Forestry
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Development

WORKING PAPER 4

Improving Water Quality Monitoring For Decision Making: A Plan of Action and Proposal for Implementation

by

James Perry, Hans Gregersen, Allen Lundgren,
Nels H. Troelstrup, Jr., and Charlie Blinn

December 1988

Forestry For Sustainable Development Program
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PREFACE

This is the fourth in a series of working papers produced for the Forestry For Sustainable Development (FFSD) Program at the University of Minnesota that represent work in progress. Their purpose is to stimulate discussion among individuals working in the field of interest.

The major objectives of the FFSD Program are to:

1. Improve the availability and usefulness of existing technical knowledge related to forestry for sustainable development - translate state-of-the-art scientific and technical information into practical and easily usable management guides and training materials that can be used effectively in planning and implementing development projects that will contribute to sustainable development; and

2. Improve the policy and organizational environment to encourage application of sustainability strategies - identify and develop effective institutional mechanisms, both at the policy and project levels, for introducing sustainability strategies into the development planning process at an early enough stage to influence project or program design.

The focus of the Program is on social forestry and related strategies within a watershed management framework as an integrating mechanism for moving toward sustainability in land use and in natural resource-based development projects. It involves an interdisciplinary group of faculty from the University of Minnesota, and associates at the University of Arizona, Yale University, Oxford University, the InterAmerican Development Bank, and other development groups. The FFSD Program is part of the University of Minnesota's Center for Natural Resource Policy and Management in the College of Natural Resources.

The FFSD Program is supported by a grant from The Pew Charitable Trusts, by the University of Minnesota's College of Natural Resources and Department of Forest Resources, by the Minnesota Agricultural Experiment Station under Projects 42-25, 42-40, and 42-49 of the McIntire-Stennis Cooperative Forestry Research Program, and by contributions from other organizations. Published as contribution no. 16,277 of the Minnesota Agricultural Experiment Station.

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EXECUTIVE SUMMARY

Water quality impacts from development activities can make a significant difference in the perception of success or failure of a project. Traditional monitoring programs to detect and manage those impacts are expensive, complex and difficult to use. We suggest that there is a need to develop simpler, more practical decision support tools that can be used to guide project managers in:

a) assessing and monitoring impacts of various development activities;
b) tracing a series of observed impacts back to probable causes;
c) identifying corrective actions (i.e., technical solutions) that would mitigate observed impacts; and
d) understanding the economic and social impacts of various technical solutions.

We suggest that assessments should use a series of integrative indicators developed specifically for water quality monitoring in a given region. Indicator variables would be based on practical, simple field techniques that are usable with the skills and technologies available, are readily interpretable and support defensible decision making. The variables should be packaged in field book and laptop computer formats that allow a user to pose questions about: likely water quality impact(s) of a development project, likely cause(s) of observed water impacts, most useful "minimum data set" representing a water quality monitoring design, and/or possible prescriptions for observed water quality impacts. Such prescriptions should also involve assessment of the economic and social impacts of suggested alternatives. That is, a monitoring design is not useful if it is too costly to implement, or if it presents technical solutions that are not politically or economically feasible. In all cases, the focus should be on practical tools that can be adopted and used under the economic and physical realities present in the region under consideration. That implies that the monitoring designs and tools must be economical as well as practical, and must be conceptually clear so that adoption by local management teams will be most likely. It further suggests that there are generic concepts and tools useful on a global basis, but that local/regional calibration will be required. Here we suggest that such models and tools be developed first in the Windward and Leeward Islands of the Eastern Caribbean as an example of the approach. Based on that exemplary application, the procedure for development of the package would be modified and adapted for use in other regions of the world.

IMPROVING WATER QUALITY MONITORING FOR DECISION MAKING:

A Plan of Action and Proposal for Implementation

James Perry, Hans Gregersen, Allen Lundgren,
Nels Troelstrup, Jr. and Charlie Blinn[1]

INTRODUCTION

Expanded production and consumption of goods and services can help increase the welfare of the urban and rural poor in developing countries. Sustaining such expanded production over time requires protection of the natural resource base upon which the production depends. A need to recognize that production-protection relationship underlies the concept of sustainable development.

Moving more toward sustainable development (or away from nonsustainable development) requires, in many cases, major policy adjustments that set the stage for "production with protection." However, as Warford (1987) has pointed out, success also depends on the very specific, local actions of the millions of individuals who produce and consume resource-based goods and services. National level policy and local level action are requisite partners; neither alone can solve the problems of nonsustainable development. Recognition of that linkage provides one of the major philosophical underpinnings of the Forestry For Sustainable Development program (FFSD) (Gregersen and Lundgren 1987).

Sustainability issues are being discussed actively around the world. Many of those discussions are focused on the local level, action side of the equation. One of the major concerns of the FFSD program in this area is to identify ways we can take the most sophisticated technological and scientific knowledge available and turn it into simple, practical tools for local action to increase the sustainability of human welfare on the ground. The FFSD effort involves developing the tools themselves and then linking them to broader policy intervention to ensure that the tools are effectively and widely used. It does little good to have an effective tool available for identifying, for example, emerging water quality problems if the policy environment and means for using that knowledge are lacking.

This paper suggests a three stage approach to developing effective local level action to avoid or reduce nonsustainability elements in development programs. The first stage involves development of monitoring tools that provide us with early warning signals when elements of nonsustainability are developing. The second stage involves development of a practical means for determining the causes of observed changes and how those causes can be addressed through technical prescriptions. The final stage in the overall approach involves adaptation and choice of technical options in light of the existing policy environment, the existing economic and social conditions which shape the problems being addressed, and the potential for changes in both the policy and social-economic conditions.

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Although the approach suggested here could be applied to any environmental quality issue area, the specific focus in this discussion is on water quality changes. In current practice water quality is considered a component of development only when problems require attention. For example, a significant change in public health, or problems with operation and maintenance of a public water supply, result in interventions to treat those specific problems. In order to reduce the nonsustainability of development efforts, water quality issues must be addressed in such a way that linkages between upstream development impacts and downstream water management are well understood.

Changes in land use in a watershed frequently result in significant water quality impacts downstream (e.g., to a fishery, a water supply, an irrigation system or a coastal zone). In some cases such changes represent acceptable costs of development (i.e., impacts are not always unacceptable). However, development conducted without awareness of impacts is not acceptable. Sustainable development involves conscious decision-making where alternative courses of action and their impacts are weighed against each other.

The current failure to incorporate water quality considerations into many development projects results in a reduced ability to sustain downstream uses, and in a long term degradation of the environment (e.g., loss of diversity, reductions in fishery productivity, loss of soil nutrient reserves). Those impacts now come as surprises to management agencies, usually at a place and time far removed from the specific project. We suggest that incorporation of water quality considerations into design, assessment, management and evaluation phases of a project will avert those surprises.

Many recently developed water quality monitoring designs attempt to incorporate new technologies and tools that are beyond the need (and resources) of local managers in developing countries (Perry and Blinn 1987). As these designs generally attempt to address all concerns simultaneously and try to make large advances all at once, they frequently overwhelm the absorptive capacity of local managers and technicians dealing with water quality issues (Gladwell 1986, Hollick 1986). What is needed are incremental advances that realistically can be absorbed into existing management systems, given the political and economic realities surrounding such systems.

The point to emphasize is that significant improvements in local water quality management can be made by incremental changes in current operations supported by enlightened policies. Evolutionary rather than revolutionary changes in management are needed. This is the only politically realistic way to approach water quality management problems (Gross 1986). If we can provide managers with easily used tools that relate development activities to water quality impacts over time, and with monitoring variables that allow those impacts to be detected early enough for action, it can make their work much more effective (Ruddle and Rondinelli 1981, Smith 1987).

A SUGGESTED APPROACH

In sum, the approach suggested here involves: 1) development of simple, practical methods of generating information on actual or potential water quality problems; 2) identification of links between such information and cost effective means of correcting existing problems and avoiding potential problems; and 3) ways in which policy level activity can be linked more effectively to local level actions. The general structure of the approach could be developed and applied anywhere. However, the specifics of the system developed would vary with the environmental, political and economic conditions encountered.

To make our suggestions more concrete, we have chosen to illustrate the approach with the specific conditions of the Caribbean Region as an example. This region was chosen for several reasons, including our own current involvement there. Our awareness of the water quality issues of concern to managers in the Region has arisen through our work in the Eastern Caribbean during the last two years (Perry and Blinn 1987, Blinn and Perry 1988). In that work, which was supported by the United States Agency for International Development through the Caribbean Agricultural Extension Program (CAEP), we have attempted to increase the role of data in policy level decision making.

During our travels in the region, we have discussed water quality data management and the need for more practical water quality monitoring designs with many local and regional managers. Common responses to the question "What are the key issues?" include the following (after Perry and Blinn 1987):

. there is not enough useful information upon which to base decisions
. additional data collection is very expensive
. no one seems to know what happened to the data that were collected by the last monitoring effort.

There is agreement that: 1) a definite need exists for practical, simple field methods that are widely applicable (Perry et al. 1986); 2) those methods must be useful with the skills, technologies and data currently available in the Region (Gladwell 1986); and 3) those methods must provide results that readily can be interpreted and defended, within a reasonable cost (Carpenter 1981).

We have found that oftentimes policies are made, and priorities are set, with very little data input. Data sets are often collected with little regard for the policy level questions that led to the development of the data collection effort (Elmendorf and Buckles 1980, Huffschmidt 1985). Individuals setting priorities, establishing policies and collecting data are very interested in increasing this data-policy or macro-micro linkage. However, they feel that they lack the tools for such a linkage (Smith 1987, Walther 1987). Our initial efforts have been directed toward development of data base management systems that will allow people to make better use of existing data (Perry and Blinn 1987, Kritayakirana 1987).

The need for improved, practical water quality indicators and management tools in the Caribbean Region also has been indicated by others (e.g., Herricks et al. 1986, Bowonder 1985). A brief summary of the existing problems in the Region are presented below before we discuss the specific approach we suggest be developed for dealing with the problems.

Water Quality Management Problems in the Caribbean

The nations of the Caribbean and Central America are experiencing rapid population growth, an expanding tourist trade, and increasing pressures on natural resources (Anon. 1987, Lackhan 1984). Coastal and inland water quality is one of the most significant resources in the Region. As a result of increasing land use pressures, water quality has been severely impacted (Watts 1988, Perry and Blinn 1987). Although many development projects include a focus on water quality management, the short term improvements in water quality produced by such projects have not been sustainable. Thus water quality problems in the Region remain unresolved.

Many people in the Region do not have access to safe drinking water or sanitation (Feacham 1975, Falkenmark et al. 1987). In addition, the economic base of the Region is centered around two competing components: 1) the tourism industry, which relies upon clean water, safe beaches, and attractive coastal zones; and 2) agriculture, light industry, and food processing which rely upon consumptive uses of natural resources and, in turn, impact water quality. Those two elements are often in conflict; as a result, governments have to resolve disputes regarding "acceptable" versus "unacceptable" changes in water quality and disputes regarding the source of various impacts. One of the areas most severely impacted is the coastal zone, which receives both surface and groundwater from the interior, has been subject to intense development, and serves as the interface with the sea. Yet that area has received relatively little attention from people in relating human activity to ecosystem impact (Watts 1988).

The economic activities described above adversely affect downstream water quality through increases in sedimentation, toxic materials, bacteriological contamination from sources such as tourism, agriculture, light industry, as well as in many other ways. These water quality impacts threaten public water supplies (Feacham 1975), reduce irrigation water quantity and quality (Annis and Cox 1982), threaten the integrity and stability of the offshore reef and the fishery (Saejis et al. 1986), and cause loss of biotic diversity in streams, rivers, ponds, and nearshore areas (Dasmann 1985). Solutions to these problems exist now. Unfortunately the solutions are not implemented because decision-makers often are unaware of the extent and magnitude of the problems, and are not aware that solutions are available. There is thus a need for monitoring programs to detect and report impacts, as well as for tools useful in developing prescriptions to mitigate impacts (Anderson 1988, Blinn and Perry 1988).

Any monitoring efforts and/or tools oriented toward prescriptions for the Region must consider long term, delayed and cumulative effects. Many of the actions taken on the land surface today will have significant effects that occur at some remote location (e.g., downstream or off-site), or that are only detectable after some period of time (Working Group on Watershed Management and Development 1988). For example, impacts such as reservoirs filled with sediment, depleted soil nutrient banks or reduced productivity of the aquatic resource may be both cumulative and delayed. Impacts such as a failure to sustain given levels of productivity within a cropping system, or nonsustainability of an institutional mechanism for development, represent long-term changes that will not be immediately apparent, but may emerge gradually over a long time period. In this latter case development activities may appear successful at the time of completion but later prove to be nonsustainable. Monitoring designs, and tools for improving sustainability have traditionally been weak in assessing these long-term, cumulative, and delayed effects (Perry and Dixon 1986).

In sum, resource managers and governmental agents in the Region need to understand better the relationships between development activity and ultimate use of water resources affected by such a development. They need a practical method to measure impacts of alternative practices, using available skills and technologies. If we can provide managers with easily used tools that relate development activities to water quality impacts over time, and with monitoring variables that allow those impacts to be detected early enough for action, resource management in the Region can be improved significantly (Ruddle and Rondinelli 1981, Smith 1987).

A Model for Water Quality Assessment, Monitoring, and Evaluation

A set of indicators and tools to meet the needs of resource managers and government agencies in the Region is needed (Herricks et al. 1986, Bowonder 1985). This should include a set of field guidelines that will allow managers to quantitatively address three issues for different areas and conditions within the Region: 1) What are the likely extent and severity of water quality impacts from specific land use alternatives?; 2) What are the likely causes of specific, observed water quality impacts?; and 3) What variables represent the "minimum data set" that should be employed in monitoring an environment or a specific development activity through time?

These guidelines should include: a) a calibrated set of quantitative water quality **indicator variables** that will facilitate economical, defensible decisions; b) field-book and laptop-computer based water quality **monitoring and data management guides** that will assist users in applying those indicator variables and encourage improved data storage and data analysis; and c) a **training package** presented throughout the Caribbean so people will be able to use the tools and programs developed.

Relationships among development action, impairment of human use of the water resource, and monitoring variables can be described in the form of a model (Dixon and Perry 1986a, Wright and Greene 1987). In such a model, there is a series of formal or informal development activities (e.g., road building, land clearing for agriculture) on one level, and a series of human uses of water affected by such activities at another level. The interior of the model consists of a series of detectable changes in the environment. Thus, there is a chain of events that leads from development activity to impairment of human use, and there are discrete "markers" along that chain. If we measure an appropriate set of markers, we can identify causes (e.g., some development activity) and identify present or anticipated impairment in human use of the resource (Perry et al. 1985, 1987; Perry and Troelstrup 1988).

Such a model, if quantified and calibrated for a given area, would allow a user to pose questions about a development activity, to estimate its potential environmental effects and to identify the indicators which could be used most effectively to monitor those effects. Similarly, a user could pose questions about observed effects and their causes, and derive information about the variables that need to be measured in order to detect or isolate those causes. Finally, a user could select a subset of variables in the center of the model to be monitored for assessing over time changes in the relationships among any set of development activities and environmental effects.

Watershed management is the science and art of addressing numerous biophysical and sociocultural variables in an integrated approach, and doing so in the context of a landscape unit (i.e., a watershed). Gregersen at al. (1987) have presented a graphic illustration of some of the interactions inherent in a watershed management approach (Figure 1). The figure illustrates the complexities involved in understanding economic and environmental impacts of a development project.

We have selected a subset of the Gregersen et al. (1987) model to illustrate the role that water quality can play in an activity (Figure 2). The model in Figure 2 suggests that removal of forest cover and increased agricultural production can have many effects, one of which may be increased exposure of the soil surface. Exposed soil may lead (among other things) to increased erosion and increased delivery of sediment to the stream channel. The increased sediment would increase turbidity, and would (among other things) decrease capacity of the

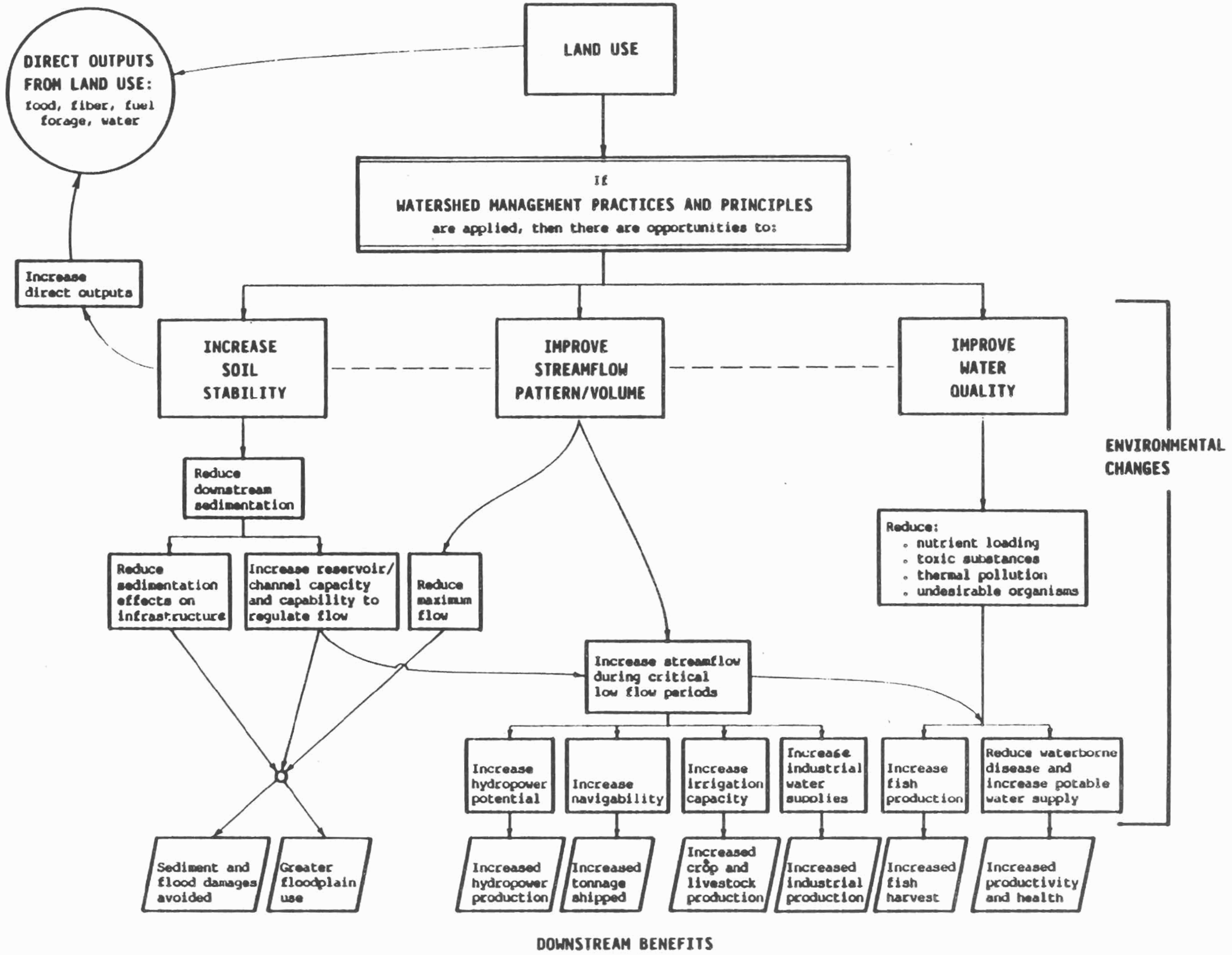

Figure 1. *Environmental changes and downstream benefits from watershed management (modified from Gregersen, Brooks, Dixon, and Hamilton. 1987. Guidelines for the economic appraisal of watershed management projects. FAO Conservation Guide No. 16. Rome.*

public water supply and increase the rate at which water supply collection facilities have to be cleaned. Thus a relationship can be identified between forest and agricultural land use, and public water supply quantity and quality. These types of relationships are neither new nor unknown (Perry and Dixon 1986, Dixon and Perry 1986b, Najaran et al. 1986). What remains is to calibrate the relationships for the Caribbean-Central American Region, and package that information into a form that is readily usable by field practitioners.

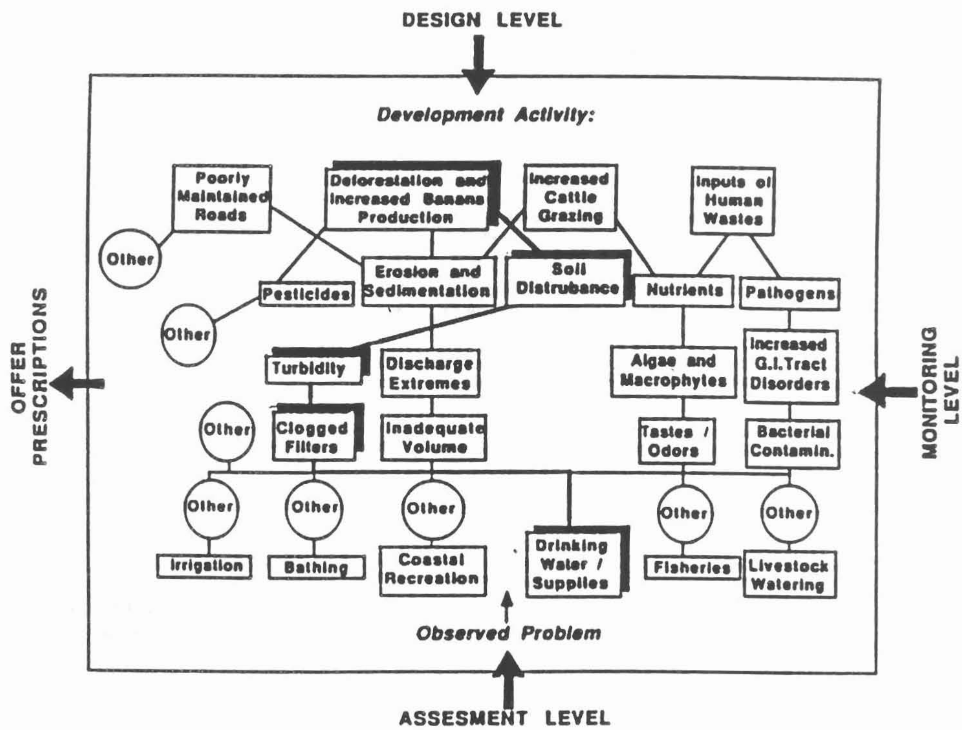

Figure 2. Format of a model for understanding water quality impacts. Model may be used to guide **project design**, to design **water quality monitoring** programs, or to **assess water quality problems**. A product of the model is identification of potential **prescriptions** for mitigating unacceptable water quality conditions. Highlighted path is shown in more detail in Figure 3.

In Figure 3 we have detailed one set of linkages in one chain indicated in Figure 2 to show the development of indicator variables. A user could enter the chain at any of three points (assessment, monitoring, or design). In each case there are a series of linked steps that follow throughout the model. Each development activity is associated with specific monitoring markers and specific environmental impacts that might occur. Similarly, monitoring results lead clearly to one or more potential causes and to clear suggestions of potential significance. Observed changes in the environment (i.e., a water quality impact) are then tied to a series of suggested prescriptions that could be considered.

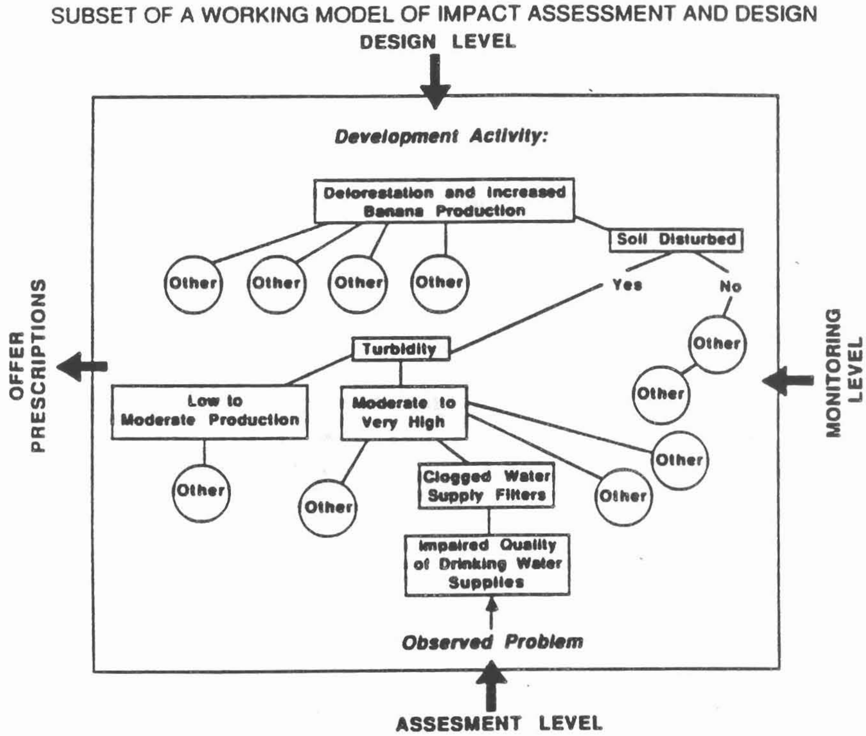

Figure 3. Detail of one pathway of a water quality assessment model. An activity (e.g., deforestation) produces several impacts, including soil disturbance. Soil disturbance produces several observable responses including increased turbidity, which in turn may impair drinking water supplies. Model would include avenues to potential prescriptions. "Other" implies linkages to additional components of the model.

Actions Needed to Make the Model Operational

We suggest that it would be productive for resource management agencies to use an approach similar to that in Figure 2 to begin analyses of water quality issues. The calibrated model would be presented in field book and computerized format. Initially a user would follow the model format to identify the development activities and water resource uses most commonly encountered and/or the ones most significant to the water quality concerns of his or her region. We recognize that the issues, the resources, and the technologies may be specific to specific countries within the Caribbean Region (Ruttan 1986, Zuleta 1986, Chapman 1985, 1987). However the types of problems being encountered, and the tools and techniques needed to address those problems have a generic component (Walther 1987). The basic principle we suggest following is that each development activity has its own unique set of attributes or markers that describe the ways in which it impacts water quality under given conditions. That unique set of attributes can form the basis of the field book and the modelling approaches developed.

The basic strategy we suggest is to develop a catalog of the most common and/or most significant (from the standpoint of water quality impairment) land use practices and development activities in the Region, and then to develop a draft set of indicators for each. That catalog would be developed on the basis of interviews with development agencies and working counterparts in the Region, on-site reviews and the literature. The catalog of development activities and their potential effects would be calibrated to incorporate local and subregional variations in climatic, topographic and geologic conditions. For example the effects of development activities would be expected to be similar within, but differ between, classes such as windward versus leeward islands versus the mainland. Erosion and surface water concerns will be critical on steep lands such as St. Lucia, Grenada or Dominica. Groundwater quality and quantity will be of more concern in flatter, more coralline areas such as Antigua or Barbados. The identified attributes or markers would then be calibrated through field work in the streams, rivers, reservoirs, ponds, groundwaters, and coasts of the Region.

In this particular example relationships would have to be established between: a) a series of typical development activities conducted in the Caribbean; b) a series of problems (impaired uses) that may occur as a result of those activities; c) a series of indicators that could be measured and interpreted by development agents in the field; and d) prescriptions that could be implemented to minimize or mitigate the effects of certain practices. This catalog of uses and relationships would then be packaged in a framework based on an expanded version of Figure 2, including the kinds of details suggested in Figure 3.

The package would be built into a loose-leaf notebook for use in the field. An expanded version of the package also would be built for use on inexpensive laptop computers, since these computers are becoming practical and useful tools in field management situations. In field use, a user might initiate interaction with the model at any of three levels: design, monitoring, or assessment. Outputs from such use might include suggested monitoring designs, identification of likely causes of observed problems, or likely downstream implications of an observed problem. Outputs could also include suggested prescriptions to resolve problems or mitigate impacts. An example describing those uses of the model is presented later.

We suggest development of preliminary versions of indicator variables based on literature estimates. Those variables would be calibrated based on the catalog of development activities important to the Caribbean Region. Full calibration of these tools in all countries in the Region would be a very large effort. Therefore we suggest that initial calibrations be conducted in several watersheds on each of two landscape types in the Region: a Windward island (e.g., St. Vincent, St. Lucia or Grenada), and an island with Leeward characteristics (e.g., Antigua, Montseraat or Barbados). If the approach proves to be useful and effective, it could be expanded at a later date.

ANTICIPATED OUTPUTS FROM THE APPROACH SUGGESTED

The final products suggested for development are:

1) A catalog of common/significant development activities;

2) A unique set of simple, quantitative indicators (i.e., markers) describing the detectable water quality effects of each of those activities;

3) A catalog of relationships between activities, markers, and human uses of the water resource;

4) A tabulation of the social and economic significance of various water quality impacts in the Eastern Caribbean Region;

5) A catalog of prescriptions available for mitigating or averting specific water quality impacts in the Region, each with an attendant level of economic and social significance;

6) A field book format that facilitates tracing activity to effect, tracing effect to cause, or in designing an appropriate water quality monitoring strategy;

7) A lap-top computer version of the field book that allows users to consider a wider range of options;

8) Examples from several watersheds in each of two Eastern Caribbean locales (i.e., Windward and Leeward islands); and

9) A series of training sessions in the Region to present the tools and describe their use.

EXAMPLES OF THE USE OF THE PRODUCTS SUGGESTED IN THIS PAPER

The following three scenarios represent alternative ways a manager might wish to use the products suggested here (based on Figure 2).

A. Project Design Level

In this scenario an individual may be interested in designing a development activity and want to assess the potential water quality impacts. The following example of a development activity to convert native forest land to banana and root crop production illustrates the steps to be followed in the approach:

1. Characterize the nature, extent and duration of the activity

The model would require that the development activity be described in some detail. For example: "The watershed in question is a steep, south-facing, 500 ha system on St. Lucia, dominated by native trees. We will remove 80% of the forest cover using chain saws, axes and hand labor. Trees will be winched down to a road in the valley, and sold on the commercial market. The remaining land will be cleared by hand. Bananas will be planted on a specific spacing (i.e., 3 m) and a root crop (dasheen) will be inter-cropped. Vegetation will be removed from approximately 50% of the land surface; a vegetative cover will return within 90 days. The banana and root crops will be harvested about every 9 months. During harvest of the root crops the soil surface will remain bare for about 30 days."

2. Characterize the water resource:

The model would ask a series of questions to obtain more complete information about topography, rainfall, soil type, distance from bottom of plot to stream, distance from plot to water supply intake, intensity of pesticide and fertilizer use, extent and severity of land use change, and other information required for evaluating alternatives. Some information would not have to be entered. For example, certain climatic characteristics may be sufficiently uniform that, once a user specifies a class of system (e.g., a Windward island) the model calibration data may be able to provide default choices that the user could then accept or modify. The user would have the option of saying that some information was not available. In those cases, certain aspects of the evaluation would not be as precise as they could be if additional information were available. These areas might be flagged for further research.

3. Monitoring variables:

Based on the answers to the questions in (2), the model would select the variables to be monitored, and suggest the frequency of monitoring. That is, the model would present the "what, when and where" of monitoring. Additional information in an appendix (of the field book) or on a help-screen (of the computer) would also be available to present the "how" of monitoring, if desired. These variables would be measured after project implementation, and would be designed as "early warning signals" to alert managers to impending problems following project implementation. These variables are the water quality indicators of nonsustainability that we suggest be developed (Gregersen et al. 1987, Brown et al. 1987).

As an example, there may be a suggestion that water transparency and settleable solids be measured at the entrance to a canal system after every major storm, or that stream banks be examined for signs of recent erosion on a schedule of every three months, or that specific sensitive biological indicators of water quality be measured monthly at stations above and below a development project, as well as above the intake of a public water supply.

If users were not familiar with the monitoring variables, they would have access to a series of detailed descriptions to describe the collection and analytical methods for suggested variables. It should be stressed that we are striving not for the most scientifically sophisticated methods, but instead for practical tools that actually can be adopted and used under the economic, technical, and physical conditions present.

It is not possible at this stage of the development to discuss variables and methods in detail since they would be developed in a specific project. However, as an example, sediment transported in a stream might be seen to be a valuable indicator. The methods section would present a brief paragraph about the goals and objectives of a sediment measurement in order to give the user a clear idea of what he or she is trying to measure. Then paragraphs would be presented that described the simple measuring tool(s) needed, the use of it (them) in the field, example data sheets for tabulating field results or recording field information, and comments on how to determine what samples to take, in what way, and over what time frame. Additional information would be presented later that would assist in interpretation of the results of these samples after the data had been collected.

If a given individual were using the laptop computer version of the package, they could return to this element of the program and enter their field results. That would then allow interaction with the model to assist in interpretation. For example, a user may report that turbidity was very high after the storm, and there were 4 instances of bank erosion in a 500 meter reach. The model would then offer comments on potential significance to downstream users, such as increased likelihood of clogging drinking water filters and potential impact on stream fish populations. In our example, the model might also suggest that the results are: (a) probably very significant for the water supply intake; (b) only marginally significant to offshore coral reef habitats; and (c) probably not of significance to soil productivity within the banana plantation. Then it might further suggest that additional monitoring is needed, and would specify variables, locations and frequencies.

Through the long term this component of the model would lead toward development of an "expert system" for water quality management. The idea of an expert system is that the practical experience of several individuals can be incorporated into a series of decision-making rules. People make decisions by comparing the current situation to a series of alternatives, and to an historical experience base. In an expert system, a computer is equipped to offer decision-making guidance in the same way that humans act. In our example, the significance of different levels of a contaminant, or the contamination resulting from a development action, would be entered into a data base. That data base would then serve as the historical record for future decision-making. Although this expert system component of the program can be both powerful and informative, it requires extensive calibration and experience. Therefore, we regard development of this part of the program as a long term activity. More immediate products will include the straight-forward field book and lap-top computer tools described earlier.

4. Technical Prescriptions

At this stage the user would have access to a series of suggested technical prescriptions (management practices and/or mitigating techniques) that may be useful in controlling impacts. Given the watershed characteristics, the development activities being conducted, and the water quality impacts, the model would then offer a series of corrective actions or prescriptions that could play some role in correcting the observed or anticipated problems. As wide a variety of prescriptions as possible would be presented so that the most appropriate ones could be further evaluated. Examples of prescriptions might include stream-side buffer strips of specified width and nature, terraces in the watershed, grassed waterways, altered drainage patterns, leaving green vegetation on the watershed for longer periods of time or in different spatial or temporal patterns, harvesting and planting at different times of the year to take advantage of rainy and dry spells. In another case the level of pesticides being applied may fall outside the range of normal for the given conditions on this watershed in this country or region. That may be endangering downstream uses, so the model may suggest that reductions in pesticide use should be considered.

5. Economic and political implications

Finally there would be a component of the model that addresses institutional considerations. The preceding sections address development of technical options for monitoring water quality and for identifying specific water quality problems and the technical means of dealing with them. That is, we have addressed: 1) identification of actual water quality related problems or potential problems (as in the case of project design); 2) identification of likely causes of such problems; and 3) identification and design of technical solutions for dealing with those problems.

Once technical problems are well understood it is necessary to bring in the political, social and economic desirability of implementing alternative solutions (i.e., the institutional design for implementing solutions to water quality management problems as shown in the lower box of Figure 4). The usefulness of suggested technical solutions depends upon the extent to which they are adopted and used to develop improved water quality management. Such adoption depends in turn upon the political and economic contexts of the countries and institutions involved, and the extent to which technical solutions have benefits which exceed costs within those contexts. Costs and benefits must be presented in terms of the particular economic, political, and social realities found in the country or region involved.

In this framework an analysis would draw heavily upon the work already completed in relating water quality to health and other measures of welfare. Thus, much of this final component will consist of adapting existing social, economic and political analytical models (c.f., Gregersen et al. 1987; Gregersen and Contreras 1979) for application to the specific watershed characteristics and institutional setting being examined.

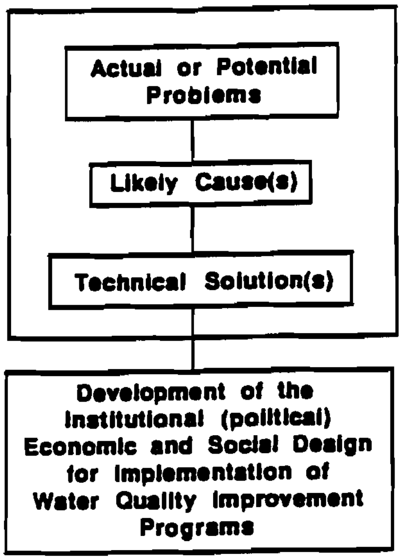

Figure 4. Overall structure of the water quality assessment procedures suggested here. Problems are traced to likely causes, and potential solutions are identified. However, problems and solutions are described in the context of economic, social and institutional costs. Monitoring designs, or technical prescriptions that are economically, socially or institutionally impractical have limited (if any) use in resolving water quality issues.

B. Monitoring Level

In this case, a user may wish to conduct an ongoing assessment of land use practices and water uses, in order to guard against the occurrence of unforseen problems. Here the procedure would be:

1. Characterize the watershed(s):

The model would ask a series of questions such as those in A.2. above.

2. Characterize the uses of the water resource:

The model would ask a series of questions about the ways that people use the water resource.

3. Measurement variables/monitoring design guidance:

The model would suggest certain variables and frequencies for measurement, and would allow data storage and preliminary analysis, as in A.3. above.

C. Problem Assessment Level

In this case, a user may have one or more reported problems on the watershed, usually reported in terms of impaired uses. For example, there may be tastes or odors in the water supply, bacterial contamination problems reported by the Health Department, inadequate water volume, reports of offshore fish kills in or near estuaries, or accumulation of sediment in water-plant settling tanks. In this section the questions lead to potential causes of the observed problems, and suggested prescriptions. The steps to be followed in this case would be:

1. Characterize the uses of the water resource:

Similar to B.2. above.

2. Characterize the problems reported from the watershed:

The user would respond to a series of menus representing water resource problems.

3. Characterize the watershed(s):

The model would ask questions like those in A.2., but the questions would be limited to those necessary to draw conclusions about the specified uses.

4. Monitoring and measurement suggestions:

Initially the model would ask a series of questions intended to take the user from the bottom of Figure 2 to the top. If the user were able to answer all the questions, one or more suggested causal land use practices would be presented. The user would then have access to a dictionary of prescriptions, as listed in A.4.

If the user were unable to answer the questions, the model would suggest a data collection program, similar to that described in B.3.

CONCLUSIONS: AN AGENDA FOR ACTION

Water quality is a highly valuable, and severely impacted resource in the Caribbean Region. Knowledge and techniques to reduce impacts are currently available. However, solutions remain difficult or impossible to implement because of limitations in monitoring and assessment programs, among other things.

The concepts and procedures suggested in this paper represent the first steps in attaining solutions to water quality problems in the Caribbean Region. We have presented guidelines and suggestions for resolving the limitations in monitoring and assessment, including attention to economic impacts of current and alternative practices. The following steps would accomplish the goals and objectives outlined here:

1. Develop a catalog to describe development activities in the Caribbean Region. For each significant activity, the catalog should address potential water quality impacts and local climatic, topographic, geologic and social-institutional variables that are expected to influence those impacts. The catalog should be automated to facilitate retrieval and analysis, and to increase its utility in the following steps.

2. Conduct a review to identify candidate indicators of nonsustainability that might have value in assessing and monitoring the impacts identified in Step 1. Both biophysical and socio-economic indicators of response must be identified. The socio-economic indicators should be responsive to economic and biophysical implications of alternative management

practices. In addition, indicators and monitoring/assessment programs must be economically defensible so they can be incorporated effectively into project development activities.

3. Field test the draft indicators derived in Step 2. Tests should be conducted throughout the Region to isolate monitoring and assessment variables that have the most potential for application by field managers working under Caribbean and Latin American bio-physical and socio-cultural conditions.

4. Based on Steps 1 and 3, develop relationships between water quality problems, indicator variables, and management prescriptions. This step will allow managers to identify problems and their causes, and then to identify likely management prescriptions to alleviate those problems. In this context, indicators must be developed such that they lead to one or few specific development activities as the likely causes of identified water quality problems. The available prescriptions must be presented in sufficient detail to allow the user to weigh the biophysical and economic implications of water quality problems and the desirability of alternative prescriptions available to alleviate those problems.

5. Package the indicators selected from Step 3, and the prescriptions selected from Step 4 into decision-making tools useful to field managers. These tools should be in the format of field-book and laptop-computer tools presented in such a way that they are readily useful in designing and implementing a monitoring program, and in guiding the interpretation of data that results from such a program. The emphasis in this step must be on developing tools that effectively meet the needs of field managers working with development projects in the Region.

6. Train users in the field in the use of these decision-analysis tools, and then monitor the performance of the tools. Through training programs, managers in the Region should become familiar with the operation of the tools. They should be encouraged to use the tools in developing monitoring and assessment programs and in interpreting results from those programs. Further, however, the performance of the tools themselves should be monitored, and the tools should be changed as necessary to ensure that they continue to meet the needs of managers in the field.

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APPENDIX

EXAMPLES OF RELEVANT LITERATURE

This series of literature citations provides an example of the material upon which such a project would draw. The list is not exhaustive, but is representative of the diversity and depth of literature available.

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