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

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Background

Environmental remediation efforts are well supported through the application of adaptive management approaches. Adaptive management is a structured analysis of the best action under uncertainty and gains knowledge of a system through action (Gregory, Ohlsen, and Arvai 2006). In order to incorporate adaptive management into a remedial approach, three elements must be developed. First, a comprehensive set of objectives that are necessary to accomplish or maintain must be enumerated. Second, a set of actions and related hypotheses – or models – are needed to predict the efficacy of actions to meet the stated objectives. Third, it is necessary to develop a consensus of when new, additional or different action would better serve the needs of the project. These elements can be developed through a series of analyses and conversations. However, when a system or situation becomes increasingly complex, decision analytical tools can provide transparency, align terminology and support communication, be the foundation for visualization of trade-offs, and archive the effects analyses for the actions under consideration. We have termed this decision-analytical supported adaptive management approach, enhanced adaptive management (EAM; Foran et al. 2015)

Introduction

A conceptual EAM framework was developed to integrate the efficacy of pilot studies and on-going monitoring information into a multi-criteria decision analytical tool to designed to reflect the best, current understanding of the river system and support communication between stakeholders (Foran et al. 2015). This conceptual approach incorporated a simple and unrealistic, mass-balance model for prediction of changes in mercury in fish and water. Also included were several elements to provide a placeholder for specific objectives raised by stakeholders, such a habitat value. The results of the conceptual effort show that the ranking of remedial alternatives is influenced by uncertainty and by the relative weights placed on different criteria. The process itself demonstrated that a decision model could be used to integrate modeling efforts, monitoring results and stakeholder priorities into an adaptive management approach for this project.

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), the dynamic Mercury Cycling Model (dMCM) under development by Reed Harris, statistical model developed by John Green. In order to do this, the evaluation criteria for considering any remedial actions may need to be modified to align across all the model outputs. A soft linkage is anticipated across these models or outputs; a series of independent runs from each model will provide a set of values and probabilities that will be entered as inputs to the EAM model. The EAM approach should be aligned with the remediation approach including development of specific performance metrics that inform those objectives. Following these modifications, the model and supporting user documents will be delivered.

The EAM approach should be aligned with the remediation approach including development of specific performance metrics that inform those objectives; conceptual criteria may need to be further modified to align with RCRA threshold and balancing criteria. Following these modifications, the model and supporting user documents will be delivered.

Materials and Methods

The EAM model is a spreadsheet-based multi-criteria decision model, based in Multi-Attribute Value Theory (MAVT; Ref). It has a series of tabs that allow used to step through setting up the model. The first tab ("PROGRESS") is a table including a set of time stamps for review of when each aspect of the decision model was filled. The next three tabs ("Weight Instructions" "mini-SMARTER" and "Weight Report") are designed to capture the relative importance of different factors in the decision tree to a specific user or set of users. The next tab "Data Input Instructions" allows the user to specify a tab for each remedial option; the data entry tabs are created from a template, and named sequentially (i.e. Alt_1, Alt_2, etc.). The MCDA model tab is where all the previous information is collected and macros used to calculate the relative value for the alternatives. The output is visualized in an additional tab ("Data Output").

Decision Model. The decision model needs to capture all the criteria that may be considered in the development of remedial action plan. The contribution of those criteria, and any particular aspect of the criteria can be changed by the user by changing the weights on criteria. In order for users to be able to weight each criteria accord to its value, the criteria should only be included once and should be independent of each other.

Statistical Model. The EAM model is designed to capture the current best understanding of the effects of any remedial action. That includes the integration of an analysis of years of sampling along the river. Statistical models were developed from these sample, and used to estimate the potential reduction in mercury in sediment and water following reductions in loading the first two river miles (25, 50, 75, or 100 percent). These estimates, and their confidence intervals, can be added to the EAM model to be associated with different remedial action plans corresponding to the reduction in loading.

Mercury Cycling Model. The MCM is under development and 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 ecosystem services derived from river use, water quality, swimming, fishing and boating. Each remedial alternative under consideration is predicted to alter the environmental conditions that are inputs to the RRM. In addition to the predicted change in mercury, the remedial action may alter bacterial loading, suspended solids or pH, or change the shading in a way that alters water temperature. If changes to all the inputs are estimated, the impact of each remedial alternative can be associated with a change in the relative risk of population continuity, or the risk to the human use value of the river. The change in risk predicted under each remedial alternative (the output of the RRM) provides metrics to assess the potential disruption to ecological receptors or ecosystem services associated with each remedial plan.

Monitoring Plan. Application of the EAM model requires incorporation of those metrics that will be used to determine the efficacy of any treatment. Therefore, it should reflect the short and long term monitoring plans. These measure will be used to update all the predictive models described here, 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. The most current measurements from the monitoring plans have been utilized in the EAM.

Progress

Each of the models or programs has reported results or outcomes based on conceptualized reductions in mercury loading, with the exception of the dMCM which is still under development. Those outcomes were put into an initial formulation of the EAM which was presented at the SRST meeting in September 2015. Based on that presentation, a series of conference calls resulted in feedback which substantially changed the decision model criteria. The new structure more directly reflects the threshold and balancing criteria under the Resource Conservation and Recovery Act (RCRA) Corrective Action guidance. The model has been updated with the new decision model structure. The next step will be presentation of the new decision model and, potentially, development of a case study reflecting implementation of the entire cycle of adaptive management.

Implications

The EAM approach is designed to assist and focus decision-making under adaptive management. EAM includes a decision model which is used to capture predictions from other models, or expert judgments, about 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 the degree to which the actions will perform along all the evaluation criteria. As subsequent phases of remediation are implemented, the EAM will be updated following the monitoring plan improving the accuracy for subsequent reaches.

References

Foran CM, Baker KM, Grosso NR, Linkov I (2015) An enhanced adaptive management approach for remediation of legacy mercury in the South River. PLoS ONE 10(2): e0117140. doi:10.1371/journal.pone.0117140.

Gregory R, Ohlson D, Arvai J (2006) Deconstructing adaptive management: Criteria for applications to environmental management. Ecological Applications, 16(6), 2006, pp. 2411–2425