source loadings of AMD and other pollutants, as well as instream transformations. The model is based on algorithms in the HSPF version 11 model, but is specifically tailored to AMD-impacted watersheds.

The major difference between WARMF on the one hand, and MDAS and HSPF on the other, is that WARMF models nonpoint AMD generation and associated processes in some detail, while MDAS takes a more generalized land use-based flow and load estimation approach. WARMF calculates AMD pollutant loads based on the

characteristics of mines and soil as well as hydrologic processes. In MDAS and HSPF, each mine is represented as an individual land use, and loading contributions are estimated based primarily on that mine's (or land use's) characteristics, including hydrologic processes, water quality monitoring data, and discharge monitoring reports.

B. Major Defining and Limiting Considerations

With a clear understanding of the broad purpose and objectives of a model in a regulatory context, the scientific context needs to be addressed.

i. Does the AMD model consider all the relevant processes (e.g., transport, diffusion, chemical reactions, removal mechanisms, etc.) for developing TMDLs?

Groenenberg: The model considers the most relevant processes to develop TMDLs for AMD. Processes which are ignored, i.e. Fe precipitation with sulfides (in the case of sulfate reduction) and pyrite oxidation by nitrate (in anaerobic parts of the soil) are assumed to be of minor importance.

Hyman: It is not clear from the presentation how the formation and transport of hydrous iron hydroxides and their sorbed metals are considered. The hydrolysis reactions that Fe^{+2}, Fe^{+3}, and Al^{+3} undergo, contributing to acidity loads, do no appear to be considered in the AMD model.

Bush: As stated above, it appears that WARMF does not address all of these processes well. However, nobody to my knowledge has developed a completely accurate AMD model, since it is such a highly complex system of biologically catalyzed, pH dependent reactions also including precipitation and sorption reactions out of equilibrium.

ii. Are relevant temporal and spatial scales considered?

Groenenberg: The temporal scale of 24 hours is time demanding for calculations but necessary because of the large importance of dynamics in hydrology for the oxygen transport and consequently for the oxidation of pyrite. The horizontal scale seems to be good, I have however questions regarding the vertical spatial scale. The pyrite containing (bottom) layer is quite thick (2 m) which will have negative consequences for the modeling of oxygen transport and pyrite oxidation.

Hyman: In general, yes. The presentation recognizes problems with modeling mines, especially abandoned ones and refuse piles. My field experience indicates that these can have quite profound local effects on surface and ground water qualities. Effects in a watershed tend to be fairly localized, although transported metals (Zn, Cu, etc.) can have significant downstream effects on aquatic life. Metal can either be transported in solution or as sorbed phases on hydrous iron hydroxides; desorbing later in more dilute waters downstream.

Bush: WARMF uses a 24 hour time step, which may not be adequate to capture some important diurnal processes such as barometric and temperature change, as well as biological

processes such as plant transpiration, which may affect soil saturation and water balance. The spatial scale seems to be adequate to capture relevant inputs.

Keller: As presented in the documentation, WARMD/AMD considers the main chemical processes that are the result of AMD. It specifically deals with iron oxidation, the generation of acidic species, and the related chemical equilibria. It does not address other mineral constituents present in the mine tailings, such as trace metals, which might be released due to the low pH and can also have very deleterious effects. The temporal scales are relevant for most processes, although for some processes which occur within the daily cycle it would be useful to have the model at a smaller time step. Lack of data is a valid reason not to attempt to reduce the time step. The issue of spatial scale is important, since WARMF is forced to address these processes on a sub-catchment scale, averaging out major compartments into a uniform behavior.

Gray:

- The problem with AMD is the complexity and multifunctionality of the impacts on the biota, making water quality assessment of little value in terms of simulating what is happening in the river community. Water metal levels are probably the least important impact. Fluctuations in acidity, salinization, sediment/turbidity are all critical factors, especially in poorly buffered systems. High DOC levels, co-precipitation of metals, metal solubility - pH relationships are all key issues.
- The concept of sediment toxicity in AMD situations is largely ignored.
- The simulation of storm event situations is usually critical in AMD situations. The model appeared to handle these well, although l was unable to test these on real data.

Hansen: The WARMF AMD model considers generation of AMD pollutants, transport through soil and into water bodies, transport through water bodies, and chemical reactions and removal mechanisms such as the precipitation of iron and aluminum in soil and in water bodies.

WARMF is run on a daily time step. Although it can be run on an hourly time step, data are generally not available for this purpose. A daily time step is acceptable for TMDL development, but is not ideal for modeling TMDLs based on acute water quality standards for which one-hour average concentrations must be met. This issue is not unique to WARMF, however.

WARMF's spatial scale is flexible; catchment delineations for the Cheat were determined by Systech in consultation with EPA. Within each catchment, AMD parameters are averaged. So, for example, if more than one strip mine and more than one deep mine exist within a catchment, only a single set of strip mine parameters and a single set of deep mine parameters are entered. Refuse piles, which can generate significant amounts of AMD, are not modeled in the Cheat watershed. According to Systech's report, "Adaptation of WARMF to Calculate TMDLs for the Acid Mine Impaired Cheat River, West Virginia," refuse piles were not modeled for the Cheat because data describing their locations were not available. But WARMF does not seem to be built to model refuse piles at all, which are made up of AMD-producing materials without necessarily being covered by overburden.

In the Cheat application, only one mining point source is modeled as a point source. All others are modeled as non-point sources. Systech justifies this decision because data describing point source discharges are scarce. However, modeling treated permitted point source discharges as non-point sources has the potential to overestimate AMD pollutant loads, because WARMF's AMD generation algorithms do not account for treatment.

C. Theoretical Basis for the Model

Once the regulatory and scientific contexts of a model have been defined, the basis for problem solving must be formulated.

i. Is the conceptual model for AMD adequate for addressing TMDLs?

Groenenberg: The conceptual model is adequate to address TMDLs.

Hyman: Based upon general comments above, the model appears to match SO_4 fairly well; an important point, but that probably represents the competent modeling of flows more than the geochemical modeling aspects of this model.

Bush: Inspection of the Cheat results shows a fair match of the model with the flow and sulfate, but not very close for pH and some metals in all cases. Again, considering the complexity of the systems involved it may be the best that can be done with the current data and knowledge.

ii. Are algorithms used within the AMD model based on sound scientific principles?

Groenenberg: The information on algorithms is too scarce to judge the scientific basis. Especially the oxygen transport model is a black box .

Hyman: The algorithms used appear to be based upon sound scientific principles. My concerns are more focused on completeness of the suite of relevant geochemical reactions.

The modeling of pollutant release from mine or mine waste sources appears to be dependent on kinetics of pyrite oxidation. This is a reasonable assumption in well-flushed leaching systems. Real world sources have stored acidic salts that can release “slugs” of these pollutants (acidity, metals, sulphate, etc.) in response to rainfall or snowmelt events. The concentrations of contaminants are controlled by solubility and they are quite high for these salts.

Bush: As stated previously, the assumption of equilibrium in using the thermodynamic equations to determine concentrations is a big assumption, and apparently leads to some error in the results. Also the reactions included are fairly limited in scope.

iii. Is the mechanistic basis adequate?

Groenenberg: The mechanistic basis is in general adequate, only for the oxygen transport model the mechanistic basis can not be judged. This part of the model should be described in more detail. Also because this model distinguishes it from other models in which oxygen diffusion is modeled whereas here the advection of oxygen is modeled. The chemistry of Al is modeled with the precipitation and dissolution of $Al(OH)_3$ The dependence of the

aluminum concentration therefore depends on the H^+ concentration to the power 3. This dependency is to strong which can also be seen from the comparison of model results with measurements, which shows too much dynamics in the simulated Al concentration. The overestimation of Al dynamics is general for models with $AlOH_3$ regulating the Al concentration in solution. The model can be improved on a completely empirical base by making the H coefficient variable and to determine this coefficient by model calibration. For Zinc only the dissolution from primary minerals is modeled. Zinc can be adsorbed to the soil especially by organic matter. Sorption and desorption of zinc (which are strongly pH dependant) could also be important processes regulating the Zn concentration in soils.

Hyman: Model needs to consider hydrous iron hydroxide formation and geochemistry as well as acidic salts.

iv. Is the method of numerical solution stable and robust?

Groenenberg: I have not tested the numerical stability and robustness.

Hyman: Not seen as such in presentation.

Bush: Since I have yet to run a simulation and the method of solution is not described in the report, I can't comment.

v. How does the basis for problem solving compare to existing models?

Groenenberg: Comparable.

Hyman: Good in a sparse field as there are no other better AMD-impacted watershed models available in public domain that I am aware of. There are some models that consider much smaller areas (i.e. mine site or small stream branch scales) and are fairly site-specific.

Bush: WARMF goes a long way toward presenting a rational basis for prescribing TMDLs. I am not aware of any better alternatives at this time.

vi. What are the shortcomings of the modeling approach (e.g., missing or oversimplification of key processes, restrictive dimensionality, etc.)?

Groenenberg: As stated earlier the oxygen transport model cannot be judged from the little information give in the manual. If the model only considers advection of oxygen, I see this as a possible oversimplification. Vertical transport of oxygen takes place through cracks and large pores, however the lateral transport of oxygen into soil aggregates will be by diffusion of oxygen. Under anaerobic conditions pyrite will be oxidized by nitrate, this process is not incorporated in the model.

Hyman: See comments above. Especially the modeling of pollutant release from mine or mine waste sources appears to be dependent on kinetics of pyrite oxidation. This is a reasonable assumption in well-flushed leaching systems. Real world sources have stored acidic salts that can release "slugs" of these pollutants (acidity, metals, sulphate, etc.) in response to rainfall or snow melt events. The concentrations of contaminants are controlled by solubility and they are quite high for these salts.

Bush: The rationale used in WARMF is to determine the loading of pollutants at a given point in a watershed using previous years of flow and water quality data to predict the outcome of specified treatment actions.

vii. What are the major potential sources of error in the model?

Groenenberg: A possible major source of error in the model is the thickness of the pyritic soil layer. A finer vertical resolution will give better results especially for longer time scales when the pyrite in the top of this layer will be depleted by oxidation while (as how I understand the model description) in the model a lower (average) pyrite content for the whole layer will be calculated. If the depth at which the pyrite layer starts is deeper oxidation will only occur if the water table drops below this depth. The depth at which pyrite starts is very crucial in the modeling of pyrite oxidation.

Hyman: Major sources of error appear to be hydrolysis reactions and impact on acidity and pH (note that since pH is a logarithmic scale, the changes noted in figure 4.17 are quite significant). Also hydrous iron hydroxide transport and fate. The omission of acidity as a "pollutant" of consideration should be reviewed.

Bush: The calculation of alkalinity using ion balances, the lack of hydrolysis, redox, and precipitation of iron compounds and the impact on pH and other metals calculated.

viii. Can the magnitude of the error(s) be estimated?

Groenenberg: The magnitude of the error of the thick pyritic layer is difficult to estimate. It will cause a systematic overprediction of pyrite oxidation after a longer time. It would be interesting to split the pyritic layers into two or more layers and to see what differences this makes. If the nitrate concentration on itself is of interest the process can not be neglected.

Hyman: Not readily in this presentation given water quality data density. Especially from "slug" loading of pollutants from acidic salts "stored" in sources and released wholesale in significant runoff or snowmelt events.

Bush: I don't believe so. A sensitivity analysis might be done to determine how adjusting for these other processes changes the results. Even if the actual process is not included, one could determine the impact based on variations in input data or in calculations used as the model is now.

ix. Can the error or uncertainty be tracked in the model to provide a basis for estimating the uncertainty in the calculated TMDLs?

Groenenberg: It is difficult to track the uncertainty in the model.

Hyman: Not with data presented.

Bush: Again, the way to get a handle on this is to perform a sensitivity analysis on various input parameters or calculations.

x. Are there particular processes that the WARMF/AMD model does not address adequately?

Groenenberg: See discussion above.

Hyman: See comments above.

Keller: The conceptual model is simplified in that it considers only AMD from mining and is mostly focused on pyrite. Other minerals can also produce considerable AMD. It is an adequate initial assessment of the problem. The chemical reactions are well established, and the reaction rates are within the reasonable range, although they are considered to remain constant, mostly independent of environmental conditions. The mechanistic basis is adequate. The documentation does not present at all the method of numerical solution, which is an important shortcoming that would not be acceptable in a peer-reviewed publication. There are no comparable existing models at this scale; BASINS does not address AMD, and the models that do address AMD are not at the watershed scale . The model does not provide means for tracking uncertainty, so a user would have to perform independent sensitivity analysis for the various parameters.

Gray: The model is primarily aimed at AMD derived from coal mining. It should include other important cations such as Cu, which along with Zn is commonly associated with pyritic ore mining and of course is more toxic. All sewage-derived metals and compounds should be considered for inclusion in the main model. Using the model, it is clearly stable and robust, but the dimensionality of the AMD component is limited.

Hansen: Algorithms used to calculate AMD generation, transport, and removal seem to be based on sound underlying principles. However, the equations and data needed to adequately model AMD generation may be overly simplified. One example of this simplification is that WARMF ignores possible time lags between the time that water enters and exits deep mines. In reality, AMD does not necessarily exit deep mines as soon as it enters the mine. Errors could be introduced due to nonlinear relationships between precipitation and mine outflows.

D. Key Assumptions

The applicability of a model depends on the adequacy of its basic underlying assumptions.

i. What are the key assumptions?

Groenenberg: A key assumption is that the amount of pyrite oxidation is determined by oxygen availability. The part of the pyrite that is oxidized by Fe(III) is not important because Fe(II) has to be oxidized by oxygen as well. The driving force for pyrite oxidation is oxygen.

Hyman: The modeling of pollutant release from mine or mine waste sources appears to be dependent on kinetics of pyrite oxidation. This is a reasonable assumption in well-flushed leaching systems. Real world sources are not; they have stored acidic salts that can release "slugs" of these pollutants (acidity, metals, sulphate, etc.) in response to rainfall

or snow melt events. The concentrations of contaminants are controlled by solubility and they are quite high for these salts. Not sure what assumptions are made on the formation, transport, and deposition of iron.

Bush: The key assumptions were not stated very clearly in the Cheat report, and should be addressed more rigorously for the benefit of the end users.

Hansen: Probably the most fundamental key assumption is that AMD generation can be adequately modeled based on a relatively small number of variables. It is certainly possible that AMD generation is so difficult to model accurately that a different approach would be advised for calculating AMD TMDLs. A different approach would not attempt to model AMD generation, and would instead start with measured loadings that discharge from AMD sites, or that enter water bodies.

ii. What is the basis for each key assumption and what is the range of possible alternatives?

Groenenberg: An alternative would be a separated description of pyrite oxidation by oxygen and Fe(III).

iii. How sensitive is the model toward modifying key assumptions?

Groenenberg: I do not expect any influence of separating pyrite oxidation by oxygen and Fe(III).

Hyman: Not having seen the actual code, I'm not sure what efforts would be required to add the mineral and aqueous equilibrium models and the salt storage effects.

Bush: This needs to be addressed by the developers of the model and delineated for the benefit of the end users.

Keller: The AMD model is based on ferrous oxidation by oxygen and acid neutralization from the alkalinity provided by the watershed. It is assumed that the sources are identified, and that their impact can be "averaged" for the subcatchment, regardless of the location of the mine with respect to the river or stream. The basis is adequate, but simplified to address this scale. It would be very useful if Systech would explicitly provide the key assumptions in the documentation, and also performed a sensitivity analysis of the parameters involved in AMD, to present the information to the users and reviewers.

Gray:

- The key assumptions are adequate being based on ANC and ferrous oxidation.
- Additional questions that need to be answered: Is the model sensitive enough to predict settlement-cementation-resuspension cycles in the affected channel sections? Hydroxide formation generally leads to permanent substrate damage where inputs of AMD are constant. Can all impacts from AMD be controlled by TMDLs?

E. Parameter Value Estimation

Parameter value estimation may be based on case specific data or in their absence, on default values. In the latter case, it is important to understand how parameter value defaults were established.

i. Are the methods used for parameter value estimation valid?

Groenenberg: It is not clear how all parameters were estimated.

ii. Is there adequate data available for parameter value estimation?

Groenenberg: The amount of water quality data to calibrate the model parameters is limited.

Hyman: Parameters related to pyrite oxidation kinetics are reasonably valid, but most real world mine and mine waste systems impacts on receiving drainages are controlled by salt solubilities (very high) and occur as function of precipitation and snowmelt events.

Keller: The parameter values used for the AMD were obtained from the literature, mostly from AMD models at a smaller scale. It is not clear at all that these parameter values have been adjusted for the Cheat River to consider local effects. No additional data or experiments were conducted to calibrate the model or verify that the parameter values were adequate. The water quality data is sparse and might not in general provide enough points for a valid verification.

Gray: On the whole parameter value estimation methods in the model were rather good for a model of this size. The default values were also reasonable and well considered.

It is often difficult to be specific when describing abandoned mine sites, especially metal ore mines. There is usually large variation within the spoil in terms of key ore species and pyrite concentrations. This is also made more complex by the degree of weathering of the spoil as earlier piles are exposed and either moved or reworked.

F. Data Quality/Quantity

All models require the input of various types and amount of data. Models may also rely on experimental data to help shape their computational algorithms. In large measure, the utility of a model for regulatory purposes depends on the quality, quantity, and spatial and temporal adequacy of data used in its design and in support of its application

i. What kinds of data are required to apply the model?

Groenenberg: Input data: Land use, meteorology, soil data (including pyrite contents and the depth at which pyrite starts); data for comparison of model calculation with measurements.

Hyman: In general, while there appeared to be adequate flow data to calibrate the model, there were insufficient water quality data to really exercise the AMD-amended model. It was not clear in the presentation if sufficient storm of snowmelt period water quality data were available to evaluate the effects of salt dissolution on receiving stream water quality. May have been the source of some modeling match problems.

ii. To what extent are these data available and what are the key data gaps?

Groenenberg: I guess the largest gap in the available input data is the dept at which pyrite starts and the thickness of the pyritic layer. The low amount of sites with measured water quality which are often also not very complete in time hampers to determine the model performance and therefore also model calibration. Zn concentrations could not be compared to measurements which hampers calibration and model verification.

Hyman: Unknown availability; my experiences have indicated that one generally has to go out and get the data by oneself, as data of sufficient quality and density are usually not available.

iii. Is the quantity of data sufficient to address the likely variability?

Hyman: Does not appear to be, but this is not an unusual situation for an AMD-impacted watershed.

iv. Do additional data need to be collected and for what purpose?

Groenenberg: I do not completely understand how the depth was determined at which the pyritic layer starts. This method could be checked with measurements in the field

Hyman: Higher density and more seasonally-disposed water quality data at key nodes in the watershed.

Keller: The data needed for this model would include land-use, soil data, chemical parameter values, hydrologic and water quality data at high temporal resolution, meteorological information, etc. For the most part, the hydrologic and meteorological data is available at sufficient resolution. Chemical data, including local parameter values and water quality information are in general not sufficient, due to lack of data collection by the appropriate stakeholders. The WARMF model should serve to guide them on the type of data needed and the frequency of data collection.

Gray: The amount of hydroxide formed should be linked directly to turbidity as this affects a number of key items (e.g. primary productivity, feeding efficiency etc.). It should include other important cations such as Cu which are commonly associated with pyritic ore mining.

Hansen: Key data needed to apply WARMF's AMD model include daily precipitation in each catchment, the extent of surface and deep mines in each catchment, parameters that describe these mines, and soil characteristics in catchments in which mining has

occurred. To model AMD generation from active mining operations, or for inactive mining operations that still treat their effluent before discharging into water bodies, daily concentration and flow data that characterizes the discharge would be ideal. If daily data are not available, monthly data could be used.

Precipitation data are generally available from nearby meteorological stations. In West Virginia, mine maps that show mined areas were available after some searching. Data are difficult to find that describe pyrite content for specific mines. Soil characteristics are generally available.

Daily point source data are difficult to obtain. Discharge monitoring reports (DMRs) are typically submitted monthly, and typically only report daily maximum and average monthly values. DMRs do not show daily variations. Daily values may be available from mining companies directly. One method typically used when calculating TMDLs involving point sources is to reserve the maximum permitted loading for each point source. This method is appropriate when a point source is permitted for a particular loading, which is typical of municipal and industrial sources. In West Virginia, mines are typically assigned technology-based NPDES discharge limits that are written in terms of concentrations, and flows are not limited. Therefore, it is impossible to reserve maximum permitted loadings for these point sources based on NPDES limits. Estimates of maximum historical loadings could be calculated from DMRs.

G. Model Performance Measures

The most basic test of a model's adequacy is to understand how well its results compare with real world measurements.

i. What criteria have been used to assess model performance?

Groenenberg: Visual inspection of the time series of model outcome compared to the measurements. Comparison of frequency distributions of model outcome with measurements.

Hyman: Flow data with corroboration by sulphate data to some extent. As sulphate is usually a conservative ion in AMD systems, this is a good check.

ii. Does the model exhibit any overall bias throughout the range of its predictions? Bias is an important test of the model's formulation since intrinsic system uncertainty is not present.

Groenenberg: The total iron concentration is for a few comparisons, which in most cases were possibly underestimated, rather than overestimated. The dynamics of the aluminum concentration are overestimated.

Hyman: Departures of predictions from real water quality data do not appear to be particularly systematic.

iii. How well does the model address, distinguish, and report variability and uncertainty in its output?

Groenenberg: Uncertainty was not addressed in the application for the Cheat river.

Hyman: Appears to be visual interpretation from graphs by reader. Summary statistics are presented as well. Point of interest, AMD data are generally not normally distributed.

iv. Which parameters and key assumptions are most significant in determining the model's variability and uncertainty?

Groenenberg: The most important parameter for uncertainty is the depth of pyrite.

Hyman: At this point, I would offer that the salt storage effects and hydrous iron hydroxide chemistry impacts on acidity are major actors here.

v. How does the model perform relative to other models in this application niche?

Groenenberg: The model performance is comparable to the performance of other models to calculate pyrite oxidation and acidification. Which is quite good as WARMF is applied to a large area.

Hyman: Sparse field at watershed scale.

vi. Is the model reasonably calibrated against the observed water quality data?

Groenenberg: The model is reasonably calibrated. The low availability of water quality data (and incomplete time series) hamper the calibration and the use of more objective methods to calibrate the model.

Hyman: Higher density and more seasonally-disposed water quality data at key nodes in the watershed are required to significantly improve calibration after model has had geochemistry upgraded.

vii. Are the WARMF model's parameter values adjusted in a scientifically sound basis to match the observed data?

Groenenberg: As far as possible the model parameters are adjusted in a scientifically sound basis.

Keller: The new version of the WARMF model includes the means to compare the model output with the existing data using a number of statistical measures, including not only the mean and standard deviation, but also through more detailed analysis of the mean square error or a comparison of cumulative values. There is no clear bias in the model, although some concentrations (e.g. Al) tend to be either overestimated or underestimated. The model does not specifically address variability or uncertainty in the parameter values or field measurements. There is no adequate basis for comparing WARMF to other models, since it is the only one operating at this scale . However, it should be pointed out that overall it does a decent job of matching the available water quality data. The process of calibration

is now more clearly spelled out in the WARMF documentation, although it is not specific for the AMD module. There is no information to know if the parameter values are adjusted in a scientifically sound basis, although presumably the modelers have used the statistical methods to make their adjustments.

Gray: The situation at Avoca, which is Ireland's only AMD site, is very different to that described for the Cheat River. Here we have low alkalinity water (<12 mg $CaCO_3$/L) of variable flow (0.5 - >75 m^3s^{-1}) rich in humic acids, highly acidic AMD (pH 1.5 - 3), rich in iron and associated metals (e.g. Cu, Zn, Pb, Cr, Cd, As etc.) entering the river through main adits, interflow, river bed discharge and surface runoff. I was unable to adjust the model to simulate a similar situation or to test it using real (personal) data or scenarios. So l have had to rely on the scenario presented. I feel that the model may be less reliable for the common ore-mining AMD scenario of low ANC receiving waters.

The most important impact of AMD in European situations is river bed substrate damage. It would appear that the settlement of precipitate is very difficult to model realistically. Yet it is this problem which is the key to biological community damage through habitat and niche loss. Sediment is the major factor in AMD impact in the situations l have studied. The fine hydroxide floc leads to significant substrate modification and loss of habitat diversity and hence species reduction.

While l appreciate that the objective of the review is to assess the applicability of the model for developing TMDLs, l am concerned that in the case of AMD the impact limitations that lead to the setting of TMDLs may not be fully interpreted by the component equations employed.

Due to the number of cations emanating from AMD sites, and their different relative toxicity's, would not a total toxicity loading be more appropriate in helping to identify the most appropriate management solution in river sections?

Hansen: To assess WARMF's performance in modeling AMD pollutants, Systech calibrated the model against observed in-stream data. This calibration relied on visual inspections of time series results. New statistical features allow a more systematic calibration process, but it is not clear that these statistical methods were used to calibrate the Cheat model. These statistical methods do not provide an automatic method for calibration.

Ideally the model’s bias would be tested by comparing the uncalibrated model with observed data; an uncalibrated model has not been provided to reviewers.

The Cheat application is the first in which WARMF's AMD model is used. The quality of the Cheat’s calibration is one way to determine whether or not the results are reasonable. Hydrology calibration seems to be quite good, especially in downstream segments for which daily in-stream flow data are available.

Water quality calibration is less consistent. In the most recent version of WARMF (4.15), statistical measures are built into the model to help the WARMF user judge the quality of a particular calibration run. These statistical measures are valuable, and can be improved further. There is currently no automatic way to adjust specified parameters in order to achieve the “best” calibration; instead, the WARMF user must adjust parameters by hand, run the model, and evaluate the statistics to determine if the calibration is adequate.

WARMF's calibration can be evaluated using the following methods:

- Visual comparisons of time series output of simulated versus observed flows and pollutant concentrations;
- Visual comparisons of simulated and observed frequency distribution charts, scatter plots, and cumulative quantity over time charts; and
- Statistical parameters such as mean, minimum, and maximum for the simulated and observed results, and the relative error, absolute error, RMS error, and R squared for comparisons between simulated and observed results.

H. TMDL and Consensus Process

In addition to modeling watershed processes, WARMF provides a process for developing TMDLs, and for incorporating the criteria of different stakeholders into the decision making process. WARMF does not provide a unique solution, but rather allows the stakeholder group to evaluate different scenarios and determine the scenario which best satisfies all the parties involved.

i. Are the TMDL and consensus processes clear?

Groenenberg: The TMDL and consensus process is clear.

ii. Are the TMDL and consensus processes adequate for a variety of situations and/or stakeholder groups?

Groenenberg: Yes.

iii. Does WARMF/AMD provide adequate documentation of stakeholder interests for future reference?

Groenenberg: Yes.

iv. Is the process for evaluating different scenarios adequate?

Groenenberg: Yes.

v. Are the WARMF/AMD model output files and graphics sufficient to convey the information to the various stakeholders?

Groenenberg: Yes.

Hyman: I did not get a chance to run the actual model on a computer (various computer problems and time), but those in the presentation appeared to be generally adequate. Might be clearer if source impacts could be shown as "plumes" with colors "proportional" to impact/contribution.

Keller: WARMF really excels in this area. It has the best graphical representation of model output of any watershed model. It also provides a great roadmap for developing TMDLs and consensus. The documentation in this area is good, although there is little guidance to the users as to how to proceed in terms of reducing the loading to a watershed from non-point sources. It provides very good means of tracking the various scenarios and keeping notes for the users.

Gray: The model is very clear, the graphics excellent, the model robust allowing varied scenarios. It allows stakeholders to simulate a wide range of actions, providing a tool with which to understand the consequences of actions on the catchment. Excellent.

A future linkage with biological prediction and simulation using BMWP and RivPac simulation would make this a complete and formidable tool for European management, taking it a little further from its current TMDL role to actual ecological simulation and prediction.

AMD is a mixture of point and non-point inputs, and so should be modeled as such if possible. I understand that by treating it as a point source the complexity of AMD generation, which is so site specific, is largely overcome. This does not however, overcome the problem that AMD discharges from mines are often complex and variable, especially in older heavily reworked mines. Therefore stakeholders will want to simulate multiple possible solutions of TMDLs for combinations of nonpoint and point sources for each mine. To this end it would be useful to be able to model actual mine sites in more detail within the WARMF/AMD framework to allow for more detailed simulation. This would also be necessary for abandoned sites where remediation actions apart from liming may wish to be simulated (e.g. covering spoil with overburden and planting).

Hansen: The TMDL process for AMD pollutants can be made clearer. Many AMD-impacted water bodies are impaired by multiple pollutants and do not meet water quality standards for pH, iron, aluminum, manganese, and zinc. Generation of these pollutants is linked. It would be most convenient for the WARMF user to be able to calculate TMDLs, and to evaluate allocation scenarios, in a single process rather than doing so for each pollutant individually.

WARMF's output files and graphics help convey information to stakeholders, and help stakeholders understand the model results. These outputs are some of WARMF's strong points.

I. Model Documentation and User's Guide

The utility of a model for regulatory purposes depends on the availability of a clear documentation report and a comprehensive users guide. Do these cover:

i. Model applicability and limitations?

Groenenberg: Model applicability and limitations can be read from the manual but it would be clearer if they were more explicitly stated.

ii. Data input? Interpretation of results?

Groenenberg: Data input should be described in some more detail concerning oxygen transport and Fe-oxidation. Interpretation of results are described satisfactorily.

iii. Mathematical formulation?

Groenenberg: The mathematical formulation should be described for Oxygen transport.

iv. Numerical solution algorithms?

Groenenberg: Numerical solution algorithms are not described.

v. Calibration procedures?

Groenenberg: Calibration procedures are described.

vi. Other key aspects such as verification testing?

Groenenberg: Verification is described.

vii. User-friendly instructions for all stakeholders?

Groenenberg: User friendly instructions are included.

Hyman: Presentation was really more of a discussion of how it was done with the Cheat; not how to do it with a given watershed; the more general case.

Keller: The AMD module documentation is good, although it should be proof-read in more detail in terms of grammatical errors. It also does not flow well in all cases, presenting some of the information several pages after the topic is first introduced, which leads to confusion. It could use some editing to make sure it is clear. Other important gaps have been mentioned previously in the answers to other questions.

Gray: Documentation is excellent. More detail of actual equations used would be helpful. For example l did not see how the relative solubility of metals were calculated or how the biologically available portions of metal loads in rivers were assessed.

Hansen: The User's Guide would be improved if it included the following:

- a description of how to collect point source data (from NPDES permits and DMRs) and how to analyze the data for input into WARMF. In particular, issues around mining point source data should be discussed.
- a discussion of how to model refuse piles.
- a description of how to use WARMF to calculate TMDLs based on acute water quality standards. The User's Guide mentions WARMF's capability to run on hourly time step and suggests that this would require hourly meteorological data. But it does not discuss whether or not it is appropriate to use average daily results to evaluate compliance with acute standards, and it does not discuss possible methods of post-processing average daily outputs to determine corresponding maximum hourly averages.

- a better description of the Mining Soil Coefficients Area parameter, especially in cases where there is more than one surface or deep mine and in cases where more than one mine is located above one another
- a better description of what is meant by all water in deep mines being discharged through a portal. No information is entered about whether or not there is a portal, its size, or its location. Is the assumption that all water that enters a deep mine in a time period is discharged from the mine to the water body within that same time period?

A
SYSTECH RESPONSE TO THE PEER REVIEW

We at Systech appreciate the effort made by the peer reviewers. From their reports, it is evident that they have spent time and effort on the model review. Their thoughtful comments and constructive suggestions will help us advance the science of AMD modeling. Their discussions will also bring out issues important to the users.

We would like to address some key issues raised by the peer reviewers. We will also clarify parts of the AMD algorithms.

Alkalinity and pH

Richard Bush notes that alkalinity is calculated as the sum of cations less the sum of anions. He states that a small percentage error for a major ion such as calcium or sulfate would result in significant error in calculating alkalinity.

Alkalinity is a measure of acid neutralizing capacity (ANC) of the water. It can be measured by titrating the water with acid to a low pH. Traditionally, the end point of titration is 4.5. Above pH 4.5, carbonate system (CO_3, HCO_3, and H_2CO_3) adjusts itself to adsorb or release hydrogen ions. Below pH 4.5, the carbonate system is not operative. To extend the alkalinity definition below pH 4.5, ANC is the sum of cations less the sum of anions. Without the carbonate to adsorb hydrogen ion (i.e. complete protonation), one mole increase of acid anions (i.e. sulfate or chloride) is matched by one mole increase of acid cation (i.e. hydrogen ion).

WARMF simulates a complete suite of cations and anions in the water. WARMF maintains electrical neutrality for cations and anions in the water. It is internally consistent, not supposed to have relative error on the ion species.

The sensitivity of pH with respect to alkalinity depends on the pH ranges. At neutral pH, the carbonate system dominates. The pH is buffered so that errors in cations and anions (alkalinity) do not have a large impact on pH. Below pH 3, $[H^+]$ and $[SO_4^{-2}]$ are dominate ions. Errors in $[SO_4^{-2}]$ concentration can cause comparable errors in $[H^+]$ concentration. However, these errors translate to a small error in pH value, because of the logarithmic scale. Errors in predicting pH are largest in the pH range of 4 to 4.5.

We believe that the model predictions of pH are generally good throughout the watershed. In cases where pH is not predicted well, there may be some unusual phenomenon occurring in the watershed, not considered in the WARMF model.

Acidity Not Calculated

David Hyman states that WARMF does not capture the concept of acidity. This is true, because there are theoretical equations to calculate pH as a function of alkalinity. But, there is no theoretical equation to calculate pH from acidity.

Acidity is a measure of alkaline neutralizing capacity, which can be measured by titrating the water with [NaOH] to the end point of pH 8.3. Both alkalinity and acidity are expressed in mg/l of calcium carbonate.

Sometimes, acidity is referred to as a measure of hydrogen ion concentration in the water. Under such definition, WARMF can calculate alkalinity, pH and $[H^+]$ concentration. Below pH 4.5, the value of alkalinity becomes negative. It is referred to as negative alkalinity, which is not the same as acidity.

Precipitation of Iron and Aluminum

Richard Bush cites as a potential major source of error "the lack of hydrolysis, redox, and precipitation of iron compounds". The inclusion of redox will increase the complexity of modeling substantially. However, WARMF does include oxidation of ferrous ion to ferric ion and the formation of hydroxide precipitates, $Fe(OH)_3$ and $Al(OH)_3$. The precipitates are filtered out by the soil. This is the reason why the molar ratio of sulfate to iron in stream is much higher than the 2:1, expected from the stoichiometry of pyrite.

WARMF does not adsorb such ions as zinc to the hydroxide precipitates. The hydroxides are in micro-crystal form that precipitates out very slowly. When the water samples are taken to laboratory and acidified for aluminum analysis, one can measure $Al(OH)_3$ present in the water. WARMF does simulate the adsorption of metals to suspended sediment. Under most natural conditions, suspended sediment is higher than hydroxide precipitates. However, suspended sediment was negligible in the Cheat River, according to available data. Whether these assumptions are correct, we remain to be corrected.

Inclusion of Copper Ion

Nicholas Gray noted that copper was not included in the Cheat River application, but it is often associated with AMD and is an important source of toxicity. We agree with his statement. Copper was left out because there was no requirement to determine TMDL of copper for the Cheat River. However, WARMF provides a frame work to add additional ions if necessary.

Time frame of simulations

Richard Bush noted that the 8-year simulation period used in the Cheat River watershed (1989-1997) may be adequate but noted that the same simulation period would not necessarily be representative of weather and flow conditions in a drier climate. We agree with his statement, which should be made clear to the users of WARMF. However, we wish to point out that

WARMF can simulate any length of time period for which input data (meteorology, air quality, etc.) is provided. The length of the simulation and the specific years simulated must be determined for each application to cover the range of hydrologic conditions.

Habitat modification not addressed by TMDLs

Nicholas Gray noted that AMD causes permanent damage to the substrate, which is not directly addressed by TMDLs or by WARMF. We agree with his statement. The key assumption of TMDLs is that water quality impairment is precursor to the habitat damage and that the water quality impairment is caused by waste loads. By reducing the waste load to the TMDL, it is hoped that the habitat will improve.

Incidentally, WARMF can address water diversion, which is another precursor to the habitat damage. However, it is not an issue for the Cheat River.

Time lag between precipitation and AMD generation in deep mines

Evan Hansen stated that it was not clear exactly how WARMF handles possible time lags between precipitation and AMD generation. We wish to clarify the issue raised.

WARMF tracks many flow paths that precipitation water can take. The water can become evapotranspiration, overland flow, lateral flows from the soil layers, or percolated down to deep mine tunnel for exit through portal. The AMD water would have traveled downward through the upper soil layers and then through the bedrock above the mines. The speed with which the water travels downward is limited by the vertical hydraulic conductivity of the soil (or bedrock) layer. While passing through the pyrite-containing layer, the water picks up the by-products of pyrite oxidation. When the water reaches the deep mine tunnels, it flows to a portal and out to a stream.

In WARMF, there is no flow routing in deep mine tunnels, due to a lack of geometric information. We assume that majority of time lag between precipitation and deep mine AMD is caused by the time spent in percolating water through the soil layers. The time lag spent in the open channel flow in the tunnels is relatively small and is assumed to be negligible. If one compares the timing of precipitation and deep mine outflow in the WARMF output, it is evident that there is a nonlinear time lag.

Calibration integrity/procedure

Evan Hansen wanted to know which parameters were adjusted during calibration and how much adjustments were made. He worried that the calibration process might compromise the model's underlining scientific principles and also give a false sense of confidence.

We share his concerns. As a modeler, we do not want to make the simulated results match the observed data through any means, to the extent of compromising science. We want to create a model, which simulates natural processes according to science. We want to assure the integrity of model calibration by providing all input data and model coefficients for open inspections.

As described in the technical report, the first step of calibration is hydrology. The calibration parameters are precipitation adjustment factor, snow melt coefficients, and soil coefficients, i.e. infiltration rate, field capacity, and porosity (saturated moisture). Most of the coefficients are selected from literature values and adjusted slightly to match the timing and magnitude of hydrograph. For small streams, there is no measured flow data to check the results. The flows from all ungaged streams are routed downstream until there is a gaging station. In that case, we applied uniform coefficients to all the ungaged tributaries, because there is no reason to assume otherwise. The procedure is believed to be scientifically correct.

For the AMD strength, the overburden thickness and its pyrite content are two important calibration parameters for total amount of sulfate in AMD. As explained in the technical report, the adjustment of overburden thickness was constrained by the topographic map. The pyrite content was 0.5% according to limited data that is available. We do not deviate from this value too much in the calibration.

The maximum pyrite oxidation rate was 0.02 per year at the oxygen content of the atmosphere. The ferrous oxidation rate was 0.216 per day or 0.009 per hour. As it turns out, oxygen is the limiting factor for pyrite oxidation. The oxygen concentration is controlled by soil porosity (saturated moisture). The field capacity of soil was set around 0.05 and the saturated moisture was set around 0.2, within the range of literature values.

To summarize, there are a large number of variables that can be adjusted in model calibrations. For that reason, there is a potential for abuse. The only way to prevent abuse is to obtain more data to constrain the parameter estimate. AMD modeling , like any scientific investigation, is a never ending process. Further improvement can be made as more data becomes available. So far, we have exercised restraint to not venture outside the range of available scientific data.

Treating AMD as nonpoint source

This issue is one where regulation and science are in conflict. From a scientific perspective, AMD is nonpoint source pollution. It is weather driven and is controlled by natural processes occurring in the ground. From a regulatory perspective, a portal discharge may be a permitted point source discharge.

WARMF can actually handle AMD either as point source or nonpoint source loads. If AMD is to be treated as a point source, WARMF can simply read in the flow and pollution loads data of AMD as the point source load. If AMD is to be treated as nonpoint source, WARMF has incorporated the AMD generating algorithms for its simulation.

For a pragmatic resolution of the issue, we must answer the following questions:

Are the regulated point sources significant?

The answer to this question is important, because the mining map cannot provide detailed delineation of drainage area for individual mines. For that reason, WARMF simulates the AMD from a catchment by lumped parameters. If we want to include permitted AMD as point source,

we need to find a way to subtract their tributary watershed from the mine area to prevent a double accounting of AMD loading.

We believe that the issue can be resolved by the following. If the permitted AMD represents a small fraction, say 1%, of the AMD loading from a catchment, the permitted AMD can be added as point source discharge without making too much error. If the contribution is significant, we need to subtract the mine area tributary to the permitted AMD to avoid double-accounting.

Alternatively, we can use WARMF to simulate all AMD as nonpoint source load. The permitted AMD load can be subtracted from the total AMD to arrive at the legally defined nonpoint source AMD.

Is there sufficient flow and loading data to accurately simulate AMD as point sources?

AMD is by its nature highly variable in flow and loading. Unfortunately, the AMD data is generally scarce and of poor quality. Often, only a single data value is available. If the permitted AMD is entered as a constant point source loading, the performance of the model will be diminished.

Is the permitted AMD treated with lime?

If it is, WARMF can be used to simulate the permitted AMD as nonpoint source load. The lime can be added as the point source discharge of calcium carbonate.

Well flushed system or slug release

David Hyman mentioned that WARMF would work for well flushed system. Real world sources store acidic salts for slug release.

We just like to clarify that WARMF does simulate some slug release. During the dry period, the ground water table drops and oxygen content in the soil increases to accelerate pyrite oxidation. By-products of pyrite oxidation are stored in the soil. The by-products are dissolved into percolating water for slug releases during the raining days or snow melt period. A complete dissolution of by-products is assumed.

Other Types of Mine Drainage

WARMF has been applied to Chartiers Creek in Pennsylvania. Because of the calcite content in the mine layer, the AMD has a neutral pH and high sulfate content. Aluminum and manganese are low. So, WARMF is applicable to neutral mine drainage or contaminated mine drainage, as suggested by David Hyman.

Nicholas Gray has mentioned the AMD at Avoca in Ireland. Based on the data provided, we cannot determine whether the AMD is caused by pyrite oxidation or humic acids. If the AMD is caused by pyrite oxidation, the model can be adapted to the site with little modification. If the AMD is caused by humic acids, we need to include humic acids in pH equilibrium calculations.

In the original ILWAS model, from which WARMF is descended, there are the equilibrium for 3 systems : pH-carbonate, pH-aluminum, and pH-humic acids. For the interest of computation time, we have de-activated the pH-humic acids equilibrium system for WARMF.

Numerical method/ assumptions

Arturo Keller noted a deficiency in documenting the numerical methods and assumptions. We will improve the coverage of these topics in the next update of the WARMF Technical Documentation.

Using MDAS to predict AMD

During the peer review of WARMF/AMD, Evan Hansen indicated that WARMF might not be the only watershed model for AMD. He indicated that Tetra Tech has developed a program called MDAS (Mining Data Assessment System). MDAS was used to develop TMDLs for AMD pollutants in the Tygart Valley River Basin in West Virginia.

Tetra Tech was hired by EPA to develop TMDLs of iron, sulfate, zinc, manganese, and aluminum for the Cheat River Basin, using WARMF. Because WARMF simulates all AMD as nonpoint source and EPA wishes to treat permitted AMD as point sources, there was a question about whether WARMF was a suitable tool. Tetra Tech at one time wrote a memo to EPA that suggested the use of MDAS instead of WARMF for the TMDL of Cheat River. EPA did not accept the suggestion.

We have since modified WARMF so that the permitted AMD can be simulated as nonpoint source but treated as point source in TMDL calculations. The revised WARMF CD was sent to EPA and Tetra Tech the week of January 1, 2001. The revision only involves the bookkeeping involved in loading sources. It has not changed the algorithm of AMD.

Not much was known about MDAS prior to the peer review. Evan Hansen attended a workshop on MDAS, but the handout about MDAS does not explain how MDAS simulates AMD.

EPA sent us a MDAS CD-ROM for Tygart Valley River application. The CD contains a draft MDAS manual. The report indicates that MDAS relies on HSPC as the simulation engine. HSPC is the hydrologic simulation program in C, which is C version of HSPF, the hydrologic simulation program in FORTRAN. HSPF is the simulation engine of BASINS.

I am familiar with HSPF. I know that HSPF does not have algorithm for AMD. So, I checked the input data to find out how MDAS simulates AMD.

HSPC and HSPF GUI provide the numerical values of FORTRAN variables. I found that both QIFWFG and QAFWFG were marked with a check, indicating that all water quality parameters are associated with interflow and groundwater flow. I could not find the input data for MON-IFLW-CONC and MON-GRND-CONC, which are the prescribed concentrations of pollutants in interflow and groundwater respectively. But, I found an input table of sqo, potfw, potis, acqop,

sqlim, wsqop, ioqc and aoqc for QUALID 410 (alkalinity), 945 (sulfate), 1045 (total iron) 1055 (manganese), and 1105 (aluminum).

sqo = initial storage of pollutant on the land surface

potfw = wash off potency factor

potfs = scour potency factor

acqop = accumulation rate of pollutant on land surface

sqolim = maximum storage of the pollutant on land surface

wsqop = wash off rate

ioqc = concentration of interflow

aoqc = concentration of ground water

The input table suggests that MDAS does not simulate pyrite oxidation for AMD. It simulates the accumulation and wash-off of alkalinity, sulfate, iron, manganese, and aluminum on the land surface like other pollutants (BOD, coliform, nitrogen, phosphorus, etc.). The accumulation and wash-off rates are constant for the entire year or simulation period. We consider this as nonpoint source AMD, associated with the surface runoff from the pervious area of the mine.

The HSPC and HSPF also simulate daily interflow and groundwater seepage from land catchments to river segments. Their concentrations of alkalinity, iron, sulfate, manganese and aluminum must be prescribed as input data. These concentrations are assumed to be constant for the entire period of simulation, at least according to the input tables.

MDAS does not require the input data for the amount of pyrite or its oxidation rate. It computes the accumulation and wash off of alkalinity, iron, sulfate, manganese, and aluminum as if they are accumulated from atmospheric sources. The rate coefficients for the calculation are not derived from any scientific data. Tetra Tech did not explain how they estimated those numbers for input to MDAS.

TMDL Allocation

Mary Beck raises four points:

1. WARMF needs to allocate load between permitted and un-permitted mines.
2. WARMF needs to accept technologically based limits for permitted mines.
3. WARMF needs to attribute nonpoint load to individual land uses.
4. The proprietary nature of WARMF may raise questions regarding its credibility.

WARMF Version 4.15 (7/2000), which was reviewed by Mary Beck, could not do items 1, 2, and 3. In that version, WARMF calculated nonpoint source loads from individual land uses. However, their identities were lost once they mixed into the mainstream of flow. We have modified the program to maintain the identity of nonpoint source loads from individual land uses. This change was made for all pollutants, not just those associated with AMD.

WARMF Version 5.6 (4/2001) can now attribute nonpoint source loads to individual land uses. The loading output can be viewed in both kilogram of pollutant per day and kilogram per square meter per day from each land use. For the permitted AMD, WARMF can handle three options. Option 1 is to treat the AMD as a point source load, like the T&T Mine, where there is sufficient data for the time series of flows and pollution loads. Option 2 is to input permitted concentrations of the AMD (see Mary Beck's second point above) and to rely on WARMF to provide simulated daily flows. Option 3 is to input land use for each permitted mine and rely on WARMF to simulate flows and concentrations of the AMD. In all three options, the users can view the pollution loads from individual permitted mines. The pollution loads from permitted AMD are treated as point source load (WLA) in the TMDL allocation. These changes were documented in the user's guide contained in the WARMF CD (4/2001). The CD for the new version of WARMF for Cheat River application has recently been delivered to USEPA Region 3.

With respect to the proprietary nature of WARMF and whether or not this might undermine its credibility, our response is as follows: WARMF's algorithms have been fully documented in readily available publications; papers on WARMF applications have been published in peer reviewed journals; and WARMF has passed a highly rigorous peer review by independent experts using EPA guidelines.

Target:
TMDL, Watershed, and Ecosystem Issues

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