Use of an Enhanced Adaptive Management Approach for Integration of Mercury Cycling Modeling, Relative Risk Modeling and Monitoring Data

Christy Foran and Igor Linkov,
United States Army Engineer Research and Development Center, Concord, MA

Nancy Grosso, DuPont Corporate Remediation Group

Background

Uncertainties about future conditions and the effects of remedial actions, as well as increasing resource scarcity, have been driving forces in the utilization of adaptive management strategies. However, many applications of adaptive management have been criticized for shortcomings including lack of direct links between anticipated outcomes and management alternatives and the complexity of coordination of the series of decisions with stakeholder input or values. We supplement existing adaptive management approaches with a decision-analytical approach that guides initial selection of management alternatives and also allows for incorporation of stakeholder values and learning based on monitoring information. The model provides the remedial implementation team with a transparent set of recommendations for further consideration. We illustrate the use of this enhanced adaptive management (EAM) framework to analyze remedial alternatives at the South River near Waynesboro, VA based on an understanding of mercury loading and behavior in the river. The results show that the performance of alternatives is highly influenced by the importance placed on different evaluation criteria, by uncertainty in the contaminant loading model and by cost estimates. The process demonstrates that a decision model can link environmental models and short- and long-term monitoring information with management choices to help inform a remediation approach and provides information useful for adaptive incremental implementation.

Introduction

A conceptual EAM framework has been developed that integrates decision analysis with monitoring information to provide managers and decision-makers with a tool for visualizing how remedial approaches may be modified or changed based on additional information. The EAM approach requires integration of several research projects, modeling efforts and observations: (1) A decision framework specifying the criteria to be used in evaluating the remedial alternatives (evaluation criteria); (2) Enumeration of the relative importance or trade-offs among these criteria (relative weights); (3) Empirical results and physical models relating the hypothesized effects and the stated aims; (4) Linkages, assumptions, or models providing a basis to hypothesize the effects of management actions or remedial alternatives on the stated aims.

EAM requires specification of the remedial action objectives, clear hypotheses about the potential impacts of remedial actions, and suggests a monitoring plan that increases the certainty and accuracy of the remedial outcomes. The short term remedial action objectives for the South River are to reduce exposure and transport of mercury and to enhance ecological habitat. The evaluation criteria for the decision model include effectiveness of the action in achieving the remedial action objectives, implementability including stakeholder acceptance, and cost including construction and long term maintenance and monitoring costs (see Remediation Proposal, 2013). The Phase 1 remedial action is proposed to begin in the first two-mile stretch of the river adjacent to the former plant's outfall. The EAM approach was designed to be utilized to support decisions in the context of planning and implementation of South River remediation. The initial EAM framework application was designed to demonstrate the utility of this approach.

The objective for the current effort is to refine, apply and transfer the EAM approach to the SRST ROP Work Group. The approach needs to be refined to encompass output from the Relative Risk Model (RRM) under development by Wayne Landis (Western Washington University) and the Mercury Cycling Model (MCM) under development by Reed Harris. In order to do this, the evaluation criteria may need to be modified and aligned across the projects. The EAM approach will be aligned with the remedial objectives including development of specific performance metrics that inform those objectives. Following these modifications, the model and supporting user documents will be delivered.

Materials and Methods

Adaptive management requires that decision makers hypothesize the potential outcomes and mechanisms behind the effectiveness of remedial actions, so that they may test those elements after remedial actions are performed. The relationships between the effects and the outcomes should be based on modeling, empirical relationships, previous research, or expert hypotheses that can be measured and updated. One evaluation criterion, the effectiveness in the reducing smallmouth bass tissue MeHg, may be predicted by the MCM which utilizes the specifics of a remedial action to determine potential changes in Hg concentration at the downstream end of the remediation reach. Another evaluation criterion, reducing the risk to ecological receptors, can be modeled using the Landis RRM. The decision model allows quantitative effects analysis, and provides an archive of the most up-to-date understanding of the system and the relative priorities of stakeholders. The predictions and relationships in the model are updated with monitoring results.

Decision Model. The decision model needs to reflect the decision process for selecting the best remedial alternative and the expected effects of that alternative. The initial set of evaluation criteria in undertaking remedial action were considered to be (1) effectiveness in achieving the remedial action objectives (2) implementability and (3) cost. The long term remedial objectives include reduction in MeHg in smallmouth bass tissue and the preservation or enhancement of ecological resources, as reflected in the potential of an alternative to create habitat and avoid risks to the ecological community. To this we add a criterion to consider the change in habitat conditions associated with any remedial actions.

An initial set of remedial alternatives have been developed to use for the integration effort. The alternatives are different combinations of technologies including vegetative bank stabilization, MNR, and outflow source control in the reaches closest to the outfall. Each alternative can then be evaluated based on its collective performance on all the objectives. The model uses the performance of the alternatives on each evaluation criterion (?) to calculate the relative value of each alternative. Multi-attribute value theory is used to compare the alternative using a local scale for each criteria and objective (Linkov and Moberg, 2012). The "value" of each alternative is a normalized score for each objective with the highest performing alternative(s) given a value score of 1, and the lowest performing alternative given a 0. The total utility, $U(\boldsymbol{a})$, for that alternative, $\boldsymbol{a}$, is then calculated as a weighted sum across the four objectives,

$$U(\boldsymbol{a}) = w_1 \cdot V_1(a_1) + \ldots + w_n \cdot V_n(a_n) \ , \quad \text{(Keeney and Raiffa, 1976)}$$

where a_i is the performance score of alternative $\boldsymbol{a}$ on objective O_i for $i = 1$ to n, $V_i(a_i)$ is the value of alternative $\boldsymbol{a}$ reflecting its performance on criterion O_i and w_i is the weight of criterion O_i where $\Sigma w_i = 1$.

Incorporating the Remediation Proposal and the Interim Measures Work Plan. The Remediation Proposal (2013) and the Interim Measures Work Plan (2014) specify a set of remedial action objectives that need to be met in order for a remedial action to be considered effective. From those documents, a comprehensive set of ultimate objectives and metrics for assessing success will be developed. These will be refined with input from stakeholders, the SRST and other decision makers.

Mercury Cycling Model. The MCM will be developed that will provide a prediction of the concentrations of Hg in specific environmental compartments in the river, based on the anticipated efficacy of remedial alternatives. The MCM output includes predictions of resulting concentrations in surface water and sediment and can include resulting concentrations in biota, or the sediment and surface water concentration output can be used in the BASS model to anticipate changes in key food web biota. Additionally, Hg concentrations can be represented as a distribution range of predicted outcomes in different environmental compartments that can be input into the EAM Model.

Relative Risk Model. The RRM predicts the risk of population continuity for four endpoint species: belted kingfisher, Carolina wren, smallmouth bass, and white sucker and for four water quality parameters tied to ecosystem services. Each remedial alternative under consideration is predicted to alter the environmental conditions that are inputs to the RRM, such as bank stabilization, sediment loading, etc. Therefore, the impact of each remedial alternative can be associated with a change in the relative risk of population continuity for the four ecological receptors of interest. The change in risk predicted under each remedial alternative (the output of the RRM) provides metrics to assess the potential ecological disruption associated with each remedial plan. A soft linkage for the models is anticipated; a series of RRM runs will provide a set of values and probabilities that will be entered as inputs to the EAM model.

Monitoring Plan. The EAM model is designed to reflect an understanding of the current conditions within the river. An important aspect of the application of the model, therefore, is specification of a series of measurements that should be taken in order to update the model, reduce uncertainty and increase understanding of the relationship between parameters that influence the predicted outcomes. The parameters form the basis of a short- and long-term monitoring plan which is necessary to inform the ranking of alternatives in subsequent phases of implementation. Initial discussions with the team suggest that certain monitoring parameters will be useful in assessing success such as Hg and MeHg in surface water, sediment, mayflies, clams, and young of year fish.

Progress

Each of the 5 components of the integration effort is in a different stage of development. Initial EAM model structure and function has been presented to the group, allowing the first iteration of what an EAM approach integrating all the components would look like. The first steps will be to make a comprehensive list of objectives, and metrics by which to measure a successful remedial action. The next steps will be to collect the input parameters for the RRM and MCM that may be influenced by any remedial action plan. A hypothetical monitoring data set will be developed based on anticipated parameter changes that result from the current proposed action. This hypothetical data set will be used to test the evaluation process and the overall adaptive management approach.

Implications

The EAM approach is designed to assist and focus decision-making under adaptive management. EAM includes a decision model which is used to predict the expected outcomes in response to implementation of different remedial alternatives. The decision model serves as both an archive of the understanding of the system as it relates to the decision objectives, and a way to compare different courses of action. It is not an ecological or conceptual site model. It provides a simple description of the relationship between actions (remedial alternatives) and their impacts on the evaluation criteria (reduction in MeHg in smallmouth bass, cost, etc.). The decision model forces a quantitative evaluation of alternatives and a relative value score is calculated for each one. This score is based on a combined evaluation of how well the alterative meets the objectives and other evaluation criteria. As subsequent phases of remediation are implemented, the EAM may be updated improving the accuracy of the evaluation for each remedial alternative.

References

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