MONITORING, MODELING AND DECISION MAKING: MAKING IT WORK

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ABSTRACT

If done properly, the integration of monitoring and modeling for decision making has the potential to increase the effectiveness of most watershed management projects. Several examples from section 319 and other watershed-based projects will be presented documenting failures and success associated with decisions made based on results generated from effective or ineffective integration of monitoring and modeling. Recommendations concerning program and technical aspects for monitoring and modeling to support decision making will also be presented.

KEYWORDS
Monitoring, modeling, watershed management

INTRODUCTION

Project managers can improve their decisions in both the planning and implementation stages of a watershed project by using data generated from appropriately integrating monitoring and modeling efforts. With better watershed-specific information, decision makers can move away from “one-size-fits-all” management approaches to develop solutions tailored to an individual watershed. Successful integration of monitoring and modeling, however, is a challenge because of potentially different data needs and limited project budgets.

Water quality monitoring has long been a major component of water quality management efforts. While monitoring provides tremendous quantities of data on actual environmental conditions, there are many challenges facing the effective collection and use of such data. Monitoring is expensive and requires good design and careful analysis to serve the objectives for which the data are collected. Ward et al. (1986) noted the need for rigorous design of monitoring programs so that routine monitoring can meet the information expectations placed on it. In a recent analysis of data needs and challenges for national assessment of ecosystem condition, the Heinz Center (2006) called for increased integration of fragmented environmental monitoring efforts to improve the collection, analysis, and reporting of data. The authors defined integration as both strategic assessment of overall monitoring objectives and tactical linkages, in which specific tools and techniques can be reconciled to produce data of wider utility.

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Models are invaluable tools for forecasting and for evaluating the potential effects of alternative choices, but application and interpretation of models can be challenging. Jones et al. (2002) stressed that the application of models in the absence of observed data causes problems for the practitioner in determining valid parameter values and leaves great uncertainty associated with model predictions. The resulting skepticism toward model output can compromise its use for watershed planning. A recent example of this issue is the use of the SPARROW (*SPAtially Referenced Regressions On Watershed Attributes)* model to identify source areas to the Gulf of Mexico hypoxia condition (Alexander et al. 2008). SPARROW relates in-stream water-quality measurements to spatially-referenced characteristics of watersheds, including contaminant sources and transport factors (USGS 2008). The model predicts contaminant flux, concentration, and yield in streams and has been used to evaluate alternative hypotheses about the important contaminant sources and watershed properties that control transport over large spatial scales. Some have considered SPARROW modeling results to be actual measures of source loads while others have discounted the results as having no value. This disparity can be a particular problem in situations where economic and political conflicts arise over source identification and the choice of potential actions for remediation (e.g., UMCES 2008).

Another prominent example of difficulty in combining model predictions and observed conditions occurred in the Chesapeake Bay watershed. At one time, the sophisticated Chesapeake Bay Watershed Model (CBP 2007) yielded estimates of 20 percent decreases in nutrient concentrations in tributary flow to the Bay since 1985, a result promoted as indicating success in the Bay restoration program. However, concurrent monitoring data showed either increasing or flat trends in tributary nutrient concentrations. This disparity became publicly contentious and resulted in a GAO audit of the Chesapeake Bay Program (Blankenship 2004). The GAO found that the presentation of diverging trends that downplayed the deteriorated conditions of the Bay was not credible and made it difficult for stakeholders and the public to determine the actual condition of the bay and status of the restoration effort (GAO 2006). A peer review of the model called for by the GAO concluded that “modeling and monitoring need to be effectively combined within this framework such that the modeling activity and results should be used to guide monitoring, while monitoring should be used to continuously test and refine the model structure and parameter sets” (Band et al. 2005).

These examples are not intended to claim that the particular models are faulty but rather argue that the exclusive reliance on models to inform policy decisions can be hazardous to effective watershed management.

Within a watershed, the ability to determine how well implemented best management practices (BMPs) will protect or improve water quality depends upon the integration of monitoring and modeling efforts. Monitoring can serve to measure pollutant losses or impacts on receiving waters, to generate input data for models, and to document the accuracy of model predictions. Modeling can be used to evaluate the effects of alternative BMP scenarios, to predict future water quality, and to extrapolate the effects of BMPs to be implemented elsewhere. Water quality, relative source loads, hydrologic, and land-based data on the watershed scale are needed for effective use of models to develop watershed specific solutions. The integration of monitoring data documenting pollutant loads and impacts with appropriate model results can be useful for managing NPS problems on a watershed basis, optimally managing technical and

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financial resources, developing local delivery approaches, and documenting achievement of watershed management goals.

ROLE OF MONITORING

Monitoring helps to identify problems, establish baseline conditions, document change, inform stakeholders, assess compliance with regulations, and provide information/data to support models. Simply put, monitoring data that documents desired water quality improvements lends credibility to project planning and implementation activities. Measurement of actual watershed conditions can be the most powerful tool for getting individuals to change behavior.

The process of watershed monitoring can be difficult, frustrating, time consuming, and expensive. Reid (2001) identified a number of reasons monitoring efforts fail, classified as problems in design (e.g., failure to measure what is needed, fundamental misunderstanding of the system being monitored, lack of statistical control) and procedural problems (e.g., failure to evaluate data regularly, lack of collateral information, poor institutional integration). Although problems in execution can sabotage a well-designed monitoring program, such problems can be corrected by good management, training, and additional resources. Flawed design, however, can doom a monitoring project from the start and no amount of additional money can salvage it.

An effective and successful watershed monitoring program is one that produces desired information at an acceptable level of effort and cost. Several examples of well-planned monitoring projects can be found in the on-going USEPA Section 319 National NPS Monitoring Program, a program in which projects with limited budgets continue to produce data useful at both project level and beyond (e.g., Schilling 2002, Meals 2004, Szpir et al. 2006, Phillips et al. 2007).

Good planning is essential to successful watershed monitoring programs. At a minimum, planning for an effective monitoring program includes:

- Clear understanding of water quality problems, including pollutants and sources;
- Statement of monitoring objectives;
- Specific experimental design that defines how monitoring will meet program objectives while controlling for exogenous factors such as weather and land use;
- Where, when, how, and how often samples will be taken;
- How samples will be analyzed;
- How the resulting data will be stored, retrieved, analyzed, and interpreted; and
- How the program results will be communicated.

Planning a monitoring program is an iterative process that should involve a multidisciplinary team. A planning team consisting of members representing a full range of groups and individuals with an interest in the project is extremely important for maximizing use of the data for both the modeling and evaluation efforts. Working from clearly defined monitoring objectives that address the evaluation and modeling needs, the team should plan a monitoring effort that generates the needed data. Monitoring of project effectiveness almost always involves monitoring before and after implementation of BMPs, but monitoring to support modeling will

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depend upon the model used and the input data needed. Watershed projects typically need to document whether and by how much the project improved water quality, but may also wish to know what worked and didn't work to aid in the planning of other projects. It is absolutely essential that all monitoring programs include appropriate statistical control to maximize the potential for documenting changes in water quality at an acceptable confidence level (Dressing 1997). Moreover, monitoring to evaluate the effectiveness of a watershed management program – i.e., not only to document water quality change but also to attribute that change to the management effort – often requires a design that can control for the effects of year to year weather changes and for the influence of land use in the watershed. Monitoring in this context demands careful design (e.g., Clausen and Spooner 1993) and sometimes monitoring outside the study watershed to obtain information on reference conditions.

ROLE OF MODELING

Watershed planning involves the consideration of how different strategies and decisions might affect and improve the health of a watershed, leading to choices about which path to take toward the future. Modeling often represents an efficient means to forecast the likely impacts of alternative management options. For example, the development of TMDLs often requires the use of watershed loading models to evaluate the effects of land use and practices on pollutant loading to a waterbody. Model outputs can be an effective tool for visualizing potential results during the planning process.

In the absence of complete monitoring data, screening-level models can provide initial estimates of flow and loads necessary for watershed characterization in the early planning process. This initial modeling effort can guide subsequent monitoring, based on identified gaps in knowledge and areas of major uncertainty.

There is never sufficient monitoring data to answer all possible questions about water quality in the planning process for a particular watershed; projects may need to complement monitoring with modeling that:

- Links sources to water quality impacts; and
- Evaluates the relative magnitude of source loadings.

Mid-range models like AGNPS, GWLF, and SWAT can be used to evaluate pollution sources and impacts over a broad geographic range and assist in determining which watershed areas should be targeted for control efforts. The Bayou Plaquemine Brule (LA) project used AnnAGNPS to predict the amounts of water and sediment transported through the watershed, to assist in identifying hot-spots of high pollutant loading, and to predict the effectiveness of recommended BMPs (USEPA 2002). NNPSMP projects combined modeling efforts for critical area delineation with personal observations (Long Creek, NC) and intensive habitat surveys (Peacheater Creek, OK). In the Otter Creek Project (WI), the BARNY model was used to supplement a rigorous site assessment protocol to rank critical dairies based on phosphorous loadings from animal confinement areas. Warner Creek (MD) used SWAT modeling to indicate that subsurface flow from outside the basin needed to be considered when developing a suitable management approach.

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Most models used in the NNPSMP and other Section 319 projects are loading models that represent and simulate the generation and movement of pollution from its source to an endpoint, usually receiving waters. These models are usually used for planning and design alone to meet the EPA's watershed management plan requirements (USEPA 2003). White Clay Lake (WI), for example, used a mass balance modeling to support an implementation approach. White Clay Lake was initially assumed to be a surface-water fed lake until an analysis of the water budget showed that surface runoff contributed only 35% of the water volume, while groundwater contributed 40% and direct precipitation contributed an estimated 25%. This budget indicated that management of surface water inputs might not have a significant influence on in-lake water quality due to the small percentage of lake inflow coming from surface runoff. An updated assessment incorporating the water budget and monitoring data showed that surface contributed 50% of phosphorus inputs to the lake.

Modeling results can be useful in designing treatment practices to be implemented in a watershed, as well as to forecast the effectiveness and costs of alternative management strategies. In addition to using BARNY to identify barnyards needing treatment, the Otter Creek Project used regressions relating storm loads to climate and seasonal condition variables to determine if there were differences between pre- and post-BMP periods (Corsi et al. 2005). The regressions for pre- and post-BMP periods were used to predict theoretical loads from the same set of measured rainfall parameters. Using this approach, average load reductions for TSS, TP, and NH_3 were estimated for both growing and non-growing seasons, helping to predict if a specified treatment approach will achieve goals for the watershed plan. Such modeling results can also be used to aid in interpretation and extrapolation from observed areas to unstudied areas. Wisconsin used the localized monitoring results from the Otter Creek NNPSMP Project to project improvements in water quality and fisheries resources elsewhere in the state.

Geographic Information Systems (GIS) are important components of many modeling tools for both planning and performance evaluations because they can assist in the study, design, analysis, interpretation, and presentation of spatially-explicit results. In some cases, model input is prepared using GIS coverages. GIS has been used effectively in the planning stage by many projects to display potential outcomes of alternative watershed management scenarios simulated using a large suite of NPS models developed by various agencies, universities and consulting firms throughout the U.S. GIS has also been used to track land use and land treatment in a number of NNPSMP projects.

Models that include the capacity to simulate waterbody response as well as watershed loading can be helpful not only in evaluating alternative management strategies but also in establishing realistic and achievable project goals and objectives. The BASINS model, for example, can simulate both point and nonpoint source pollutant loading and predict in-stream water quality response to changes in loading. This process is often key to the development of a TMDL.

Models can also guide the development of monitoring programs. By providing predictions – e.g., in pollutant loads, source areas, BMP performance, watershed load reductions, or waterbody response – model results provide testable hypotheses by which to evaluate program effectiveness. The duration of the monitoring program and the allocation of available monitoring

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resources to variable selection, sampling stations and their locations, and sampling frequency can be guided by modeling results.

The ability to model future water quality changes can be used to estimate the time required (i.e., lag time) to achieve reduced pollutant loads and water quality improvements from watershed treatment programs. For example, Clausen et al. (1992) used a simple dynamic mass balance model based on RCWP data to predict that even following complete elimination of fertilizer P inputs to a crop field with an excessive soil P level, 32 years would be required to reach 50 percent of the new equilibrium P concentration in runoff, and over 100 years would be needed to reach 90 percent of the new equilibrium. A recent, more sophisticated P mass balance model of silage corn production in Vermont (Meals et al. 2006) predicted that, following restriction of P inputs in manure and fertilizer to less than crop removal rate, 25 years would elapse before soil test P declines below the "high" level and soil test P would not decline below "optimum" levels for another 15 years. Appreciation of such lag time issues has obvious implications for monitoring to evaluate the effectiveness of nutrient management practices.

As with monitoring, application of modeling to watershed planning is subject to a number of limitations. Models generally require data, e.g., for setting model parameters, for calibration, and for validation; therefore modeling cannot be conducted entirely apart from monitoring. Proper application of models and interpretation of modeling results also require a level of technical and financial resources comparable to that required for monitoring. The Elm Creek (NE) NNPSMP project attempted to use modeling to relate BMP implementation to water quality, but later abandoned the effort because of insufficient funds, losing valuable time and resources in the project.

The ability of a model to effectively identify critical processes and areas of concern in a watershed may be impaired by limitations in the model scope or in the modeling approach itself. Approaches based on decades-old data (e.g., soils) or on inappropriate applications of methods and sub-models (e.g., curve numbers, TR-55) may yield erroneous results (Garen and Moore 2005, Walter et al. 2007). Two projects from the RCWP – Highland Silver Lake (IL) and Garvin Brook (MN), used modeling to help identify critical areas. Unfortunately, the models used by these projects could not represent the landscape adequately nor could they simulate water quality conditions accurately. Modeling for Highland Silver Lake indicated that highly erosive lands were the critical areas, but the water quality problem was caused primarily by natric soils problems (Gale et al. 1993). Critical area modeling for the Garvin Brook project was of limited value because groundwater, a significant source of the pollutants of concern, was not addressed by the model used. These experiences underline the need for full documentation of the model and full understanding of the utility of information generated by models.

Models are often said to be more accurate in a relative sense than in an absolute sense, for example providing information on the comparative magnitude of pollutant load among several alternative scenarios, rather than giving valid quantitative load estimates. However, if differences between model predictions and measured loads are nonlinear, then even relative magnitudes may be inaccurate. Thus, model results require analysis and interpretation to be used for improving problem definition and for aiding decision-making. Models assist, but do not replace, planning.

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Finally, while models can help guide monitoring, use of models cannot replace monitoring, especially for project evaluation. The most convincing evidence of watershed project effectiveness is actual measurement of conditions in the watershed and receiving waters.

INTEGRATING MONITORING AND MODELING

Despite some strong feelings expressed in debate on the relative merits of monitoring and modeling in watershed projects, the two approaches are clearly not mutually exclusive. Each tool has strengths and weaknesses, and neither by itself can usually provide all of the information needed for water quality decision-making.

The first evidence of water quality impairment is typically based not on a model but on monitoring data, whether those data are simple observations of an algae bloom or ten years of pollutant concentration data. Similarly, the best evidence of water quality restoration is gathered through monitoring. At the same time, we cannot afford to monitor everywhere, so models can be used to extend and apply the knowledge gained through monitoring. Models are essential to forecast future response to alternative management measures because we cannot afford to wait for decades to observe which of our choices yield the best results. Although challenging on a limited budget, monitoring and modeling should be considered as complementary tools that can aid in the planning, implementation, and evaluation of watershed projects.

Models reflect an understanding of the processes involved in pollution generation from nonpoint sources. In a general sense, a model is founded on some level of monitoring data and a model is an important tool to assemble, express, and test the current state of understanding of the processes involved in pollution generation, fate, and transport from nonpoint sources. Evaluation of modeling results – including activities like validation and sensitivity analysis – can guide monitoring efforts that provide essential information about the system and at the same time contribute to further evolution of models.

Poor design and execution of monitoring programs can impair the ability of monitoring programs to meet objectives (Reid 2001). The nature and quality of data are limiting factors in modeling, as well. As shown in the RCWP (Gale et al. 1993) the choice of scale at which modeling can take place is limited to large degree by availability of appropriate data. Another challenge is the suitability or appropriateness of acceptable data that are consistently collected and available cross the entire landscape of interest. In many watershed programs, for example, the accuracy and consistency of spatial documentation of implemented BMPs is insufficient to adequately model their impacts at the watershed level. BMPs implemented through the Conservation Reserve and Environmental Quality Incentive Programs, for example, are typically reported on a polygon or 8-digit HUC basis, with more precise spatial location protected by confidentiality. Relating such data to water quality data is quite difficult. In large watershed efforts, such as work on Gulf hypoxia conditions, tributary pollutant loads may be well-documented through monitoring, but lack of adequate and consistent data coverage at local scales may hinder the calibration and interpretation of modeling efforts designed to identify sources of those pollutant

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loads. Thus, the availability of data at consistent scales and of known quality is essential to an integrated monitoring-modeling effort.

Models can be used develop timing and frequency of sampling programs for watershed projects. Applying a logic model to identify short and medium term outcomes of management actions, models can be used to establish a monitoring strategy based upon projected outcomes. Figure 1 provides an example of how integrated monitoring and modeling can be used in an urban setting to help address an excessive soil loss problem causing channel instability problems.

Monitoring and modeling can work together in a specific watershed project design. When an upstream-downstream monitoring approach collects water from a large drainage area upstream of the project site, it is may be difficult to detect small changes in water quality due to implementation of BMPs downstream against the background high loads coming from upstream. Modeling the upstream drainage area and using the upstream monitoring station data for model calibration would allows program managers to estimate the impact of the implemented BMPs based upon the monitoring data and modeling results. Additionally, program managers can estimate the potential value of addressing upstream sources.

The Sycamore Creek NNPSMP project concluded that the application of models to target nonpoint source control measures may be highly uncertain without the benefit of actual stream monitoring to verify results (Suppnick 1999). This conclusion was based on a finding that the estimated annual average suspended solids load was twice as high as measured load when monitoring data were combined with modeling, but higher by a factor of 8 to16 when modeling alone was used.

Monitoring data help define potential modeling outputs and puts modeling results in context of the watershed being managed. Adaptive management is a systematic process for continually improving management approaches by learning from the outcomes of the BMPs having been installed. Monitoring is entrenched in the watershed management process (Davenport 2003) because it begins and completes each of the four components:

1) defining the problem
2) setting goals and identifying solutions
3) implementing controls
4) measuring success and making adjustments

The ability of adaptive management to support good decision-making is directly dependent upon the quality of the monitoring program and being able to extrapolate its data to estimate the future impact of what is being implemented. The Chesapeake Bay Program is an example of an integrated iterative, goal-based inter agency watershed management program using adaptive management supported by both modeling and monitoring. Boesch et al. (2001) reported that progress toward reaching watershed goals has been tracked by an intensive monitoring program, with a comprehensive model used to guide monitoring and synthesize results.

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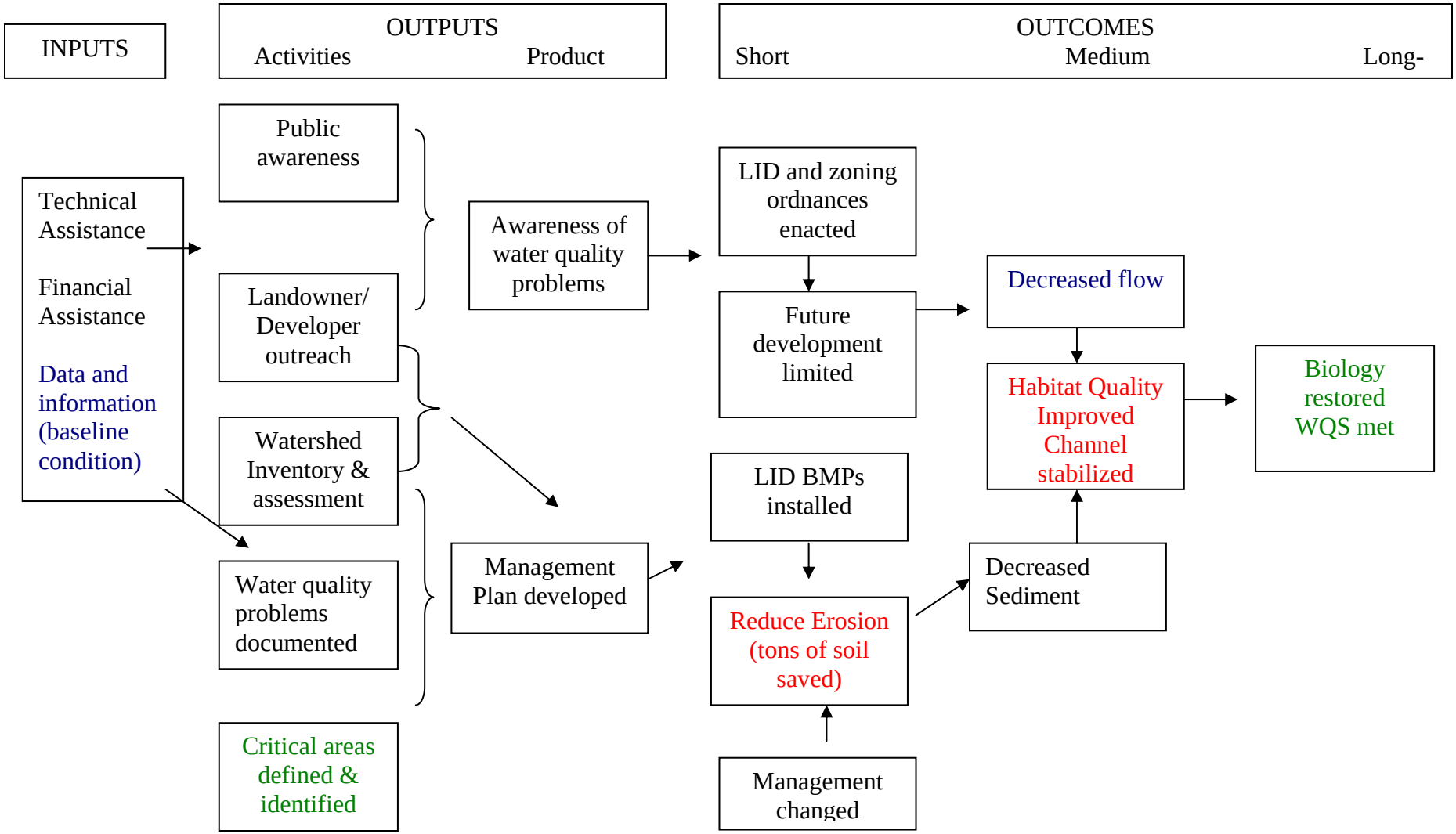
Figure 1. Logic Model. Low Impact Development (LID) channel stability example integrating modeling and monitoring (green) activities. Modeling (red) is used to help define critical areas and estimate how long until medium and long-term outcomes can be obtained. The monitoring (blue) strategy for sediment and flow strategy is based upon the model predictions.



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RECOMMENDATIONS

Neither monitoring nor modeling alone will work for most watershed projects. Both kinds of efforts are needed for effective watershed planning. Simulations and extrapolations cannot and must not replace on-the ground monitoring and inventory systems; however, modeling can provide crucial guidance on where and how the on-the-ground monitoring is best conducted. Monitoring cannot practically compare numerous alternative scenarios or extrapolate the effects of those scenarios far into the future; however, the data collected through monitoring is essential for calibration and validation of models.

Development of monitoring or modeling approaches should not be determined only by what resources are available to invest. This approach results in models being selected by cost and then determining what objectives can be achieved using the selected model and its results. Designing a monitoring program based solely on budget can result in collection of data that cannot serve project objectives because too few samples were collected infrequently. For both monitoring and modeling, begin with objectives and design the program to do what can be done well to meet those objectives. Commitment of sufficient resources upfront to the watershed program is required to produce the information needed.

Model use in watershed planning projects should always include a a model documentation plan (Davenport 2003) that includes:

1) Model name and version;
2) Source of model;
3) Purpose of model application;
4) Model assumptions. If any assumptions, such as those identified by Garen and Moore (2005), limit usability of the results from the application be listed and explained;
5) Data requirements and source of data sets; and
6) Uncertainty (confidence levels) of modeling results.

Targeting on the regional scale must be based on robust monitoring (Groffman et al. 2007). Efforts such as using SPARROW for identifying source areas of nutrients related to hypoxia need adequate and consistent data coverage to be successful.

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