EPTD DISCUSSION PAPER NO. 73

MONITORING SYSTEMS FOR MANAGING NATURAL RESOURCES: ECONOMICS, INDICATORS AND ENVIRONMENTAL EXTERNALITIES IN A COSTA RICAN WATERSHED

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with contributions by

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ABSTRACT

The worsening degradation of natural resources urgently requires the adoption of more sustainable management practices. This need has led to growing interest and investment in monitoring systems for tracking the condition of natural resources. Although grounded in concepts of sustainability, the application of monitoring systems has progressed little beyond the identification and measurement of large numbers of potentially interesting indicators. Most monitoring activities are also passive and do not lead to the changes needed to rectify the problems they identify. Too often monitoring becomes an end in itself and an expensive claim on public funds. This study is concerned with the design of monitoring systems that have direct relevance for the management of natural resources. We call these Policy Relevant Monitoring Systems (PRMS). Such systems have several key characteristics. They provide: a) a decision framework for selecting resource problems to monitor that offer potentially large social payoffs relative to the costs of monitoring, b) timely, including early warning information on emerging problems, c) a means of identifying the causes of an emerging problem, d) an analytical framework for identifying options for corrective action, e) an institutional framework for achieving ownership among key stakeholders (the resource users and those affected by the resource use) and agreement about emerging problems, the corrective actions to take, and effective implementation, and f) a built-in mechanism for learning from past experience to improve the performance of the monitoring system over time. The design and implementation of a PRMS is complicated in reality by the presence of multiple resource users with often conflicting interests, and by the presence of environmental externalities. The approach is developed and illustrated through detailed examination of the Arenal-Tempisque watershed in Costa Rica. This watershed exhibits classic multiple user and externality problems: deforestation by dairy and cattle farmers in the upper watershed leads to soil erosion and siltation of the various reservoirs that feed an important hydro-electric power generation system, and agro-chemical use by irrigated farmers has adverse impacts on a highly valued wetlands park and on wildlife and fishing in the lower reaches of the watershed.

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MONITORING SYSTEMS FOR MANAGING NATURAL RESOURCES: ECONOMICS, INDICATORS AND ENVIRONMENTAL EXTERNALITIES IN A COSTA RICAN WATERSHED

1. INTRODUCTION

We live in a world in which increasing demands on natural resources are placing them under considerable stress, and their sustainable management has taken on new urgency if they are not to be severely and irreversibly degraded. Towards this end, there has been growing interest and investment in monitoring systems for tracking the condition of natural resources, both to measure the extent of degradation that has already occurred and as an aid to more sustainable management practices. Although grounded in concepts of sustainability, the application of monitoring systems has progressed little beyond the identification and measurement of large numbers of potentially interesting indicators. Moreover, most existing monitoring activities are passive and do not lead to the changes needed to rectify the problems they identify. Unfortunately, monitoring is not a costless activity, and public funds have to be used that have alternative uses (e.g. investments in schools, roads, and education). Monitoring can all too easily become an end in itself, particularly once it has been institutionalized.

This study is concerned with the design of monitoring systems that have direct functional relevance for the management of natural resources. We call these Policy Relevant Monitoring Systems (PRMS). If monitoring systems are to serve a viable social function, then priority should be given to monitoring environmental problems that offer a potentially large social payoff relative to the costs of monitoring. This requires a framework for identifying the important problems to monitor. Moreover, if monitoring systems are to lead to rectification of the environmental problems that are being monitored then they must be designed and operated in ways that lead to corrective actions amongst the key resource users. This requires not only timely, including early warning, information on emerging problems, but also a method of identifying appropriate corrective actions to take and an institutional framework for achieving agreement among key stakeholders for the effective implementation of corrective action.

The design and implementation of PRMS is complicated by the complexity of most natural resource management problems. Individual resources are components of complex ecosystems involving multiple resources, multiple users, and often spatially but functionally interconnected sub-systems within the full system. We use a detailed examination of the Arenal-Tempisque watershed in Costa Rica to illustrate the approach The lessons learned in this exercise, however, are much more widely applicable and can be applied to any situation where there are multiple actors (or stakeholders) and interactions between the various parts of the ecosystem. As economists, we focus on the economic ramifications of these interactions, but recognize that there may also be important social and institutional dimensions In fact, as shown by this study, any effective implementation of policies to correct problems, and to try to maximize net benefits from the system, has to deal with the social, political, and institutional setting.

Nevertheless, it is economic impacts that drive much of the analysis, and the system under study. Again, as economists we are interested in the goal of maximizing social welfare in the entire system, realizing that there are likely to be conflicts between individuals and different interest groups within any system. There are few solutions in the real world where all of those involved are better off. There are many solutions, however, where social welfare (the sum of all welfare in the system) is increased, and sometimes increased substantially, even if selected "actors" may suffer individual loss.

This situation—maximization of the welfare of the system with individual "winners" and "losers"—is very common It is precisely because of the existence of significant environmental externalities within the system that a system-wide approach is required. If each group or individual in the system merely follows their own welfare maximizing strategy, then total welfare will be less than it would be with the use of the more integrated approach illustrated here.

The Report

The approach presented here is commonly found in textbooks on resource management, and only rarely found in practice. Hence the decision was made to undertake an integrated study of one discrete watershed in Costa Rica where a number of different "actors"—resource users or those affected by the use of the resource are to be found. We chose the Arenal-Tempisque watershed because it has a number of attractive features. It is relatively small, it has multiple actors and types of resource use within it, and it mixes high-valued commercial activities (hydropower generation, irrigated rice cultivation) with more traditional agricultural uses and even protected areas, fishing and recreational uses in the lower reaches. In addition, the flow of water (and the power of gravity!) means that there are clear linear relationships between different user groups and the impact of activities on those located downstream.

Since information on the physical and economic impacts of different actions is key to the analytical, and management process, the study is based on how **data, information, and indicators**, can be used to link the different parts of the physical system, serve as a monitoring and early-warning tool, and help identify the magnitudes of potential impacts and appropriate corrective actions. Hence the use of the term Policy Relevant Monitoring System (PRMS).

A formal economic model links the different elements in the watershed, and a **Payoff Matrix** is developed that explicitly shows the economic impact on each individual group, and the impacts on others, of alternative resource management decisions. In fact, if the data and indicators are the raw material and basis of the analysis, the Payoff Matrix is the way that the pieces are brought together and formal trade-offs between different management options are most clearly illustrated.

The report consists of 8 chapters: Chapter 2 introduces the concept and basic elements of a Policy Relevant Monitoring System. Chapter 3 describes the Arenal-Tempisque watershed, the major actors, and the physical links through the ecosystem. A formal economic model of the system is developed and reported on in Chapter 4 (with details of the model in the Appendix), and preliminary results for different management scenarios are illustrated in Payoff Matrix form. The formal indicator system that helps to monitor what is happening, but also serve as an early warning system of potential problems, is introduced in Chapter 5. Finally, the institutional framework of the Arenal-Tempisque watershed is introduced in Chapter 6, along with a proposal for the kind of modified structure necessary to implement a PRMS. Chapter 7 applies the lessons learned in the specific case of the Arenal-Tempisque watershed, and illustrates how the PRMS might operate in practice. Chapter 8 discusses how the approach presented here could be applied to other settings, and points out the strengths (and shortcomings) of this approach.

A Final Note

This report is the result of a research effort to illustrate an approach and its application. It is not a complete study of (nor the definitive answer to) the management problems of the Arenal-Tempisque watershed. Such a study would require much more information on the individual actors in the watershed and the valuation of different externalities. Time and resources prevented the authors of this report carrying out that level of detailed fieldwork.

Rather, the results presented here should be considered as “realistic if sometimes synthetic” and, although they are based on the best information available, should not be used to make actual management decisions. The methodology employed, however, is robust and illustrates an approach that, properly calibrated and applied, offers real promise for the more sustainable management of natural resources, in Costa Rica and in other locations around the world. We believe that the latter is the real contribution of this research effort and this report.

2. POLICY RELEVANT MONITORING SYSTEMS FOR NATURAL RESOURCE MANAGEMENT

Ujjayant Chakravorty, John Dixon, Peter Hazell, Danièle Perrot-Maître, and Lisa Segnestam

THE NEED FOR A MONITORING SYSTEM

Sustainable development means making hard decisions on trade-offs between present and future use of natural resources, and conversion of some part of a country's resource endowment to other forms of capital. Often the process of economic development involves extraction and use of natural resources such as forests, water, and soil used to produce food, fiber, and other products needed for industrial use as well as for direct consumption. Over time, unless corrective steps are taken, the finite stock of natural resources or natural capital is constantly being depleted. For example, agricultural production can lead to soil erosion and depletion of micronutrients in the soil. Clearing of forest lands for farming and for timber are the most important causes of deforestation in the developing world.

Monitoring of these and other variables is an important part of resource management. Indicators serve a valuable function in measuring both the stocks (or quality) of resources, but also the rates of change of these measures. This information, in turn, is used to highlight potential problems, identify trade-offs, and make more informed decisions.

Another important reason for periodic monitoring of the state of natural resources in developing countries is the need for compliance with new international protocols, such as the international agreement on greenhouse gas emissions (Kyoto Protocol) and the Biodiversity Convention. For instance, under the Kyoto Protocol, there will be a need to systematically monitor land-use changes, estimate carbon sequestration by forest sinks and carbon emissions from a variety of sources including agriculture.

It has been said that we need to be able to measure something in order to manage it. Hence the importance of developing systems to measure, and monitor, a nation's resource stocks. The need for developing monitoring systems also ties in with recent efforts towards developing operational notions of "sustainability" and "sustainable development." Developing countries are constantly striving towards adopting economic development strategies that do not cause irreversible damage to their limited natural resource stocks while at the same time taking corrective measures for their protection. Projects for "sustainable" natural resource management are being undertaken at the national, regional and local levels by a range of agencies including international organizations, national and state governments, non-governmental organizations, and the private sector. However, the notion of sustainable development rests on an accurate estimation of the stock of natural capital (e.g. soil, trees, mineral resources) and an agreed upon rate of their depletion and conversion to "physical capital" (i.e., machines) or for human consumption. In this sense, current notions of "sustainability" cannot be operationalized without an effective monitoring of a nation's natural resources.

The concept of monitoring is not novel, and there are numerous studies in the literature, some of which will be reviewed below. Monitoring of natural resources is not a costless activity, and public funds that are used in this exercise have a high opportunity cost in alternative uses, such as in investments in education, transportation and other infrastructure services. However, most previous studies of monitoring have treated it as a costless activity which essentially involves collecting reams of data on the health of a country's natural resources, without any attempt at integrating the data collection exercise with policy analysis. These monitoring systems are "passive" and do not lead to any improvements in the problems they were designed to identify. This also creates the danger of monitoring becoming an end in itself, especially once the process has been institutionalized. Data collected is often not prioritized, leading to a high degree of irrelevant information that only serves to overload the information system.

If monitoring services are to serve a viable social function and to be adopted more widely, then they should be in a position to offer a potentially large social payoff relative to the costs of monitoring. Realizing favorable benefit/cost ratios is more likely if:

- The environmental problems selected for monitoring have high environmental or social costs if left unchecked.
- The monitoring system is designed and used in a way that leads to a correction of the environmental problems that are being monitored.

- The monitoring system is designed and operated so that it is cost effective.

The above suggests that this extended notion of a monitoring system implies that it is not only a periodic stock-taking of the state of natural resources, but provides an estimate of the relative costs of resource and environmental degradation. These costs must in turn be compared with some notion of benefits from possible policy interventions. While corrective policy actions may move the economy closer to its production possibility frontier and thus the aggregate benefits to the country as a whole may be positive, the welfare consequences may lead to an inequitable distribution of the benefits and costs. Certain stakeholders affected by the intervention may suffer a welfare loss, while others see a net gain, and the sum-total of these effects may still be positive. To be policy relevant, the monitoring system must be able to sort through these distributional implications and the associated political economy of environmental policies.

The monitoring system must be able to generate quantitative estimates of who loses and who gains. For example, if input restrictions on fertilizer use in a watershed improves water quality in the river basin and reduces the incidence of water-borne diseases in the downstream reaches, then it is clear that downstream water users may see a net welfare gain at the expense of upstream farmers. The monitoring system would not only provide estimates of the distributional consequences of such policies but also examine the viability of alternative compensation mechanisms that ensure participation by affected stakeholders in the design and implementation of corrective policies.

OBJECTIVES OF THE MONITORING SYSTEM

The policy relevant monitoring system (PRMS) proposed here has three primary objectives: It is *Informative* about changes in the condition of key natural resources. It should provide information about: a) what is changing; b) how it is changing; and, c) the timing of the change. Ideally, the monitoring system should give advance (or lead) warning about future changes. It is *Intelligent* in that it identifies the causes of change and suggests appropriate responses by key stakeholders for fixing the problem. And, it is *Interactive* and brings the key stakeholders together to: a) obtain consensus on the problems to be addressed, their causes and solutions; and, b) assign responsibilities for implementing the agreed solutions.

A monitoring system should thus function as an *early warning system,* and provide timely information on the state of natural resource stocks that generate opportunities for real time policy intervention. Degradation and depletion of resources is often reduced or prevented at a relatively low cost through timely action. In many instances, these biological processes, such as the extinction of important plant and animal species, are irreversible. Moreover, the impacts of resource degradation to the economy may be significant. Without a real time warning system, problems may be diagnosed with a costly time lag, and a consequently expensive process of analysis and policy formulation may need to be undertaken at a late stage.

The monitoring system is expected to *generate shadow prices* for different exhaustible and renewable resources, as well as for pollution from specific point and non-point sources. These shadow prices can then form the basis for comparison of policy choices and trade-offs and prioritizing between projects. The costs of local and global externalities to the country or within a specific region can be then determined using these accounting shadow prices. An indirect benefit is the valuation of environmental resources in order to incorporate them in the computation of Net National Product (Dasgupta and Maler, 1991). The generated resource shadow prices from policy modeling could be used to compute the social cost of resource degradation for the economy. These values in turn can be deducted from the GNP to obtain the NNP.

PREVIOUS RESEARCH ON MONITORING SYSTEMS

There exists a voluminous literature on the choice of indicators for sustainable development. Several alternative frameworks have been proposed. The theoretical discussion has focused on developing an analytical framework that begins by defining what sustainable development means in practice (Dasgupta and Maler, 1991; Dasgupta, 1993; Pearce, Atkinson and Dubourg, 1994). These writings have mostly focused on the choice of discount rates, inter-generational equity, and uncertainty issues. However, the focus of the operational literature has largely been on choice of monitoring indicators. Although most studies talk about the need for use of indicators in policy development as well as in sustainable management of natural resources, there is clearly a huge gap between the theory and its application in policy-making. Policy makers do not have a consistent set of operational tools for resource policy analysis and most analysis is performed on an ad hoc basis. Monitoring systems that are already in place have served as data collection efforts but without any systematic analysis of the data or involvement of stakeholders in data collection and in policy analysis and dialogue.

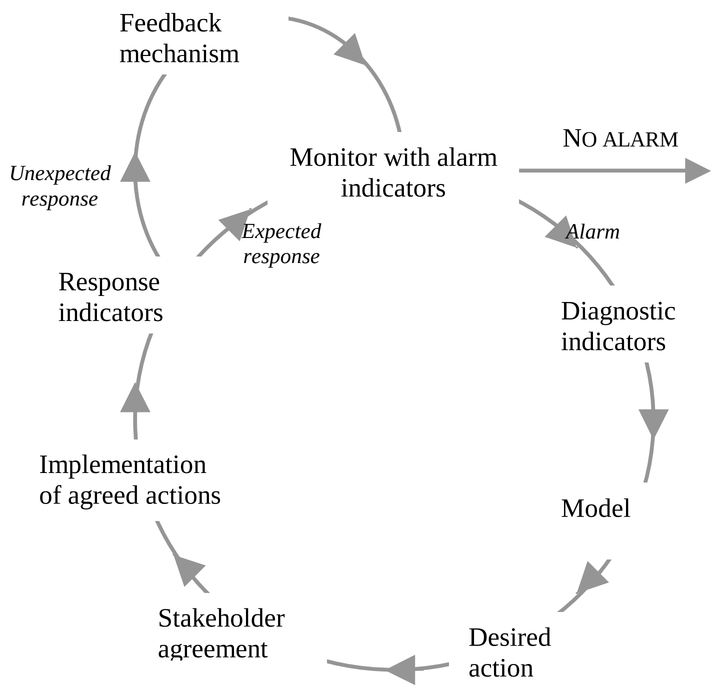
In previous operational work, the Pressure-State-Response (PSR) framework, originally popularized by the OECD, has been used extensively to develop monitoring system indicators (Hammond et. al, 1995). It involves three distinct sets of indicators that describe the state of the environment and natural resources (state indicators), causal factors (pressure indicators) and actions that affect the state of the system (response indicators). The framework relies on the premise that there is no unique set of indicators and that the appropriate set depends on the needs of different users of the monitoring system. This system focuses primarily on indicator development, which is only one aspect of the monitoring system proposed in this study.

OVERVIEW OF A POLICY RELEVANT MONITORING SYSTEM

In order to achieve the objectives of a policy relevant monitoring system, the monitoring system requires three major components. First, a set of *Indicators* for monitoring resource condition. Three types of indicators are suggested to help contain costs; *alarm* indicators, *diagnostic* indicators, and *response* indicators. Second, an *Analytical Framework* to provide a means of identifying the causes of an emerging problem and to evaluate alternative options for fixing it. Third, an *Institutional Framework* to a) manage the collection and analysis of monitoring data, b) maintain and operate the analytical framework (or model), c) provide a forum in which the different stakeholders can meet to resolve any disputes and to agree on the implementation of needed changes, and d) to monitor and assess the impact of agreed changes.

Figure 2.1 shows how all the various components would fit together in a proposed Policy Relevant Monitoring System (PRMS). It is assumed that a suitable institutional structure has been set in place to manage the monitoring system and to perform the roles identified above. At the top of the cycle are the alarm indicators. These give an early warning when a problem arises. If there is no alarm, then the monitoring agency continues to monitor on a routine basis. However, if an alarm indicator crosses a key threshold, then the monitoring agency activates a set of diagnostic indicators to enable more in-depth analysis of the causes of the alarm.

Figure 2.1—The operational cycle of the monitoring system and the role of indicators



Once information from the diagnostic indicators is available, this provides input into the analytical framework or model which is then used to evaluate the likely consequences and social and environmental costs of the problem, and to identify and evaluate appropriate corrective actions. The next step in the cycle calls for dialogue among the key stakeholders leading to an agreed plan of corrective action. The institutional structure plays a key role in promoting this dialogue, especially when there are conflicting interests among different stakeholders (e.g. when there are important environmental externalities).

Once a plan of corrective action has been agreed and implemented, then appropriate response indicators are activated to monitor its impact and to determine whether it has successfully corrected the initial problem. If the impact is successful, then the monitoring agency resorts back to the routine tracking of alarm indicators as a precaution against any future problems. But if the impact is not successful in correcting the problem then the monitoring agency engages in a learning process. This involves evaluating why the expected response did not occur and making any necessary corrections to the institutional structure, indicators, or model to avoid the same problem in the future.

We now discuss each of the components of a policy relevant monitoring system in more detail.

THE SELECTION OF INDICATORS

Types of Indicators

In order to contain costs, three types of indicators are proposed that have different functions in the monitoring system and are implemented sequentially in the monitoring cycle (Figure 2.1).

A*larm* indicators should have relatively high social return and low cost making them worthwhile to monitor on a routine basis in an early warning system. They provide an overall assessment of the health or quality of key resources. However, if the value of these indicators crosses a designated threshold level, then the monitoring agency performs an evaluation to determine if there is a need to expend additional resources and generate diagnostic indicators. Note that thresholds are a central part of the operational cycle. Without thresholds the alarm has no way of sounding, and people would not know when to react. Some indicators have "naturally" established thresholds (e.g. an indicator of appropriate land use for a particular soil type and topography has a built-in threshold —whenever the land use patterns diverges from what is appropriate, the threshold is reached). But thresholds for other indicators may have to be determined after consultation with relevant experts and stakeholders on a case-by-case basis.

Diagnostic indicators provide more detailed information on the status of the resource that has been flagged and the causes of the change that has occurred. They also need to inform the policy modeling, since once an alarm has been generated it will be necessary to evaluate, using both quantitative and qualitative techniques, the relationship between policy variables and resource degradation. Diagnostic indicators are only collected at problem detection, and are likely to be more costly than the alarm indicators. For example, they may involve fieldwork or data collection effort that could not be done at low cost or within standard budgetary allocations on a regular basis. The diagnostic indicators may also need to provide information at appropriate and multiple levels of aggregation to be useful. For example, if an alarm indicator provides a warning that forest cover in a certain region has fallen below its threshold level, then diagnostic indicator data may need to be collected on forest encroachment and settlement, extraction of timber and non-timber forest products, biodiversity, and other key variables for different types of households as well as at more aggregate landscape levels.

Response indicators are used to monitor the impact of policy and other resource management changes that have been implemented to correct a problem. The primary purpose of these indicators is to inform relevant decision makers about the consequences of their corrective actions, and whether any additional action is necessary. In some cases, alarm indicators may also serve as useful impact indicators (for example, when actions to improve water quality have been taken), but more specialized indicators may also be required, for example, to monitor the actions of particular stakeholders. The responses to be monitored should include both the implementation of agreed corrective actions by relevant stakeholders and the impacts of those actions on the resources being monitored. As long as the responses and impacts are as expected, the monitoring system can be assumed to have made the correct assumptions and appropriate changes. At this point, new readings of the alarm indicators should be back below their thresholds.

Indicators may be quantitative (such as soil erosion in tons per hectare), but others may be qualitative and based on participatory approaches, such as community and individual plot histories, group elicitation and rapid rural appraisal (RRA) techniques. The latter may often serve as proxies for preferred data that are not easy to collect, or can be directly used to construct alternate scenarios for policy analysis. They may also be helpful in the analysis and interpretation of model results. It is conceivable that model results regarding, say, the impacts of certain policies, may be tempered through information and insights acquired through participatory techniques.

Selection Criteria for Indicators

There is no universal set of indicators that is equally applicable in all cases. However, a small set of well-chosen indicators tends to be the most effective approach. Some of the more important criteria to be used in narrowing down the number of indicators are as follows.

Direct relevance to issues. The indicators selected must be closely linked to the problems that need to be addressed. Vague or overly broad problem formulations, such as "loss in biodiversity" are of little use in selecting indicators, and may well indicate that the issue itself is not very well identified.

Clarity in design. It is important to define the indicators clearly in order to avoid confusion in their development or interpretation.

Realistic collection or development costs. Indicators must be practical and realistic, and their cost of collection and development therefore needs to be considered in relation to their cost. This may lead to trade-offs between the information content of various indicators and the cost of collecting them. It is generally easier to measure the cost of collecting indicators than their benefits. Often, it may be relatively easy to determine qualitatively whether an indicator is useful in a given policy modeling exercise, and it may be more efficient to use non-quantitative and participatory approaches, such as expert assessments (e.g., Delphi), to rank the "benefit" of an indicator according to some ordinal scale.

High quality and reliability. For most monitoring systems, there is a discrepancy between the kinds of data that exist or are easy to collect and the kinds of data that would be most useful, or “ideal”, for the system. Practical indicators that partly fulfill their purpose but are not “ideal” are usually called proxies. If the “ideal” indicator to measure a problem is based on unreliable data, it is better to depart from the “ideal” indicator and use proxies instead. There is often a trade-off between the costs of data collection and the value of the resulting indicator in the PRMS process.

Appropriate spatial and temporal scale. Careful thought should be given to the appropriate spatial and temporal scale of indicators. Since the environmental impact of an activity seldom coincides with administrative boundaries, indicators often need to be measured at different spatial scales. There might also be lags in time before impacts are noticeable. This is especially important in the selection of alarm indicators since it is crucial to include indicators that allow timely reaction.

DEVELOPING AN ANALYTICAL FRAMEWORK

A major point of departure of the proposed policy relevant monitoring system relative to previous work is the use of the data in an economic model that is expected to generate quantitative estimates of the magnitude of welfare losses arising from resource degradation. Although the alarm and diagnostic indicators themselves will provide information on the state of natural resources and their cause-effect relationships, policy makers need to get quantitative estimates for different resource and environmental degradation problems in terms of aggregate welfare losses, valuation of externality damages, economic impacts on alternative beneficiary groups and stakeholders, and estimates of the stocks of different resources as well as their shadow prices. These quantitative results will allow for the analysis of policy trade-offs and the ranking of problem areas and potential interventions. Finally, sensitivity analysis could be performed on the parameters to generate plausible hypothetical scenarios. The sophistication and reliability of a model is to some extent a function of the quality of the data but also the resources and time that are available. In a full monitoring system, complex quantitative models that replicate the biophysical and economic relationships more precisely can be developed over time.

A Payoff Matrix

A useful way to display the key policy relevant information generated by a model is in a Payoff Matrix. This is a simple matrix that maps the principal activities found in the system being studied against each other. Since the same activities (or resource uses) are found in both the rows and columns, the cells on the diagonal represent the net economic benefits from that activity or use, and the off-diagonal elements represent the impact of one activity on another (the externalities). As seen in Figure 2.2, the net private benefit from Activity A is shown in cell AA. The column for A in the Payoff Matrix shows the impacts (externalities) that Activity A imposes on other activities in the system. These externalities can be either positive or negative and are a key dimension of the proposed monitoring system. For example, if Activity A is an upland agricultural land use, it may have a negative impact on Activity B located just downstream. This externality is shown in cell BA and has a negative sign, indicating that it is a "cost". Similarly, if Activity A has another impact, in this case a positive one, on Activity C further downstream, this is recorded in cell CA and has a positive sign. In this way the Policy Matrix explicitly shows both the returns to any activity from its own operation, as well as its impacts on others in the system, be they positive impacts or negative impacts.

Figure 2.2—An illustrative Payoff Matrix.

	Activity							
Activity	A	B	C	D	E	F	G	H
A	AA			-AD				
B	-BA	BB						
C	CA		CC					
D				DD				
E								
F								
G								
H								

When, as in this study, a watershed is being modeled, most of the externalities are below the diagonal. This happens since most externalities in a watershed are uni-directional and follow the downward flow of water and soil. But for other problems it is entirely possible that there may also be externalities above the diagonal, as seen in cell AD in Figure 2.2. In this case, activity D imposes a negative externality cost on activity A. In an urban case, for example, there may well be impacts between all of the major activities in a system.

While the columns of the Payoff Matrix show the private return of an activity and all of the externalities it imposes on others, the rows on the other hand show the private return of the activity on the diagonal, and all of the externalities generated by other activities that affect that activity. Both are powerful pieces of information.

The Payoff Matrix thus brings the various components of the analytical framework together and allows an explicit comparison of both private and social benefits and costs. It shows the impacts of any activity on the broader system, and shows how any activity is affected by the actions of others. It also links to the PRMS approach and helps to identify those who will benefit or lose from any changes in resource use. As an economic framework, the Payoff Matrix presents information useful for economic policy making, and can present both a private, financial analysis as well as a broader, social welfare analysis of a natural resource system and all of the stakeholders involved. It is a powerful tool that is used extensively in the case study presented in this volume.

IDENTIFYING AN INSTITUTIONAL FRAMEWORK

A monitoring system will not be effective in correcting emerging environmental problems if it does not have an adequate institutional framework or structure to manage the system and to organize and negotiate amongst the interests of different stakeholders when problems arise. Most resource management problems involve multiple stakeholders with objective functions that may not be entirely in consonance with each other. For example, at the national level, the government may be the premier stakeholder, yet there may be many non-governmental organizations and industry associations with divergent economic goals. While the objective of the government may be economic growth, full employment for its citizens or achieving a balanced budget, the non-governmental organization may be interested in resource conservation while the industry association may be more concerned with maximizing economic output and firm profits. Thus at every level of the hierarchy—national, regional and local, stakeholders may have divergent objective functions.

Stakeholder Analysis and Information Needs

It is necessary to begin with the identification of all key actors involved in using, managing and controlling the resources to be monitored. Stakeholders include all those who affect or are affected by policies and actions within the system and the Payoff Matrix is one way to clearly identify *who* are the affected groups, and the *relative importance* of their impacts. The stakeholders include individuals, communities, institutions, and professional groups, and the impacts may be felt at different scales—from the local to the national level. It may be important to recognize the special needs of certain groups in this analysis. For example, landless or women farmers tend to be under-represented in formal institutions yet they often have significant impact on resources and can be greatly affected by policy decisions.

The Role of Participation.

Monitoring system needs to be "participatory" in the sense that diverse stakeholders are adequately represented and engaged. It is important to blend participatory approaches in the various elements of a monitoring system ranging from stakeholder problem identification, to the development of indicators, to stakeholder dialogue based on model formulation and policy runs. Stakeholders often have valuable information to contribute as well as relevant skills and interest in collecting data, and their active involvement should be sought. It may complement or substitute for top-down data collection efforts in a cost-effective manner. Active involvement of the policy makers and stakeholders will ensure that over time, there is “demand” for a monitoring system and it can continue to be effective without external assistance.

Problem Identification and Defining Alarm Indicators

Stakeholder participation is particularly important in identifying the problems to be monitored. Using a variety of *participatory research tools* (e.g., participatory mapping of resources, land use and resource degradation, time lines, seasonality mapping and open and semi-structured interviews), local knowledge can be explored to develop an understanding of priority areas in natural resource management both in terms of issues and geographical locations, the magnitude of problems, and the extent to which natural resource problems are inter-linked. A tentative list of grassroots indicators commonly used by local resource users to assess resource health should be developed and the feasibility of using these indicators as proxies for key land quality indicators assessed. For example, the extent of vegetative cover or gully formation may be used as a proxy for soil degradation, or the presence of certain plant species may indicate a change in water quality. Participatory methods can also be used to graph the location of “hot spot” sites that exhibit major environmental degradation, such as point and non-point source pollution, fragile soils, areas with major deforestation or low forest quality

To develop stakeholder interest and commitment to the monitoring system, it is important to ensure that stakeholders develop a common understanding of the resource issues and economic linkages both locally and at a regional level (analytically, these links are seen clearly in the Payoff Matrix). In particular, the externality effects of local and regional resource-use decisions may need to be demonstrated. For example, most inhabitants of a typical watershed may be unaware of the consequences of their actions beyond their immediate surroundings. This awareness could be developed by organizing visits among downstream and upstream dwellers

Analysis of Causes of Resource Degradation and Diagnostic Indicators

Once a resource problem has been flagged, semi-structured interviews in the context of a participatory diagnosis can be conducted with focus groups to analyze the causes of the problem and the likely impacts of alternative corrective policies or actions. Discussions and analysis can be facilitated using graphical techniques such as flow or linkage diagrams to illustrate the size and direction of causality between variables. The effect of alternative policies on local user behavior, such as input/output prices, credit and subsidies, infrastructure, land tenure, agricultural reforms, macro and sectoral modernization policies, and forest policy can be clarified from the local resource users' standpoint. Whether or not changes in practices or the adoption of conservation technologies are due to policies or other factors can also be investigated with these methods. The analysis can be strengthened by soliciting stakeholders' views about possible solutions and outcomes.

The cost and complexity of data collection can be simplified through use of local knowledge. For example, orders of magnitude for crop production functions (relationship between yield and input use) can be estimated quickly through focus groups or key informant interviews if a prior informal survey indicates that there is no great variation in practices for a given farming or cropping system. If substantial variation is found, a more elaborate survey may have to be conducted with a stratified sample of farm households.

Table 2.1 summarizes the above discussion by illustrating the complementarity of the modeling and the participatory approaches. It highlights the multiple levels at which the results from the participatory process can feed into the model and help in developing alternative policy scenarios, and the reverse process in which model results are made accessible to stakeholders for follow-up and implementation through participatory dialogue.

Table 2.1—Use of Participatory Tools in a Natural Resource Monitoring System

TASK	TOOLS
Problem Identification	
1. Collect information on watershed-level natural resource and development issues.	Direct observation through transect walks[1], open-ended[2] and semi-structured interviews[3] with key informants[4]
2. Identify the actors at the local, regional, national and international levels.	Stakeholder analysis using Venn diagrams to illustrate links, responsibilities, common interests and conflicts among user groups .
3. Identify rules and regulations governing the use of natural resources.	Semi-structured interviews with focus groups
4. Define grassroots alarm indicators for resource degradation.	Semi-structured interviews
5. Rank natural resource issues by importance.	Listing and ranking[5]
6. Analyze time trends and spatial distribution of natural resource issues ("hot spots")	Seasonality mapping and time lines[6], participatory mapping[7] of resources, land use, and areas prone to environmental degradation
Analysis of Resource Issues and Policy Alternatives.	
1. Estimate the costs of environmental degradation, and biophysical relations.	Semi-structured interviews with focus groups[8]
2. Analyze the causes of environmental degradation/resource use (diagnostic indicators).	Flow diagram and semi-structured interviews with focus groups
3. Validate model results and discuss policy impacts, construct alternative scenarios	Semi-structured interviews with focus groups

Notes: Although the table presents an association between tasks and tools, Participatory Rural Appraisal (PRA) tools are not a pre-set package. The process itself is flexible and adaptive and modified if needed as more information and experience with informants is gained. Accuracy is achieved through triangulation which involves the use of a diversity of methods and information rather than statistical replicability. Tools are used as much to obtain information and develop an understanding as to stimulate analysis, promote interaction and develop consensus. In that sense, PRA is both a product and a process.

[1]Transect walks: walk through one or more cross-sections of the landscape to observe and discuss spatial differences with one or more key informants.

[2]Open-ended interviews: interviews in which no questions are predetermined and new questions arise during the interview in response to the respondent's answers. Open-ended interviews are important to build trust and confidence between the interviewer and the respondents and encourage people to raise and discuss issues.

[3]Semi-structured interviews: interviews which are guided by a limited number of pre-determined questions. A check list is used as a reminder of the topics to cover. New questions arise during the interview in response to the respondent's answers.

[4]Key informant: individual possessing specialized knowledge.

[5]Ranking can be performed directly from a list of issues or using a two by two ranking technique where two issues are compared at the same time to minimize ranking inconsistencies.

[6]Seasonality mapping and timelines: bar or line diagrams illustrating the change in issues over time or season when relevant.

[7]Participatory mapping: individual or a small group of informants draw a map to localize and discuss resource issues, land use or any issue with a spatial dimension. Maps are drawn with paper and pencil or directly on the ground (and later reproduced on paper) depending on the respondents' preferences. It is best to leave the maps with the informants as a reference for further discussions and work and for ownership of knowledge. This is especially relevant if a community-level natural resources monitoring system is to be designed.

[8]Focus group: a carefully selected group of individuals to discuss a specific topic in great depth. Results of the focus group exercise depend greatly on the size and composition of the group as well as the skill of the facilitator and the person taking notes.

Institution-Building through Participatory Research

Given that stakeholder participation is key to the success of a policy relevant monitoring system, it may be important to form a stakeholders committee that will represent all the major stakeholders. Such a committee could contribute to reaching consensus on relevant technical issues such as indicator selection and measurement, determination of threshold levels and problem identification as well as broader institutional issues and overall sharing of responsibilities.

The feasibility of a community monitoring system may be evaluated through a multi-level (cascade) analysis. As part of this approach, meetings could be held with different institutions and communities in order to develop an initial information base. Then participants from different stakeholder groups (e.g., groups located in the upstream and downstream regions of a watershed) could meet to exchange information and local knowledge regarding the resource and environmental interactions at the regional (e.g., watershed or river basin) level. These interactions could then form the basis for the development of participatory work plans.

There are several major factors that can make a monitoring system self-sustaining in the long run. They are:

- broad-based stakeholder participation: ensuring that stakeholders have a stake in the system will motivate action.
- fair degree of consensus within and across stakeholder groups for undertaking coordinated action.
- empowerment of stakeholders: stakeholders must be provided with adequate resources in terms of equipment, personnel, information, technical support and financial assistance to carry out their duties
- incentive schemes may need to be developed to ensure that relevant stakeholders participate in the monitoring effort. Appropriate incentives can be identified through focus group discussions with stakeholders and then discussed in committee for implementation. For example, forest dwellers inhabiting the upper slopes of a watershed and living near protected areas may be willing to

participate in monitoring in exchange for access to clean water and electricity or limited access to forest resources in the protected areas.

CONCLUSIONS

In summary, the proposed Policy Relevant Monitoring System is unique in the sense that it provides a framework for integration of monitoring data with policy analysis and stakeholder dialogue through participatory approaches. This combination is useful because a top-down resource monitoring system is likely to be highly inefficient in its use of information on the state of resources and the environment, which tends to be decentralized. Previous efforts at setting up environmental information systems in developing countries have failed because of a lack of stakeholder participation and absence of serious policy analysis of the data collected.

To illustrate the design of a Policy Relevant Monitoring System, a case study was undertaken of the Arenal-Tempisque watershed in Costa Rica, and a Payoff Matrix developed that illustrates many of the environmental and economic links in the system. As explained in the next chapter, the water flowing through this watershed is first used to support dairy and cattle production upstream, to generate electricity midstream, and then to supply irrigated rice and sugar farms downstream. The water then passes through a highly valued wetland park before draining into the Gulf of Nicoya, an important fisheries and tourist area. The wetlands and coastal fishing areas are affected by large but irregular flows of fresh water released after electricity generation, and by water contamination with fertilizers, pesticides and herbicides from irrigated farming.

There are classic externality problems in the watershed: deforestation by dairy and cattle farmers in the upper watershed leads to soil erosion and siltation of the various reservoirs that feed the electricity generation system, and agro-chemical use by irrigated farmers and soil runoff have adverse impacts on wildlife and fishing in the lower reaches of the watershed. The case study involves development of appropriate sets of indicators and a formal economic model for the watershed, and discusses options for an institutional framework that could serve the various stakeholder groups in managing the environmental externalities inherent in the watershed. The case study is designed to illustrate the application of a PRMS approach to a real watershed; the lessons learned, however are applicable to similar resource management problems in many other parts of the world.

3. INTRODUCTION TO THE ARENAL-TEMPISQUE WATERSHED

Rafael Celis, Ujjayant Chakravorty, Daniele Perrot-Maitre and Luis Gámez

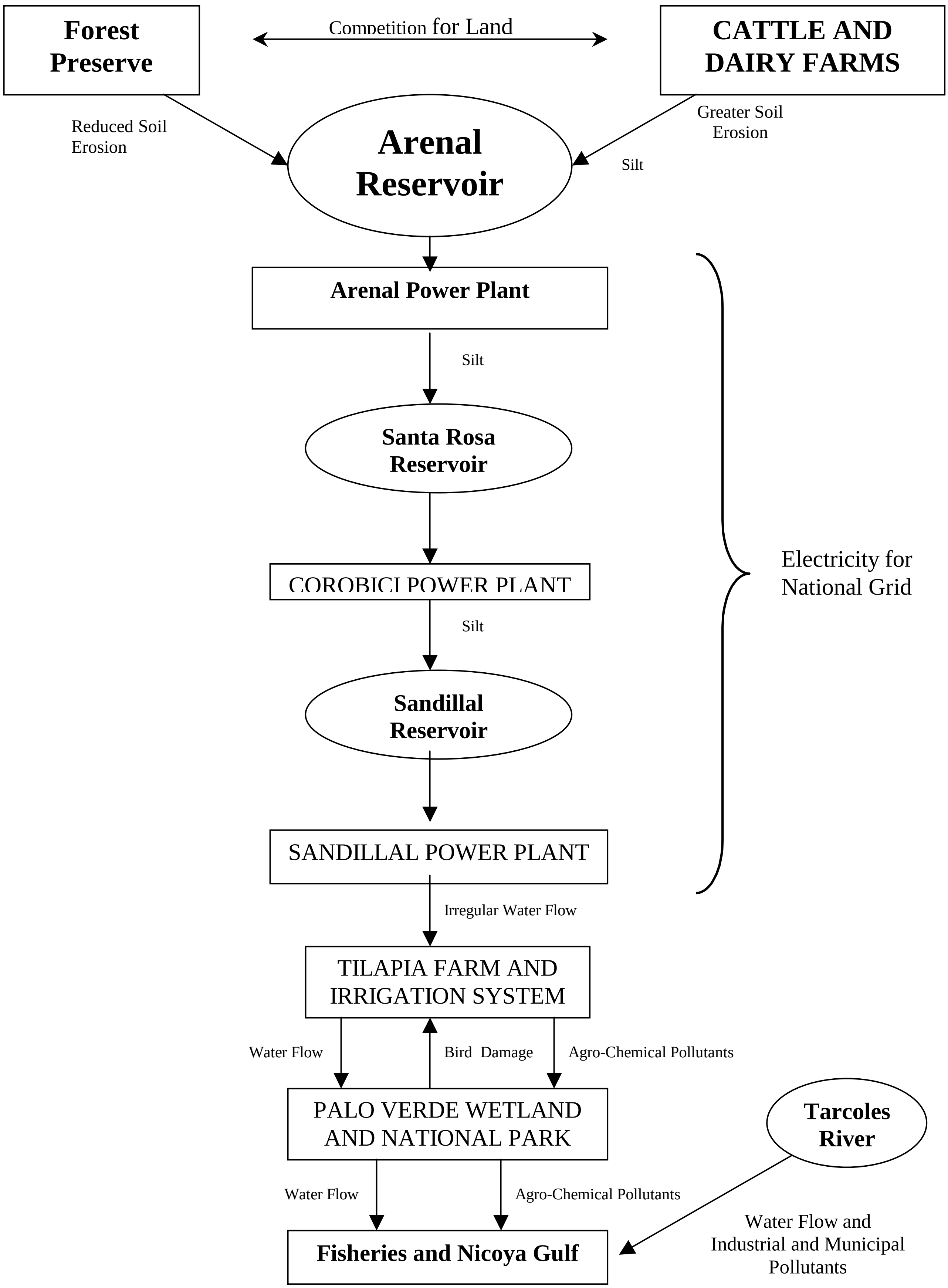
INTRODUCTION

This chapter describes the key features and problems of the Arenal-Tempisque watershed. It outlines the important environmental problems that must be addressed by a Policy Relevant Monitoring System (PRMS) and introduces the various stakeholders who would have to collaborate to make the system work. The watershed faces a number of classic land use and water quality problems that are endemic to most watersheds that are subject to intense agricultural and settlement activities. The forested upper catchment area is steadily being converted to pasture for dairy and cattle production and this leads to greater soil erosion. Soil erosion contributes to the siltation of a large lake and a series of smaller reservoirs that feed a major hydro-electric power system. From the hydro-electric power system, the water flows through a fish farm and an area of intensive irrigated farming before draining into a valued wetland park and a coastal fisheries and tourist area. The water flow is irregular, reflecting the needs of the electricity generation system, and this impacts on the availability of water for irrigation and the seasonal flow of water through the wetland. The irrigated farms use agro-chemicals and generate soil sediments, both of which pollute the drainage water and impact adversely on the wetland and coastal fisheries. And the wetlands are home to huge bird populations which are a major pest to irrigated rice farms bordering on the park. There are many diverse stakeholder interests in the watershed, and those lower down the system are impacted by the actions of many of the stakeholders further upstream. At present there is little organized attempt to manage the environmental externalities in the watershed, and the development of a natural resource monitoring system that could help improve the management of the watershed offers potentially large social benefits.

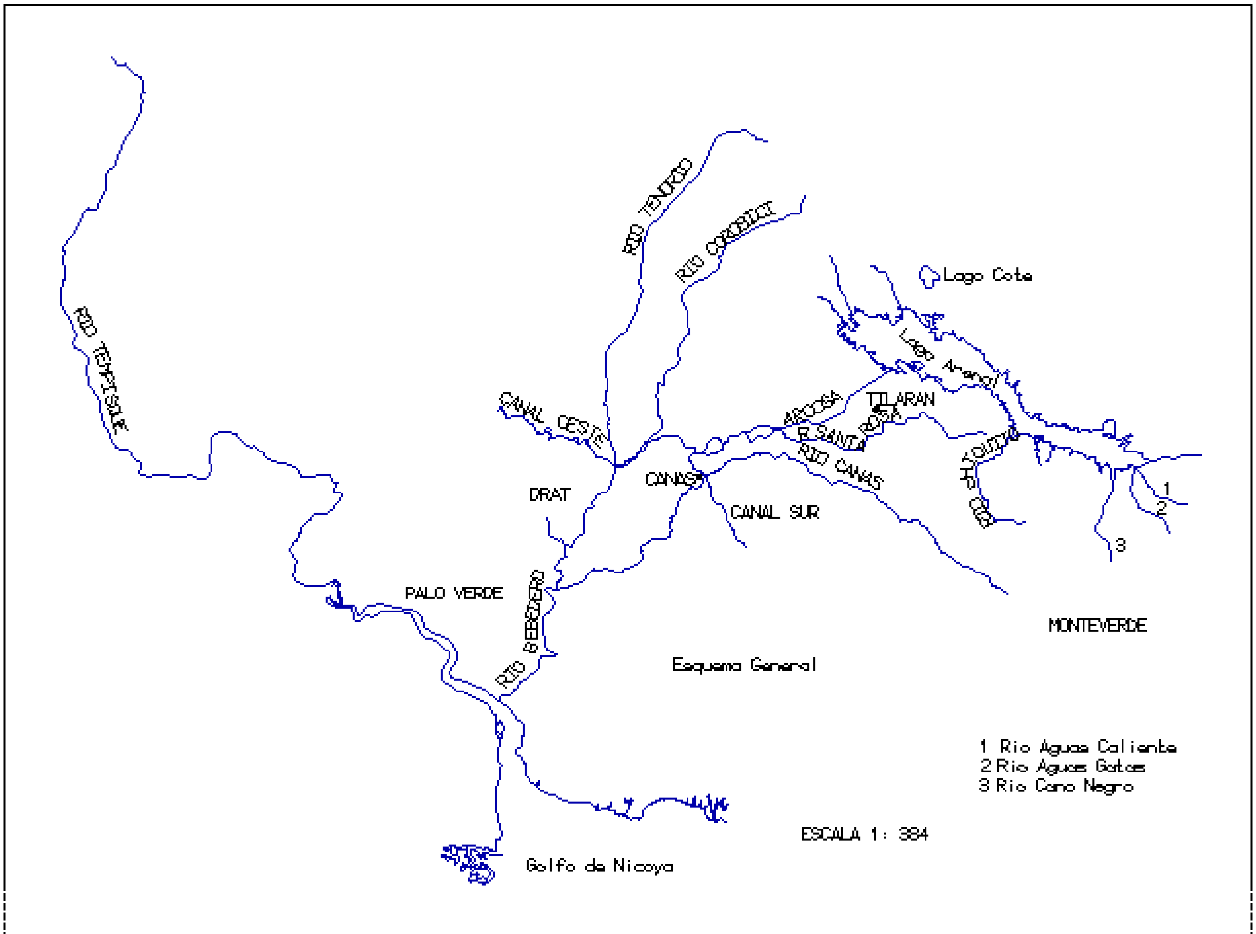
The Arenal-Tempisque watershed is located in northwestern Costa Rica and is one of the most economically productive regions in the country. The ARCOSA hydroelectric power complex provides over a third of the electricity produced in the country. The irrigation district is the largest in the country and the premier producer of rice and sugarcane. The Gulf of Nicoya downstream of the watershed is one of the most productive estuarine ecosystems in the world and accounts for about 20 percent of the total fisheries harvest in Costa Rica and houses half the total coastal population of the country. The Palo Verde National Park is a wetland of critical importance and attracts aquatic birds that migrate southwards during the winter season. Deterioration of its natural habitats has led to its inclusion in the Montreaux Register of Endangered Ramsar Wetlands following the Ramsar Convention of 1971.

Map 3.1 and Figure 3.1 summarize key characteristics of the Arenal-Tempisque watershed. Following sections discuss the various segments of the watershed in sequence, beginning with the upper catchment area. This is followed by a discussion of the key stakeholders in the watershed and their interests and inter-dependencies.

Figure 3.1—A Flow Chart of the Arenal-Tempisque Watershed



Map 3.1—Geographic location of watershed components



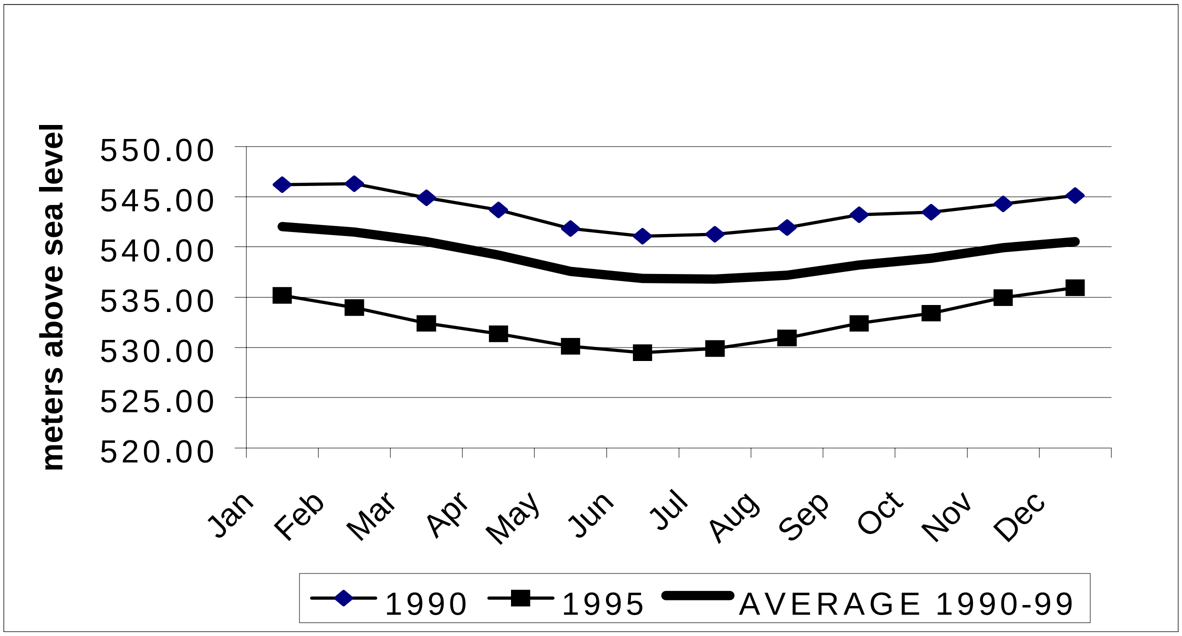
THE ARENAL RESERVOIR AND CATCHMENT AREA

Lake Arenal has a surface of 87.8 km^2 and a volume of 2.416 billion m^3. It was built in the 1970s to supply water to the hydroelectric complex and the irrigation district. The lake feeds a cascade of three turbines and three dams which produce a maximum of 363.4 MW of electricity. Lake Arenal is the core of the catchment and storage system. It was built and is managed by the Instituto Costarricense de Electricidad (ICE), an autonomous parastatal, which until 1991 enjoyed a monopoly in electricity production. The starting point was the construction of a dam to retain the water flow of Arenal River, which was the natural drainage towards the Atlantic Ocean of the old Arenal Lagoon. Lake Arenal was filled for the first time in 1979; that same year the first powerhouse came into operation, and water was diverted towards the Pacific Ocean. Since then, the lake is replenished by direct rainfall on its surface and by water coming from the South and North catchment areas.

At the southern rim of the lake, the rivers Agua Gata, Caño Negro, and Chiquito drain directly into the lake. More recently, ICE built a dam on river Fortuna, which drains towards the Atlantic and, after allowing for a minimum water flow required to maintain life in river Fortuna, it conducts the remaining water through a tunnel into river Agua Caliente, which in turn drains directly into the lake. Other smaller creeks drain directly into the lake: San Luis, Sábalo, Piedra, Aguacate, Dos Bocas and Mata de Caña. All these rivers and creeks originate in a mountain range located farther south from the lake. The conservation of tropical cloud forests in two private reserves upstream of the lake, the Monteverde Cloud Forest Reserve and the Eternal Forest of Children, has a regulating effect on the volume of water runoff downstream. The flow of water into the lake is also reduced through consumption by dairy farms and cattle ranches, as well as by small population centers, all located along the roads that connect the towns of Santa Elena, near the conservation areas, and Tilarán, on the southern rim of Lake Arenal. On the Northern rim of the lake, ICE diverts water from Lake Cote, which used to drain to the Atlantic Ocean. By means of a dam, a water intake and a tunnel, water is diverted towards Rugama creek, which drains directly into Lake Arenal.

The water level of Lake Arenal follows a seasonal cycle. It steadily increases from June through December, the period during which most precipitation takes place, and decreases during the period January through May. Figure 3.2 shows the seasonal pattern of water levels and usable stocks of water for the best year (1990), the worst year (1995), and the monthly average for the period 1990–1999. On average, the amounts of water extracted from the lake each year seem to be in balance with the annual inflow and there is no evidence that the lake is being run down except in drought years.

Figure 3.2—Water level at Lake Arenal



Environmental Externalities

The changes that ICE has made to the upper watershed, and the activities of the dairy and cattle farms have several environmental implications. First, the reversal of water flows from the Atlantic to the Pacific Ocean may be having a significant impact on the region’s flora and fauna. This is not only because of the artificial transfer of species, but also because the increased volume of fresh water on the Pacific side necessarily affects the levels of salinity in soils and seawater. For example, the salinity in mangroves in the Gulf of Nicoya may be lowered, disturbing the breeding and feeding habitats of shrimp, fish and other species. Second, water supply to Lake Arenal will be very sensitive to decisions relating to the conservation of forests, both around river springs and along the rivers in the southern catchment and Lake Cote to the North. Third, because of the location of a cheese factory in Monteverde, dairy production is a flourishing industry that is likely to expand with increased tourism, growth in exports, and with population growth in the local communities and in the country as a whole. Expansion of dairy production will in turn increase pressure on forests and soils, thus affecting the quantity and quality of water that flows to Lake Arenal. Although current rates of siltation are minor relative to the huge capacity of Lake Arenal (at current rates of soil erosion, Lake Arenal is expected to have a useful life of about 500 years), part of the silt is carried in the water down to the hydro-electric power complex where it creates more serious problems. Fourth, as population in local communities increases in the future, more water may need to be diverted out of streams and aquifers for human consumption, thus reducing the inflow to Lake Arenal.

THE ARENAL-COROBICI-SANDILLAL (ARCOSA) HYDROPOWER GENERATION COMPLEX

ICE releases water at the southwestern point of Lake Arenal and conducts it through a tunnel, an oscillation tank and a high-pressure pipe to operate the first of three power plants lined up between the towns of Tilarán and Cañas. This first plant, named Arenal, consists of three Francis turbines that transmit mechanical energy to three power generators that produce a maximum of 157.4 MW. Water released by Arenal is stored in the Santa Rosa reservoir where the water stock is augmented by the flow of river Santa Rosa. This river continues along its natural riverbed serving as an overflow for the reservoir and as drainage to smaller creeks downstream, and feeds the system again at the Sandillal reservoir.

A water intake at the Santa Rosa reservoir, a tunnel, an oscillation tank and a high-pressure pipe transport water to the second powerhouse, Corobicí. This powerhouse is similar in design to the first one and has a maximum generating capacity of 174 MW. Water released by Corobicí is stored in the Sandillal Reservoir, which also discharges a minimum flow of water necessary to maintain the ecological balance in the river Santa Rosa during its course downstream until it finally drains into the river Magdalena.

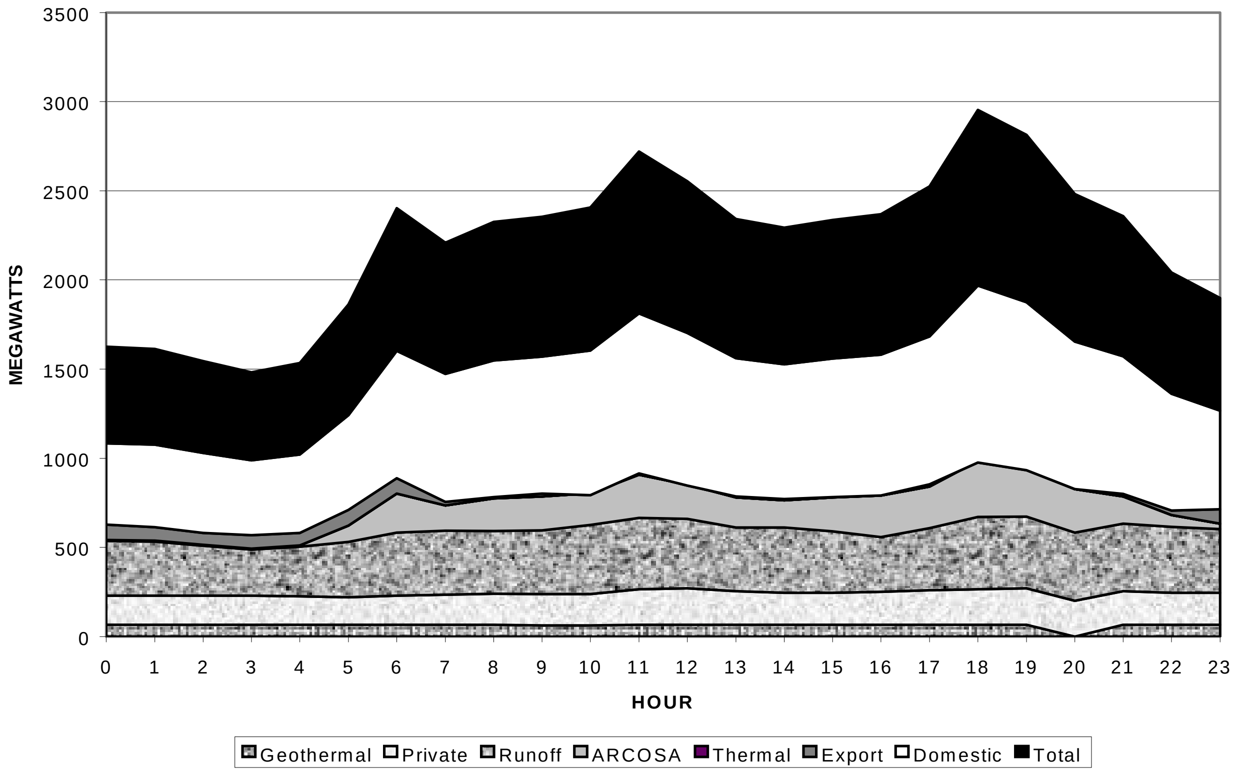
Water from the Sandillal reservoir is transported through a tunnel and a high-pressure pipe to two Kaplan turbines, which power two generators producing a maximum of 32 MW. Water discharged by Sandillal flows into the river Magdalena and feeds the Miguel Dengo diversion dam, at which point the flow is split in three: river Corobicí, and the South and West Canals that feed the Arenal-Tempisque irrigation district.

Several salient features of this power generation complex are worth noting. First, in order to fully exploit the topography of the terrain, ARCOSA uses different types of turbines; Arenal and Corobicí use Francis turbines that require greater slopes and less water, whereas Sandillal uses Kaplan turbines which require less slope, but greater volumes of water. This means that water released from Lake Arenal generates different amounts of electricity on its passage through each of the three plants. For instance, 100 m3 of water released from Lake Arenal can produce up to 160 MW at Arenal powerhouse, 180 MW at Corobicí, and 32 MW at Sandillal.

Second, as a regulation dam, Lake Arenal is intended to make water available for power generation in a discretionary fashion. Therefore, at any given time during the day, the amount of electricity generated in ARCOSA is determined at the National Center for Energy Control, located in San José. In doing so, the Center allocates electricity demand nationwide in strict order: geothermal plants are the first to enter in operation, followed by private producers of electricity, ICE's runoff river generators, the ARCOSA complex, and finally thermally generated power plants. The criteria for this rigid sequence are diverse: geothermal energy is readily available 24 hours; privately generated power from run-of river and aeolic (windpower) generators- go second because ICE has a mandate to purchase all their production between 05:00 and 21:00 hours and as needed between 21:00 and 05:00 hours; ICE's runoff plants go in third because of their very low storage capacity; ARCOSA goes in fourth to use stored water; and thermal power kicks in at the very end because thermal generators use relatively valuable imported fuel; diesel and bunker.

Figure 3.3 shows the amount of electricity produced from these sources on a typical day during the rainy season.

Figure 3.3—Costa Rica: Power generation and consumption on September 28, 1999



When it is ARCOSA's turn, the Center transmits its production order by remote control to a computer in each power plant. This PC is also connected to sensors that gauge the water availability in the reservoirs and sets in motion each of the eight generators at any level from zero to maximum capacity. The fact that the three plants all use the same water flow in sequence and which in turn is further used by the irrigation district downstream, imposes specific constraints on water management.

An additional constraint is the location of a tilapia farm that uses water from the South Canal before it enters the irrigation district. This farm demands a continuous flow of water. To cope with this requirement, ICE set up the Sandillal facility for round-the-clock operation. This means that at all times, at least one generator will always be in operation at minimum capacity; i.e. 6 MW, using between 18 m^3 and 22 m^3 of water, depending on the water level at Sandillal reservoir.

Soil erosion in the upper catchment area has potentially costly impacts on the ARCOSA complex. Lake Arenal is large, with a usable volume of 2.0 billion cubic meters. Silt from the catchment area will have little impact on this lake for many years to come. But the Santa Rosa and Sandillal reservoirs are much smaller (0.1 and 5.15 million cubic meters, respectively), so even if only a small portion of the silt flows into these reservoirs they could get rapidly silted. The Santa Rosa reservoir is not only the smallest but also the first in line, and hence silts up the fastest. Unfortunately, this reservoir feeds the Corobicí power station which also produces the cheapest electricity (1.56c/KWH, compared to 2.83c/KWH for Arenal and 7.9c/KWH for Sandillal. If the Santa Rosa reservoir were allowed to silt up, then ICE would have to move more production to the higher cost Arenal plant. This increased cost of electricity represents the opportunity cost of siltation from the catchment.

Measurements from a hydrologic station located at the Arenal Powerhouse indicate that during the period 1977─1992, sediment loads ranged from 1,117 tons to 5,390 tons per year for an annual average of 3,212 tons. At this rate, the Santa Rosa reservoir needs to be dredged every other year in order to maintain the Corobicí power plant in action. The reservoir will need to be dredged even more frequently if the expansion of dairy farming in the upper watershed continues unabated.

THE ARENAL-TEMPISQUE IRRIGATION DISTRICT

The irrigation system currently waters about 20,000 hectares of agricultural land which is mainly planted to rice and sugar cane (50 and 40 percent of the crop area, respectively). Additionally, some vegetables are grown (about 1 percent of the crop area), especially melons. Irrigation is needed during a pronounced dry season that extends from November to May, but some supplementary irrigation is also needed during the rainy season. Many of the irrigated farms are small, being beneficiaries of the state land reform program which provided 7─10 hectares of mainly rice-growing plots to approximately 600 landless families. However, the distribution of land in the district is skewed, with several farms owning several hundred to 2,000 hectares each. There are plans to construct another 20,000 ha of irrigated land, bringing the total to about 40,000 ha by 2014.

The Arenal-Tempisque Irrigation District is conceived as an integral part of the ARCOSA power generation complex. Construction of infrastructure and administration of the scheme is the responsibility of the Servicio Nacional de Riego y Avenamiento (SENARA), an autonomous parastatal. Water is delivered to the irrigation district through the South and West canals and distributed through a network of secondary and tertiary canals.

The South canal is 8 km in length and has a maximum flow capacity of 30 cubic meters per second. It is connected to a network of secondary canals, which in turn are connected to tertiary canals. Altogether, the south system currently serves a total of 8,827 hectares, i.e. land on which the infrastructure for water distribution and leveling work has been completed. By the year 2014 the canal is expected to irrigate 15,700 hectares.

The West canal is 21 km in length with a peak flow capacity of 55 cubic meters per second. It is connected to a network of secondary and tertiary canals. Altogether, the West system currently has the potential to irrigate a total of 11,025 hectares. By the year 2014 this canal is expected to irrigate 28,400 hectares.

The first user of irrigation water on the South canal is Aquacorporación Internacional, a tilapia farm. Aquacorporación runs the water through a cascade of three successive layers of one-meter-deep ponds, with a total surface of 150-160 hectares. This water returns to the Cañas River and then to other downstream farms within the irrigation district. The tilapia farm requires a constant flow of fresh water from the canal to keep the fish alive. When the tilapia farm started operations, this capacity was 7 m3/s; later on it was augmented to 12 m3/s.

To access irrigation water, landowners or tenants have to apply to SENARA and pay the approved tariff at the beginning of each semester. Water gates at the farm level are locked, and water is released only after a SENARA engineer certifies that the farm has been prepared to use irrigation. A "gate-opener" then makes daily passes along canals and opens the gates for those farmers who are ready and have no outstanding tariff payments.

The main soil in the district is vertisol, which is characterized by its high clay content. These soils have good chemical quality but poor physical characteristics; i.e., they are fertile but tend to flood in the rainy season and to dry and break during the dry season. Both rice and sugar cane grow very well in vertisol soils under controlled water applications. With reliable water supplies, melons, watermelons and other vegetables could also grow well during the dry season. However, they cannot be planted close to rice paddies because the spraying of herbicides would kill them. Besides, it is not clear that there is an immediate export market for these higher valued crops, and much depends on openings in the US market.

Water Conservation and Management

Water levels in Lake Arenal have been fairly stable during the last decade with the only exception being the drought of 1995. Thus, water availability appears to be sufficient to meet the steady increase in electricity demand in Costa Rica, which averages about 6 percent per year. However, abundance of water in the hydropower generation complex does not translate into abundance in the irrigation system. This is because the release of water from ARCOSA mimics the intra-day variation in electricity consumption and peaks during the hours of 05:00, 11:00 and 18:00 hours. During these times, there is excess water for irrigation, while in the off-peak hours, the irrigation canals could be empty.

The Sandillal reservoir was built mainly with the intention of smoothing out the flow of water to the irrigation district. However, it has proved insufficient to provide this service. SENARA and ICE are now assessing the feasibility of building two more reservoirs within the irrigation district to eliminate current and future shortages. Parallel initiatives are being considered to divert water directly from the rivers Magdalena and Corobicí to produce a continuous flow of water to the tilapia farm and other agricultural users.

Construction of irrigation canals has not gone hand in hand with the demand for water by individual farms. SENARA reports that water delivered to some farmers exceeds their needs, while others face a shortage in supply. SENARA is quite concerned about the need to improve water use efficiencies at the farm level. The agency realizes that the farming community needs to be educated about water scarcity. The current system of water tariffs based on farm size does not provide an incentive to farmers to save water or invest in increasing on-farm water efficiency. Thus other options such as volumetric pricing and markets for water permits that will charge farmers the opportunity cost of supplying water are being explored. However, it is still not clear whether these pricing systems will be implemented, and if so, under what time frame. Average water use efficiencies in the region fall in the 40–45 percent range, except for melons which can achieve 80 percent efficiency through use of drip irrigation.

The availability of irrigation water from the project has had a major impact on cropping patterns in the region. Farmers switched to project-supplied water and became less dependent on pumping water from streams or wells using more expensive electricity or gasoline-powered pumps. It also provided irrigation water to those farms for whom pumping from rivers or aquifers was not a feasible option because of their location. It increased the reliability of water supplies, which in turn enabled farmers to move from one to two crops per year, resulting in a significant increase in land productivity and contributing to national food self-sufficiency.

These changes have also caused a shift from traditional to intensive cultural practices, with a sharp increase in the use of fertilizers and pesticides. This in turn has resulted in increased levels of nitrates, phosphates and other chemicals in the drainage water. The problem is aggravated by the continued use of early high-yielding varieties of rice that have poor pest resistance and need more frequent spraying. More modern pest resistant varieties have not yet been adapted to the conditions of this region. To make matters worse, spraying is largely done from helicopters, which leads to the indiscriminate spraying of surrounding areas beyond the rice fields. Another problem is the use of mechanized land puddling methods for rice planting that lead to high soil sediment content in the drainage water. Soil sediments are contributing to the degradation of the wetlands.

Declining water quality from an increase in chemical and soil sediment loading in the runoff from the irrigation district has in recent years become a cause of major concern for SENARA. This has come about not only through increased awareness at various levels within the organization but also from discussions with the Interamerican Development Bank (IDB) which has made water quality a key component of loan provisions to finance further infrastructure construction. A proposal to monitor water quality for agricultural use before it is delivered to farmers and after it is returned to canals and drained downstream is currently under active consideration.

THE PALO VERDE WETLANDS AND NATIONAL PARK

Downstream from the Arenal-Tempisque Irrigation District is the Palo Verde National Park, a 20,000 hectare refuge for migratory waterfowl and resident water birds. The park contains a diversity of habitats: mangrove forest, riverside forest, thorny shrub land, grasslands, deciduous forest, brackish marsh, freshwater wetlands, limestone forest, savanna brush land, and evergreen forest. One section of the park, Laguna Foohas, houses an estimated 50,000 birds including ducks, herons, storks, egrets, grebes, ibis, jacanas and other forest birds such as macaws and small parrots. The Palo Verde forests are the nesting grounds of the endangered jabiru and home to the only colony of scarlet macaws in the dry tropical forest on the Pacific.

Palo Verde is subject to seasonal floods of great magnitude, due to its lack of natural drainage. This has resulted in the coexistence of diverse ecological niches; between 12 and 15 distinct habitats have been identified. They include salt and fresh water lakes and swamps, grasslands with black mangroves, mangrove swamps, pastures, lowland stunted forests, wooded savannas and evergreen forests.

The most conspicuous species and the one from which the park takes its name is the "palo verde" or horse bean, a leafy bush with its branches and parts of its trunk colored light green. The hills are home to an endemic species of cactus. The lignum-vitae, a tree prized for its wood and in imminent danger of extinction, is also found here.

Palo Verde's natural water system has created an environment capable of supporting one of the largest concentrations of waterfowl and wading birds, both native and migratory, in the country and, in fact, in all of Central America. The area also includes some of the best patches of dry forest remaining in Central America, with giant pochote, cedro, and guanacaste trees. The freshwater marsh is an important feeding ground for some 60 species of resident and migratory water birds. Within the marsh, such species as the black-bellied whistling duck and the blue-winged teal have been observed in large numbers. The park is also a principal migratory ground for many neotropical migrants, including hummingbirds, flycatchers, warblers, tanagers, orioles, vireos, owls, and falcons.

Some of the most abundant mammals are the howler and white-faced monkeys, white-nosed coati, white-tailed deer, tree squirrel, porcupine, and numerous felines including the ocelot and puma. Iguanas can be spotted in many places in the park, and crocodiles up to five meters in length have been sighted in the Tempisque River. The global importance of Palo Verde was acknowledged in 1992, when it was included in the Ramsar List of Wetlands of International Importance, sponsored by the Convention on Wetlands, signed in Ramsar, Iran, in 1971.

PARK CONSERVATION AND MANAGEMENT

There are several important issues relating to the preservation of the Palo Verde National Park. The foremost is the need to maintain a water mirror in the marshes to support resident and migratory waterfowl. Before it was officially protected, part of the park was a cattle ranch planted with African bluestem grass, which can grow up to six feet high. During the dry season, forest fires can easily ignite the grass and the flames also consume the natural vegetation. These grasses can multiply and choke the delicate ecosystem by restricting the growth of competing plant species. When the park was established, removal of cattle from the park allowed the grass to grow unchecked. Park management has successfully implemented an innovative solution for several years. It allows ranchers access to selected parts of the park who graze their cattle for a fee. Grazing cattle prevent aquatic grasses from overtaking the wetlands. However continued runoff from the irrigation district and increased loading of chemical and organic nutrients suspended in the water - caused by soil erosion and sedimentation – is likely to cause invasion of marshes by grasses and to make their control more difficult and costly.

Another important issue is the potential for conflict with agricultural operations in the areas adjacent to the park. Rice fields bordering the park are subject to invasion by birds, causing substantial income losses to farmers. Farmers often respond by shooting or poisoning birds. In other cases, thanks to cooperation with environmentalists, propane gas detonators have been used to chase away birds from destroying the crops. Birds also feed in rice fields, catching insects, fishes and poisoned rats. There have been occasional discoveries of soft and cracked eggshells of bird offspring, which suggests that increased chemical pollution in the rice paddies and wetlands may be responsible for a reduction in the survival of offspring. Thus, while an increase in bird population allows for increased ecological diversity in the Park and its tourism potential, there is a downside in terms of its impacts on agriculture in the vicinity of the park.

THE GULF OF NICOYA MARINE ESTUARY

The Gulf of Nicoya is an estuary system on the Pacific Coast of Costa Rica that supplies approximately a quarter of all fish production in the country as a whole. The outer part of the Gulf has seawater with a maximum depth of 200 meters. The inner part has low salinity, a muddy bottom, with a maximum depth of 20 meters. The middle part of the Gulf mixes both seawater and muddy water.

The inner part of the Gulf extends over approximately 630 square km and lies contiguous to the Palo Verde National Park. Two rivers, the Tempisque and Bebedero, which provide natural boundaries to the Palo Verde National Park, drain into this area of the Gulf. The salinity in this part of the Gulf is low, and the bottom is soft and muddy due to river discharges and the tidal action in the mangrove ecosystem.

The species composition of fish catches is quite different between the inner and outer parts of the Gulf. The main catches in the former include white shrimp, sea bass, mollusks and snapper. A crab fishery has recently been established. The inner part of the Gulf also serves as an important breeding ground for fish species in the entire Gulf region. Thus adverse environmental impacts through excess nutrients from fertilizers and pesticides, sediment runoffs and high volumes of fresh water discharge could have far-reaching impacts on fisheries harvests in both the inner and outer Gulf regions.

Although there is serious concern about the draining of agricultural runoff from the Tempisque watershed, there has been insufficient research to establish any direct cause and effect relationship with the state of the fisheries. Most evidence is anecdotal and based on casual observation by fishermen and tourists. Thus whether an observed depletion in fish catches is because of environmental impacts, over fishing, or climatic variation is not known. However, there is a clear and growing consensus that Gulf fish catches have declined significantly in recent years. Some reports suggest that large water aquifers lie underneath the irrigation district, but their dynamics and interaction with the rivers Tempisque and Bebedero and with the Gulf of Nicoya estuary are unknown.

The Gulf also serves as a sink to the Tarcoles River, which runs through the central valley of the country—home to 80 percent of the nation's industries and 60 percent of its population. Thus industrial and domestic wastes discharged by the Tarcoles River also affect water quality in the Gulf. The relative importance of pollution from the Tarcoles River compared to agricultural pollution from the Tempisque in impacting the fisheries is unknown. This makes it difficult to ascertain which specific pollution-generating activities need to be monitored and regulated. In addition there is a danger of undertaking costly pollution reduction programs which may not have the desired effect on water quality in the Gulf.

INSTITUTIONAL ISSUES

There are many stakeholders in the Arenal-Tempisque watershed, not all of whom live within the watershed but who nevertheless expect to have a say in its management. Some stakeholders operate in their individual capacities (e.g. many farmers), but most are organized and represented by formal institutions. Stakeholders who depend on the watershed for their living include the dairy and cattle farmers in the upper watershed, ICE, the tilapia farm, irrigated farmers and fishermen. Other stakeholders include the Ministry of Environment and Energy (MINAE) that has formal responsibility for all conservation areas, the Ministry of Agriculture which has responsibility for agricultural development, and various environmental organizations contributing to the upkeep of the forest preserves and the Palo Verde National Park.

In the initial stages of development of the watershed, institutions developed to meet specific management needs in different sections of the watershed. Poor communications infrastructure and lack of knowledge about the links between different sections in the watershed contributed to the creation of a culture of "institutional territories" that has proven difficult to overcome in seeking more integrated management of the entire watershed. This is still true, despite the fact that communications and knowledge have improved, and a new generation of institutions has emerged, like the National System of Conservation Areas (SINAC), that aim to foster institutional coordination and cooperation within the watershed. These issues are examined further in chapter 6.

Because the existing stakeholders and institutions work largely independently of one another, their actions contribute to the creation of economic (and environmental) externalities within the watershed. Stakeholders effect each other according to their location in the watershed—and most of the effects are unidirectional because of the force of gravity. Consequently, the possibilities for determining cause-effect relationships and for resolving conflicts that arise from externalities also is very dependent on location, and recognition that some impacts and actions are very far-reaching.

The Payoff-Matrix.

The interactions between different parts of the watershed, and the economic activities contained in each section, can be clearly seen in a *Payoff Matrix*. Table 3.1 portrays the spatial distribution of the major actors from upstream to downstream (from left to right and from top to bottom) and the costs and benefits that each stakeholder group imposes on other stakeholders in the watershed. The diagonal cells indicate the "own" interests of each stakeholder group, such as maximization of own income for farmers and fishermen, of optimal electricity production for ICE, and maximization of conservation efforts by park officials and environmentalists in the forest preserves and the wetland. The off-diagonal elements capture the externality and other costs (indicated by a "-" sign) and benefits (indicated by a "+" sign) within the watershed caused as a result of each stakeholder group pursuing its own best interest.

Table 3.1—Payoff matrix of stakeholder interests

	Forest Reserves	Dairy/Cattle Farmers	ICE	Tilapia Farm	Irrigated Farms	Wetland	Fishermen
Private Reserves	Maximize forest area						
Dairy/Cattle Farmers	Reduces land available for dairy/cattle (-)	Maximize livestock income					
ICE	Reduced siltation of reservoirs (+)	Siltation of reservoirs (-)	Optimize electricity production				
Tilapia Farm	NA	NA	Irregular flow of water (-)	Maximize fish income			
Irrigated Farms	NA	Reduced water in drought years (-)	Irregular flow of water (-)	NA	Maximize crop income	Bird damage to crops (-)	
Wetland	NA	Reduced water in drought years (-)	Irregular flow of water (-)	NA	Agro-chemical pollution and soil runoff (-)	Maximize conservation	
Fishermen	NA	NA	NA	NA	Agro-chemical pollution and soil runoff (-)	Agro-chemical and soil sink (+)	Maximize catch fish income

Note: NA means not applicable

Reading down a column shows the costs and benefits imposed by the stakeholder whose name appears at the top on all other stakeholders in the watershed. For example, the column for dairy/cattle farmers shows that in pursuing their own income maximization, these farmers deforest land and contribute to the siltation of the reservoirs that feed ICE’s power plants and reduces the recharge of Lake Arenal in drought years. These impacts have direct costs for ICE and the irrigated farms, which are represented by the off-diagonal elements in the dairy/cattle farmers’ column. Similarly, the irrigated farmers generate agro-chemical pollution and soil runoff that negatively affects the wetland and the fishermen, and these costs are represented in the off-diagonal elements in the column for irrigated farms. On the other hand, the wetlands generate positive environmental benefits for the fishermen since greater conservation leads to more absorption of agro-chemical and soil runoff in wetland “sinks”, reducing their flow to the Nicoya Gulf (this positive externality is indicated by a “+” sign in the Payoff Matrix). However, by increasing bird populations, greater conservation of the wetland leads to increased bird damage of irrigated crops, which is a cost for irrigated farmers. ICE imposes costs on the tilapia farm, irrigated farms and the wetland because its pursuit of optimal electricity production for the nation leads to irregular flows of water downstream, both seasonally and hourly, that do not match with the needs of downstream users.

The rows in Table 3.1 show, for each stakeholder group, the value of their own output (the diagonal entry) and the costs or benefit imposed on that stakeholder by other groups in the watershed. For example, the row for irrigated farms shows their own income on the diagonal, and the costs these farmers suffer from irregular water flows and reduced water availability in drought years that result from the actions of the dairy/cattle farmers and ICE. The lower down the watershed a stakeholder is located, then the more likely they are to be affected by the actions of everybody else upstream, and hence the more off-diagonal entries there are in their row.

Table 3.1 also provides insights into the relative bargaining power of each stakeholder, the other stakeholders they need to negotiate with, and who their natural allies might be. For example, reading across a row in the table shows all the other stakeholders that the stakeholder whose name appears on that row needs to negotiate with to minimize (maximize) the costs and benefits imposed on them. The more entries there are in the row, then the weaker the stakeholders’ negotiating power is likely to be. This is because they then face high transactions costs in entering into so many negotiated settlements. At the same time, the off-diagonal entries in the column of the stakeholders they need to negotiate with show other stakeholders who could be potential allies. For example, the tilapia farm faces a relatively simple negotiating problem. They are only negatively affected by the actions of ICE (irregular water flows) and hence have only one serious negotiation to encounter. But ICE is a powerful adversary, and the tilapia farm may need allies to help it. Fortunately, ICE's decisions about water flows also impact negatively on the irrigated farms and the wetland, so these stakeholders might be willing to collude with the tilapia farm in negotiations with ICE. In practice, the tilapia farm has been successful in negotiating a solution with ICE (see Chapter 6), which may reflect the relatively simple bargaining problem indicated by Table 3.1. On the other hand, the wetland in negatively affected by the decisions of the dairy and cattle farmers, ICE and the irrigated farmers, and hence the park management has a larger number of problems to solve with a greater number of stakeholders. They also have few potential allies for addressing agro-chemical pollution other than the fishermen who are poorly organized. Not surprisingly, there has been little resolution of the agro-chemical pollution problem in the watershed.

In the next chapter, a formal model is used to quantify many of the entries in the payoff matrix for the Arenal-Tempisque watershed. Attaching dollar values to all the entries in the matrix gives a greater sense of which costs and benefits are really important in the watershed, the economic incentive that various institutions may have to negotiate, and the potential social gains or loses arising from such bargaining processes.

CONCLUSIONS

The management of the Arenal-Tempisque watershed illustrates many of the environmental problems that haunt similar watersheds around the world. Each sector of the watershed is managed by stakeholders who pursue their own narrow interests, and in so doing impose important but unintended environmental costs and benefits on other stakeholders further downstream. An apparent inability of the relevant stakeholders to come together and negotiate a common solution to their problems means that the watershed is managed in a sub-optimal way that not only reduces aggregate social benefits, but also undermines the long-term sustainability of the system. It is a watershed that would benefit greatly from a policy relevant monitoring system that could improve the overall management of the system. Following chapters develop the components of such a system, and then discuss the kinds of institutional options that might enable the system to work.

4. AN ECONOMIC MODEL OF THE ARENAL-TEMPISQUE WATERSHED

Ujjayant Chakravorty and Yanjing Chen

INTRODUCTION

This chapter develops an economic model for the Arenal-Tempisque watershed that aims to capture the economic value of the most important activities in the watershed and estimate the value of the environmental externalities that result from these activities. Given that the case study is expected to serve as a prototype for a generic monitoring system, the modeling approach adopted was not to be comprehensive in terms of methodology and data collection, but provide a set of usable tools that can be adopted in a typical developing country setting where research budgets are severely constrained, the availability of reliable biophysical and economic data is a perennial problem and the resource and environmental degradation problems being modeled are exceedingly complex. An equally important objective of the modeling exercise is to show how the indicator information that is to be collected as part of the monitoring system feeds into the model and therefore becomes an integral part of the policy analysis. This is one important link that has been missing in the indicator work that has been done by development agencies until this point. Without an analytical framework, collection of indicator data becomes an end in itself and is difficult to prescribe in situations in which policy relevance is an important goal.

DESCRIPTION OF THE MODELING FRAMEWORK

Following the framework presented in Chapter 3, the model is divided into five modules, each of which is interconnected through biophysical relationships, such as the downstream flow of water, agricultural chemicals and sediments. Birds from the wetlands fly upstream into the rice fields in the irrigation district, and that is the only significant relationship modeled in the reverse, i.e., upstream direction. The model components are as follows:

a) The Arenal reservoir and catchment area
b) The ARCOSA hydropower generation complex
c) The Arenal-Tempisque irrigation district
d) The Palo Verde wetlands and national park, and
e) The Gulf of Nicoya marine estuary.

In the following sections we describe the modeling approach adopted for each of the above modules. The mathematical equations are given in the Appendix to this chapter. A more detailed description of the model can be obtained separately from the authors.

The Catchment System

The major land uses in the catchment area consist of tropical forests, dairy farms, cattle ranches, and smaller areas devoted to farming and residential use. Each of these land use patterns have differential impacts on the quality and quantity of water that flows down to the Arenal reservoir. Forests in the catchment watershed have important effects on the concentrations of nitrogen, acidity and dissolved oxygen in water (MacDonald et al. 1991, Likens et al. 1970). For instance, the nitrate concentration of streams draining forested areas averages about 0.23 mg/liter in the U.S. compared with an average of 3.2 mg/liter for agricultural lands (Omernik, 1976). Forests keep the pH value of water from becoming too low which in turn prevents the water from dissolving more oxygen. Relative to alternative land uses, sediment discharge from forest lands is small. Sediment loads from cropland are on average several times the rate from forests (Gianessi 1986).

Both dairy farms and cattle ranches produce livestock waste which release organic chemicals and nutrients into streams and rivers. Overgrazing of livestock causes soil erosion. Water flow from catchment areas is likely to increase with deforestation as pointed out by Aylward and Echeverria (2000). However, in the Arenal area, water flows are not a significant problem at least in the present time and therefore they are not modeled explicitly. ICE’s binding constraint seems to be the requirement that it must release a minimal amount of water for downstream irrigation, even during the hours of low electricity demand. Residential areas are also major sources of water pollution. Runoff from precipitation carries household products, pet wastes, yard applications, transportation fuel byproducts, sediment displaced from construction sites and other wastes into the river. All of these inflows increase the concentration of nutrients, sediments and toxins flowing downstream into Lake Arenal and the other reservoirs located downstream.

The aggregate revenue per hectare of forest includes both commercial and non-commercial values of the forest stock. The former includes the amortized revenues from logging of timber, assuming a standard forest rotation period while the latter includes environmental benefits from forestry such as flood control, biodiversity, soil erosion benefits and amenity values. The cost of maintaining each hectare of forest area includes amortized investment costs in forestry operations as well as harvesting, tree maintenance and other expenditures. We abstract from different types of forests and their differential time-dependent benefit and cost profiles. We distinguish between the market and non-market value of forestry services. The market value is computed as the profit from logging net the cost of maintaining the forest aggregated over the total area under forestry. The non-market value is the estimated environmental value of the forest that includes hydrologic benefits, eco-tourism, carbon sequestration and its value in pharmaceuticals. Non-market forest services are estimated to be \$158 per hectare per year, while the market value of standing forests is \$23 per hectare per year. Net benefits from the upstream forest are the sum of market and non-market values times the total forest area.

It is assumed that 50 percent of the land under pasture is used for dairying and another 50 percent for ranching. Two scenarios were run: one in which growth in dairy acreage increased by 3 percent a year and another where it remained constant. However in both scenarios, ranching acreage was assumed constant. This may be a reasonable assumption since dairying is much more profitable than ranching at current relative prices. A possible expansion of dairy operations and supporting area for forage production leads to a reduction in forest cover and increased soil erosion. Since ranching profits are a nonlinear function of herd size and other parameters, an average value for ranching profits is assumed. The present value of profits from ranching and dairying are assumed to be \$43/ha and \$2,175/ha.

The catchment area comprises of approximately 50,000 ha of which 20,000 ha is under forest cover ranging from secondary to dense forest cover. Another 18,307 ha are used for pasture and 1,586 ha for crops. We assume that 50 percent of the pasture is for dairy operations (9,153.5 ha) and while the remaining is rangeland. All the cropping in the catchment area is assumed to be used for forage production.

There is no reliable information on sediment rates in the catchment area for different types of land uses. Aylward et al (1998) uses values ranging from 13 to 28 tons/ha for different types of pasture. However studies in Honduras and other regions have shown that soil erosion is much higher on hillsides with slopes of 25 percent or more (Barbier and Bergeron, 1998). In lands covered with permanent grasses and with modest slopes, soil erosion is more in the order of 5 tons/hectare.

We have thus made the following assumptions in running the model and the various scenarios. Forest lands are assumed to have no erosion. Pasture lands (approximately 18,000 ha) are assumed to erode at the rate of 5 tons/hectare/year. Crop lands under perennial and annual crops (1,586 ha) are assumed to lose 15 tons/hectare/year. We do not differentiate between emissions per hectare and the final sediment accumulation in the water and take this figure as the relevant sediment load being carried downstream to the reservoirs. When performing a sensitivity analysis with an assumed annual growth in pasture, we assume that this growth is at the expense of forests and there is another 3 percent growth in forage crop acreage that encroaches upon the forest area. Given the importance of forests in the Costa Rican economy, it is hard to visualize a situation in which encroachment and cutting down of forests on a significant scale will be tolerated. However, when we did scenarios where dairying area increased at the expense of pasture, there was hardly any change in the results. So, the encroachment into forest land should be taken as a polar case that could be approached through destructive land use practices but not very likely to happen.

Profits from dairy farming and cattle ranching respectively are computed as net revenue (revenue net of costs) times aggregate acreage. Then the present value of aggregate benefits from land use in the entire catchment can be written as the discounted sum of annual profits from forestry, ranching and dairying.

Changes in land use patterns over time are reasonable to expect, given changes in profitability of the alternatives from longer-term variations in market prices or government policy. Although the model is dynamic, we assume no policy-induced changes in land use shares over the period studied simply because of the difficulty of predicting how market forces and government policy will impact acreage shifts in the catchment area.

To avoid double counting, the externality damages from sediments and chemicals discharged by upstream activities are evaluated in the modules downstream of the catchment area. Although the above methodology allows for evaluation of benefits and costs for all the major land use categories in the catchment area, due to limitations in data availability, we have only analyzed three activities: forestry, dairying and ranching. For the same reason, we only examined the effect of sedimentation from the catchment area on the downstream reservoirs.

Externalities such as damage from chemical pollution in the catchment area and the effect of sedimentation on downstream segments beyond the reservoir such as on irrigation, the Palo Verde wetlands and the Nicoya Gulf were not considered. It is possible that these segments could be included in later runs if further data becomes available. Other sources of pollution such as from chemicals may be important locally or episodically (such as immediately after a heavy rainfall or flooding) but have yet to be recognized as major environmental problems.

The ARCOSA Hydroelectric Complex

The demand for electricity is assumed to grow at an annual rate of 6 percent based on historic growth rates. The three power plants─Arenal, Corobicí and Sandillal respectively are located in series. Lake Arenal is the reservoir that feeds the Arenal power plant. The water is then piped to the Santa Rosa reservoir which supplies water to the Corobicí power plant. The third and last plant in the series is the Sandillal reservoir, which supplies water to the Sandillal power plant. Details of the physical features of the three plants and their reservoirs are provided in Chapter 3. However, it is important to note two features that have a bearing on the magnitude of the environmental externalities calculated by the model. The Arenal reservoir, the first in the series, is relatively much bigger than the other two. Its usable volume is 2 billion cubic meters, compared to 0.1 million cubic meters and 5.15 million cubic meters for the Santa Rosa and Sandillal reservoirs, respectively. Thus siltation from the catchment has very little impact on the Arenal Lake, but even if a small proportion of the silt ends up in the Santa Rosa reservoir, the Corobicí power plant is affected through a reduced capacity for power generation.

Secondly, the average costs of power generation are different across the three power plants. Corobicí is the cheapest at 1.56c/KWH, followed by Arenal at 2.83 c/KWH and Sandillal is the most expensive at 7.90c/KWH. Since the Santa Rosa reservoir feeding the Corobicí is the weak link in the chain, increased siltation from the upstream will force ICE to shift power generation to the more expensive Arenal reservoir in future years as demand continues to grow and supply becomes constrained because of siltation in the Santa Rosa.

The effect of increased siltation and consequent reduction in the usable volume of the power plants is computed as follows. First, we measure the volume of sediment that accumulates annually in each reservoir and compute the ratio of accumulated sediment volume to the usable capacity of the reservoir. For example, if the volume of sediment that accumulates in a reservoir is half its usable volume, then we assume that the plant can only produce at 50 percent capacity.

ICE is legislated to provide a certain volume of water to the irrigation authority SENARA so that there is enough water for agriculture as well as a small but fast growing aquaculture industry downstream of the reservoir. This limitation may impose a binding constraint on capacity utilization by ICE and therefore the aggregate revenue from electricity. However, the economic value of the aquaculture industry is small relative to other sectors such as agriculture and fisheries and we abstract from considering it in the model.

Because electricity demand and water availability vary markedly across seasons, the model is run separately in the dry (January to June) and wet (July to December) seasons. We assume that ICE is required to provide a minimum flow of 12 m^3/sec of water to SENARA. In the rainy season, the Arenal and Corobicí plants together can meet the electricity demand at night. If there was no requirement to release water to SENARA, then water could be stored in the Sandillal reservoir to be used to produce electricity during peak demand periods. Given the demand for water from irrigation, ICE ceases production in the Arenal and Corobicí plants at night and puts the generator in Sandillal into operation. Therefore, there is an opportunity cost of releasing water to SENARA in the rainy season.

The production of electricity from each plant is assumed to be a function of the amount of water flow through the turbines (Aylward et al, 1998). The parameters of the production function may differ with each power plant depending upon the size of the turbine. The aggregate electricity produced in the dry season is the daily production times the average number of operating days in the dry season for each power plant net of transmission losses. When summed over all power plants and multiplied by the price of electricity, this gives the aggregate revenue from electricity generation in the dry season. Profits are computed by netting out the cost of electricity generation for each plant.

We assume that production and cost characteristics do not change over time. However, the demand for electricity is expected to change with time because of economic and industrial growth as well as growth in population. Similarly, the water flow may change over time, which in turn will affect the electricity produced. The output price of electricity is taken to be 5.26c/KWH. Total electricity transmission losses are assumed at 2.4 percent as per ICE data.

The rainy season follows the same pattern of production as in the dry season except that now there is surplus water flow available for electricity generation. The availability of water is no longer a constraint and electricity is produced to meet demand at any given instant. The daily operating time in hours for each of the three plants is a function of the demand for electricity and the total electricity produced in the rainy season. The model utilizes the plants in order of increasing average cost of producing power. The annual profit function for electricity generation is the sum of profits from the dry and rainy seasons. The discounted profit function for a given model time horizon is obtained by summing up profits from each year.

The Arenal-Tempisque Irrigation District

The water district maximizes profits from agricultural production. The irrigation agency SENARA distributes water to farmers at flat rate prices. Farmers use water and chemical inputs to grow crops that are then sold at competitive prices. However, both the chemicals and the volume of water used in irrigation affect the wetlands downstream of the irrigation project. Thus the model needs to account for the water and the chemicals used at the farm level. Because of the difference in water availability and cropping patterns across seasons, the dry and rainy seasons are considered separately.

The irrigated acreage is 20,000 ha. The major crops grown are rice with 50 percent of the total acreage, sugarcane with 38 percent and fruits, particularly melons, which has a small acreage (0.03 percent) but is expected to grow as marketing and other infrastructural constraints to melon exports are removed over time. Other crops occupy the remaining 12 percent of the irrigated land. In the future, SENARA expects rice acreage to go down from 50 percent to 40 percent and sugarcane area to decrease from 37 percent to 14.3 percent. Fruits including melons are expected to go up to 15.8 percent of the total, while other crops make up the remaining 30 percent. For the expanded project covering 40,000 ha, we adopt these expected acreages for our analysis.

Bird damage from the wetlands to the rice fields located upstream is modeled by assuming that rice fields in the immediate proximity of the wetlands are the most affected. We do not distinguish between individual rice fields but assume that an average area of 7,000 hectares of rice is affected by bird attacks from the wetlands. This figure approximates the area of rice fields in the neighborhood of the wetlands (McCoy, et el, 2000). Some rice fields could be more prone, while others in more remote locations may be less affected, but we abstain from such consideration. The birds eat rice seedlings and farmers use a variety of methods to control damage from birds (mainly waterfowl) including fireworks, hiring workers to scare away birds at night and using detonators during the critical first 2–3 weeks of the planting season. According to the data, most of the bird damage occurs during this critical period. The cost of scaring birds is used as an estimate of bird damage.

Total damage days from birds was taken to be 20 days for each rice-growing season. The damage to rice fields is approximated by the incremental cost of preventing bird damage through hiring of labor to drive away the birds, estimated to be $15 per day. Under SENARA's expansion plans, irrigated area will increase to 40,000 ha and the corresponding area affected by bird damage will double to 14,000 ha. The profits from irrigation are computed net of bird damage.

Dry season: The production function per unit area for any given crop is assumed to be a function of water and chemicals used. A simple Cobb-Douglas production function is used. It suggests that the contribution of pesticides and fertilizers to yield increase at a decreasing rate. For simplicity, the output price of agricultural product of the crop is assumed constant. The aggregate quantity of chemicals used in agriculture in the dry season is a three-dimensional vector, representing the aggregate amount of nitrogen, phosphorus and chlorides used. Chemicals used per hectare are aggregated over the crop acreage. The water tariff is a flat land tax.

We have only considered irrigated agriculture in the dry season, since the proportion of area in rainfed farming is likely to be small, as also the degree of chemical use. The profit from farming in the dry season is the total revenue from farming minus the variable costs of water and chemicals and the fixed costs of farming. The aggregate amount of water used in irrigation in the dry season is the water used by each crop summed over its acreage taking into account losses in the system due to evaporation, seepage and percolation. If this number is larger than the water released by ICE in the dry season, it will imply water scarcity in the irrigated area.

Data on water requirements, chemical application and the cost of production for the major crops was used to estimate the Cobb-Douglas production function. For sugarcane, costs are adjusted depending on whether it is a new or established crop.

Rainy season: Profits from irrigated farming in the rainy season are computed in the same manner as above with price, cost and production data for crops grown in the rainy season. The present value of profits from irrigation is written as the discounted sum of annual profits from dry and wet season agriculture.

The Palo Verde Wetlands

Studies have shown that wetlands and mangroves are not only habitats for wildlife and sources of recreation but help recharge groundwater aquifers and reduce flooding. In the Palo Verde area, there is a large amount of anecdotal evidence that upstream water pollution caused by irrigated agriculture has had a negative impact on the environmental services provided by wetland and mangrove systems. Observers have on several occasions noticed cracked bird eggshells in the wetlands, suggesting possible adverse environmental conditions. This is of serious concern since Palo Verde is the major bird sanctuary in Central America and is host to thousands of migratory birds flying between the north and south. Because of a critical lack of quantitative information, we do not have any way of measuring the precise impact of chemical pollution from agriculture on the wetland system. We therefore consider two different scenarios: low and high chemical damage. Since there is almost no separate data available for mangroves in the Palo Verde area, and the environmental services from the mangroves are not distinguishable (at least, statistically) from those of the wetlands, we have included the area under mangroves as part of the wetlands system.

If the contaminated water is treated before it runs into the wetlands, then the concentration of chemicals in the water may be low enough that the residual chemicals could degrade in the wetlands without affecting the environmental services from the wetland system. In that case, the environmental damage would be zero. The value of wetland services in any given year are assumed to be the total acreage under wetlands times the estimated annual value of wetland services per hectare.

If the water quality entering the wetland is lower than the threshold value below which the wetland is not affected, then a positive degree of damage will occur. According to some analysts (Celis, 1999), nitrates, chlorides and phosphates are the main agro-chemicals that cause significant damage to the Palo Verde wetlands. The sediment load and the volume of runoff from irrigation will also affect the pH balance of the wetland. Therefore, we specify the damage to wetland services as a function of the chemical concentrations and the sediment load in the irrigation runoff.

The above specification does not include the capacity of the wetland to purify water. We assume that when the contaminated water enters the wetland, part of the chemicals will be degraded by the wetland, another part will accumulate in the wetland and over time diminish its cleansing capacity, and part of the chemical load will pass through the wetlands and into the downstream ecosystem. Each of the chemical contaminants are measured per year and then aggregated over time to yield cumulative damage concentrations.

The damage to the wetlands is formulated in terms of a reduction in effective area of the wetlands. This allows us, in the absence of any quantitative data, to model low and high damage scenarios under which the effective area of wetland services is reduced through pollution to a smaller or larger degree, respectively. The wetlands are totally damaged when its effective area is reduced to zero. The effective life of the wetlands under alternative damage and irrigated area assumptions are calculated by the model. The net present value of wetland services is computed as before. Wetland services can be disaggregated by season if seasonal variations are found to be significant.

The wetland area is assumed to be 20,000 ha. Social benefits from the Palo Verde wetlands are hard to compute so we have used reasonable benefit values of wetlands from the literature, estimated to be $200 per hectare per year (Ruitenbeek, 1994 and Costanza et al, 1989). The cleansing effect of the wetlands is modeled as follows: Suppose, x kilograms of chemicals are applied in the irrigation project annually, then only 0.3x of the chemicals accumulate in the wetlands and an additional 0.3x goes to the Nicoya Gulf. The remaining 0.4x are lost through cleaning by the wetlands. The low damage scenario assumes that the residual 0.3x damages 10 percent of the aggregate wetland area each year. The high damage scenario assumes that 50 percent of the wetlands are damaged annually. This year's residual chemicals (0.3x) are then added to next year's inflow (say y) and the total inflow is given by 0.3x+y. So in year 2, 0.3 of (0.3x+y) remains in the wetlands. The damaged area of the wetlands is assumed to provide no benefits while the undamaged area provides full social benefits. The mangrove area is treated as being part of the wetlands. The variable x represents the aggregate chemicals used in the base year. When the acreage is doubled under the expansion phase, then the impacts under low and high damage are correspondingly doubled. Although the sediment load also affects wetlands services and is included in the model specification, it is left out of the actual calculations because of a lack of data.

Fishery

Water pollution due to agricultural chemical use tends to reduce the stock of fish and thus increase the cost of fishing. At the same time, it decreases the demand for fish, because the water pollution affects the quality of fish. Increased pollution loads in the water will decrease water quality. The fisheries in the Nicoya Gulf are divided into three distinct zones. Zone I is closest to the wetlands, and zone III is the farthest. The effect of pollution may be most significant in zone I, with the least impact in zone III. The fishery is partitioned into three zones because that is the way catch and value data were made available for the case study.

We assume that agricultural chemicals are the only source of pollution. In other words, water quality is decided by the amount of chemicals used in irrigation that accumulate in the fisheries after passing through the wetlands. As done for the wetlands, we can calculate the residual chemical and sediment concentration that accumulates in the Gulf after passing through the wetlands each year. Then water quality in the Gulf is a function of each of the chemical concentrations, modeled exactly as in the case of the wetlands. Again, we consider two damage scenarios that account for low and high impacts on fisheries output from the gulf. The low and high damage scenario is the same as in the wetlands, except that the incoming flow of chemicals is 0.3x in the base case (see previous section). The low (high) damage case is assumed to equal a 10 (50) percent damage to the value of fish catches from the Nicoya Gulf.

Annual net benefits from each zone are computed and summed over all zones and years to give the present value of net benefits from the fishery.

The Objective function

The total present value of net benefits from the system is computed by adding up the net benefits from all the five components of the system over an infinite planning horizon. The model computes the maximum benefit for each module. For example, it calculates the discounted net benefits from land use in the catchment area and the discounted benefits from power generation in the hydroelectric complex. It is a model that is calibrated to current land use and other parameters in the watershed and is therefore not an optimization model. That is, the constraints governing land use and technology choice determine the private economic solution as if each stakeholder is operating independently of the others. Thus, the model does not internalize the externalities. In some cases, as discussed later, the value of the externality imposed may be greater than the benefit accruing from the action causing the externality. The value of dairying may be lower than the externality it imposes on power generation. A model that computes the social optimum will reduce dairying to zero. The model proposed here works with an implicit equality constraint that treats dairying acreage as a parameter whose value is exogenously given.

The integration of the model components allows us to examine the systemwide effects of policy changes. In particular, it helps in the measurement of gains and losses to stakeholders from changes in parameter values within any particular module. For instance, increased dairying activities in the upstream will lead to a faster siltation of the Santa Rosa reservoir, which in turn will force ICE to switch power generation to the more expensive Arenal and Sandillal plants. Thus, while increased area to dairying will increase net benefits in the catchment, it will decrease net benefits to ICE by raising the cost of power generation. In the next section we discuss the use of a payoff matrix to separate out the own sector impacts (e.g., benefits from dairying and ranching) from the externality impacts (e.g., cost of siltation to ICE). Similarly, higher chemical use in agriculture will mean reduced wetland services, which in turn will mean less cleansing of the pollution that enters the Gulf fishery. On the other hand, reduced wetlands acreage will mean lower bird populations, and reduced bird damage to upstream rice farms. In the following, these effects are estimated quantitatively under alternative damage scenarios.

Furthermore, although not attempted here, policy makers could quantify their goals (e.g., introduce green objectives) by according increased weights to certain stakeholders (e.g., wetlands) based on philosophical or equity considerations. Such alterations could be handled in the model in a straightforward fashion, possibly in future work.

THE MODEL RESULTS

Magnitude of Externality Damages

The baseline results are consolidated in the payoff matrix shown in Table 4.1. These figures are discounted net benefits from an infinite horizon model, using a discount rate of 6 percent. This scenario assumes a three percent rate of growth per year in dairying acreage, 20,000 ha of irrigated farming and the low damage case for impact of chemicals on the wetlands and fisheries. Diagonal elements show potential private benefits for each sector when no externality impacts are imposed upon it. Off-diagonal elements are externality costs imposed by the column sector upon the row actor. Row sums give realized benefits for each sector, i.e., potential benefit adjusted for all externality costs and benefits that affect that sector.

TABLE 4.1—Baseline payoff matrix (in present values)

	Forest	Dairy & Ranching	ICE	Irrigation	Wetlands	Fishermen	Realized Benefits
Forest	39.7						39.7
Dairy and Ranching		38					38
ICE		-703.1	1821.6				1118.5
Irrigation				195.0	-20.1		174.9
Wetlands				-51.6	70.7		19.1
Fishermen				-111.6	16.9	121.2	26.5
Net Benefit	39.7	-665.1	1821.6	31.8	67.5	121.2	1416.7

(3 percent growth in dairying, high damage, 20000 ha irrigation)

Column sums give the net benefit contributed by each sector, i.e., its potential benefit adjusted for all externality costs and benefits that are generated by the sector.

For the region as a whole, the total potential benefits are $2286.2 million, which is the sum of the diagonal terms. The total externality costs and benefits equal $869.5 million of which the big ticket items are erosion damages imposed by dairy and ranching on ICE ($703.1 million) followed by those imposed by irrigation on the fisheries and wetlands. The wetlands have positive externality effects on fisheries because of their pollution cleansing functions, and negative bird damage effects on upstream farmers. Note that except the positive externality of the wetlands on fisheries, all other externality (off-diagonal) impacts are negative. Subtracting the externalities from the total potential benefits gives us the total realized benefits of $1416.7 million, shown on the bottom right hand corner of the table. These externalities do not include any corrective actions taken by the affected stakeholders.

ICE and irrigation are the main sources of potential and realized benefits, together accounting for 88 percent of potential benefits and 91 percent of realized benefits. Dairy and ranching produce negative net benefits equal to $665.1 million because of their high externality costs. From a strictly economic efficiency point of view, these activities should not be undertaken in this watershed. Irrigated farming also has large externality costs because of chemical pollution of water affecting the wetlands and the fishing grounds. Net benefit from irrigation is only 16 percent of potential benefit.

Total externality costs ($869.5 million) amount to $0.38 per dollar of potential benefit in the region, and to $0.61 per dollar of realized benefit. This is an enormous cost burden on the region. Another way to look at it is that the region’s total social welfare could be increased by a whopping 61 percent if these externalities could be avoided.

The most serious externalities are caused by deforestation by dairy farmers and ranchers, and chemical pollution by irrigated farmers. The big losers are ICE (which bears 81 percent of total damage), the fishermen (who bear 11 percent), and the wetlands (which bear about 6 percent).

Note that the payoff matrix not only shows the extent of damage to different stakeholders, but also which stakeholders the losers need to negotiate with to resolve externalities and who their natural allies should be. This will be analyzed in more detail in Chapter 7.

The Choice of a Discount Rate

How does the discount rate affect these key results, particularly the ratio of externality costs to potential benefits and the relative importance of deforestation and chemical pollution? Table 4.2 summarizes the main results under three alternative choices of the discount rate.

Table 4.2—Benefits and externality costs under alternative discount rates

	Discount 1 percent	Discount 6 percent	Discount 12 percent
Potential benefits	14577.9	2286.2	1101.3
Externality costs:			
Total	7808.9	869.5	290.3
percent deforestation	86.3	80.9	72.6
percent chemicals	13.3	16.8	21.8
Realized benefits	6705.0	1416.7	811.0
Damage/$ realized benefit	1.16	0.61	0.36
Damage/$potential benefit	0.54	0.38	0.26

(3 percent dairy growth; 20,000 ha irrigation; and low chemical damage)

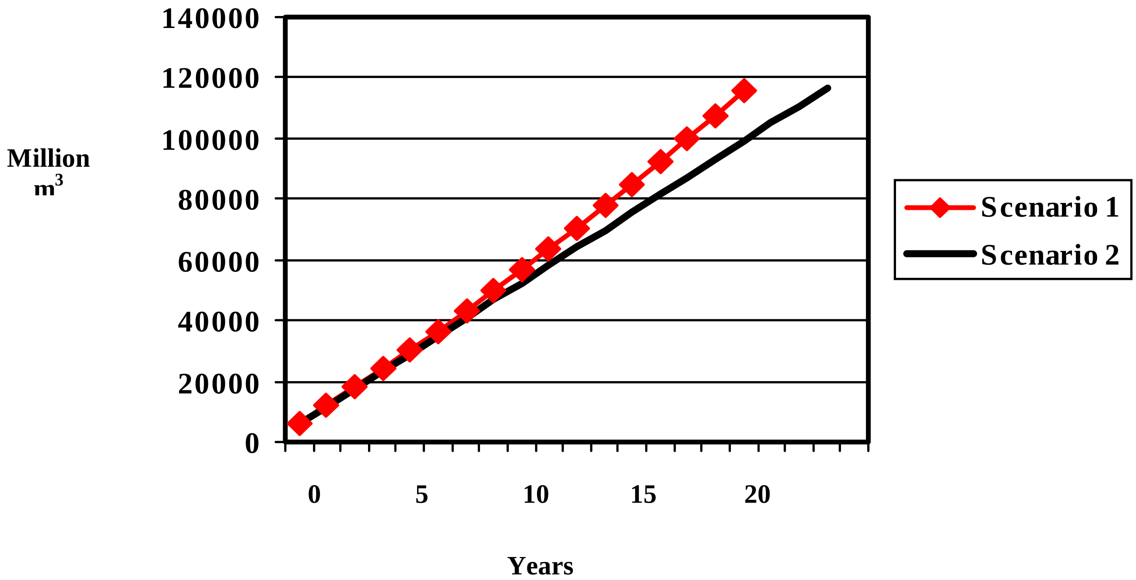
As the discount rate increases, benefits from power generation, which dominate the results, are more heavily discounted. Thus upstream externality costs, which are directly dependent on siltation of the reservoirs and the increased costs of power generation, decrease as a fraction of aggregate benefits. However, even at a high 12 percent rate of discount, externality damages are still 26 cents per dollar of potential benefit.

Effect of Upstream Deforestation on Power Generation

Given the high externality costs imposed by dairy farmers and irrigated farmers on ICE, it is important to discuss the sensitivity of the results to key model assumptions, and explore scenarios for reducing these costs. The impact of alternative sedimentation rates on power generation can be understood by examining the architecture of the Arenal reservoir system. Recall that the Corobicí power plant is the most profitable because it generates power at the lowest unit cost. However, it also has the smallest reservoir (Santa Rosa) of the three units, with a size that is a fraction of the other two reservoirs. This reservoir gets silted the quickest, while increases in sediment loads (say, from increased dairying) do not affect the larger Arenal reservoir. The Sandillal reservoir is the most expensive of the three and is primarily used to ensure constant flow of water to the irrigation system.

Since Lake Arenal is the first reservoir in the series followed by Santa Rosa and Sandillal, respectively, and its storage capacity is 2.0 billion cubic meters relative to 5.15 million cubic meters for Sandillal and 0.14 million cubic meters for Santa Rosa, we make the conservative assumption that 90 percent of the sediment load in Lake Arenal is dead storage and the remaining 10 percent is live storage. Thus, suppose for simplicity that 100 tons of sediment enter Lake Arenal. Then 90 tons is dead storage and 10 tons is live storage which then enters Santa Rosa. Half of this 10 tons (5 tons) accumulates in Santa Rosa as dead storage and the remaining passes into Sandillal and accumulates there. Santa Rosa is the weak link in the chain and is likely to get silted first. The usable volume of Lake Arenal is over 14,000 times that of Santa Rosa, and there is no danger of Lake Arenal being silted even in 500 years. It is important to understand these numbers because the upstream externalities in the model are driven by the rapid siltation of Santa Rosa. Fig 4.1 shows the siltation of the Santa Rosa reservoir under assumptions of constant upstream land use and an increase in dairying acreage.

Figure 4.1—Sediment accumulation in the Santa Rosa Reservoir



Scenario 1: Upstream pastures (includes dairy farms and ranchers) have an erosion rate of 5 tons per ha per year; farmland has an erosion rate of 15 tons per ha per year, while forests have no erosion. Dairy farm acreage increases at 3 percent per year.

Scenario 2: Scenario 1 with dairy farm acreage constant over time.

Note: The reservoir will be totally silted in 17 (20) years under Scenario 1(2).

The total usable volume of the reservoir is 0.11 million cubic meters and it silts completely in 17-20 years under the two scenarios. A high rate of siltation or serious adverse land use changes upstream could cause the reservoir to silt in 5-10 years depending on the precise erosion assumptions.

With increased siltation, production moves from low cost Corobicí to high cost Arenal, and thus ICE's profits are reduced. This situation of course does not take into account the possibility that ICE could dredge the reservoirs at reasonable cost. Table 4.3 shows the annual profits from electricity generation for the same two erosion scenarios.

Table 4.3—Effect of a 3 percent growth in dairying acreage

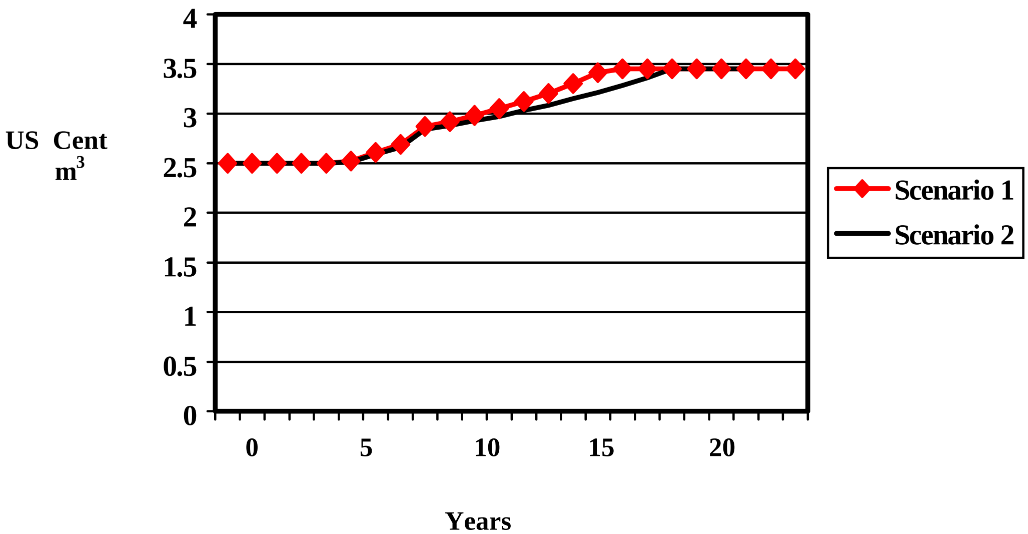
Net Benefits	Dairying Grows at 3 percent per Annum	No Dairy Expansion
Forest	39.7	61.4
Dairy and Ranching	-665.1	-642.6
ICE	1821.6	1821.6
Irrigated Farms	31.8	31.8
Wetlands	67.5	67.5
Fisheries	121.2	121.2
Total	1416.7	1460.9

(low damage)

The differences are significant but not huge. Benefits from forestry decrease with dairy growth because of the assumed encroachment of dairy and forage cropland into forestland. The added negative impact through increased siltation is valued at $22.5 million, which is the cost to ICE of the increased siltation of the Santa Rosa. Total net (and realized) benefit for the region decreases by about 3.0 percent with growth in dairying. This comparison suggests that current rates of erosion and their externality costs are already significant and further erosion will only magnify the impact. On the flip side, there may be significant benefits from a sharp reduction in upstream erosion. The results also suggest a relatively straightforward and possibly cost effective alternative solution: repeated dredging of the Santa Rosa reservoir.

Figure 4.2 shows the average cost of electricity generation, which increases with increased dairying. Siltation of the Santa Rosa forces ICE to move power generation from Corobicí to the more expensive Arenal plant.

Figure 4.2—Average cost of electricity generation



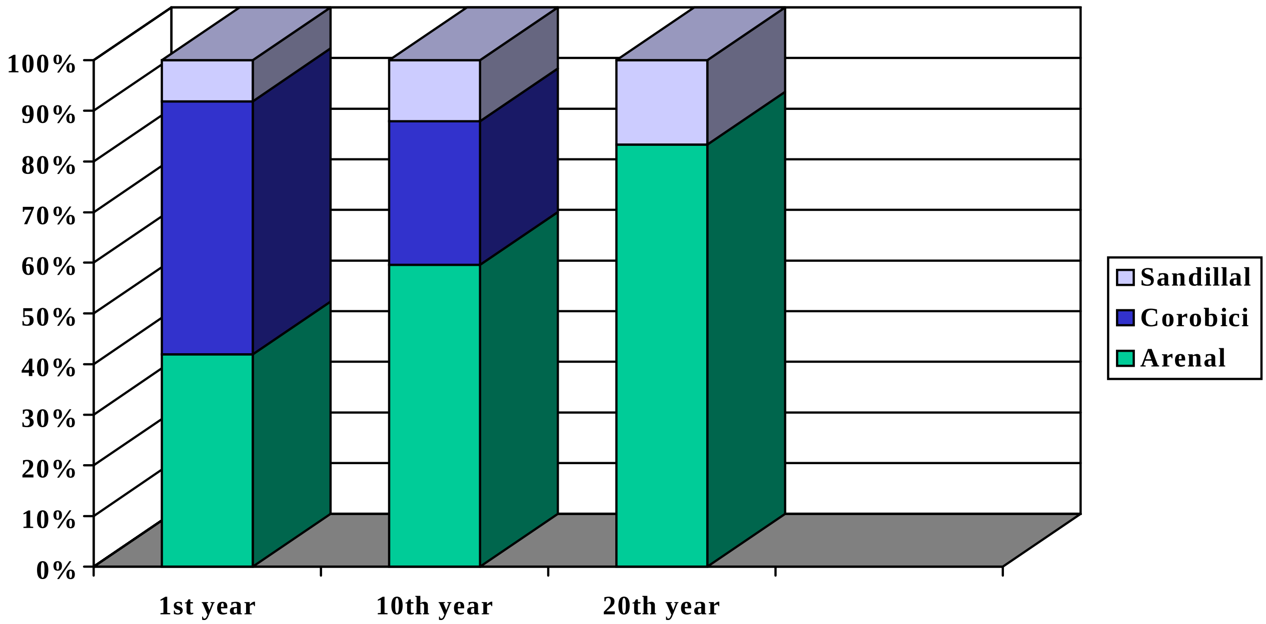
Scenario 1: Upstream pastures (includes dairy farms and ranchers) have an erosion rate of 5 tons per ha per year; farmland has an erosion rate of 15 tons per ha per year, while forests have no erosion. Dairy farm acreage increases at 3 percent per year.

Scenario 2: Scenario 1 with dairy farm acreage constant over time.

Note: With increased siltation from dairy expansion, the cost of electricity generation increases under Scenario 1 because of faster siltation of the Santa Rosa reservoir. Both costs converge when Santa Rosa is completely silted.

However, the cost curves do not diverge until about 5 years when the siltation begins to diminish the capacity of Corobicí to produce the electricity units demanded. These results assume a 6 percent annual growth in electricity demand, as specified earlier. The mix of electricity generation from the three power plants is shown in Figure 4.3.

Figure 4.3 Electricity generation mix over time



In the beginning Corobicí produces 50 percent of the power, Arenal 42 percent followed by Sandillal (8 percent). In 20 years, Arenal produces 83 percent, while Sandillal produces the remaining 17 percent and Corobicí is completely silted, unless dredging or other measures are taken.

Downstream Impacts of Chemical Pollution from Agriculture

Table 4.4 shows the same baseline payoff matrix shown in Table 4.1 but under assumptions of high damage from chemicals on the wetlands and fisheries. Notice that the numbers do change but not drastically. The benefits and externality costs upstream of the irrigated agriculture are obviously the same as before. Realized benefits from the whole system decline by about $21 million. High chemical damage further reduces the social benefit of irrigation net of externalities to only about $6 million. The social benefit from wetlands increases marginally because of their cleansing services. Negative impacts of farming upon the wetlands increase from $51.6 to $67.8 million, but the magnitude of bird damages also decreases from $20.1 to $3.1 million since the wetlands die faster in this high damage scenario.

Table 4.4—Baseline payoff matrix under high chemical damage

	Forest	Dairy & Ranching	ICE	Irrigation	Wetlands	Fishermen	Realized Benefits
Forest	39.7						39.7
Dairy and Ranching		38					38
ICE		-703.1	1821.6				1118.5
Irrigation				195.0	-3.1		191.9
Wetlands				-67.8	70.7		2.9
Fishermen				-121.2	4.2	121.2	4.2
Net Benefit	39.7	-665.1	1821.6	6.0	71.8	121.2	1395.2

(3 percent growth in dairying, high damage, 20000 ha irrigation)

Table 4.5 shows the payoff matrix for high damage when the irrigation area is extended to 40,000 ha.

Table 4.5—Payoff matrix under 40,000 ha of irrigated farming and high chemical damage

	Forest	Dairy & Ranching	ICE	Irrigation	Wetlands	Fishermen	Realized Benefits
Forest	39.7						39.7
Dairy & Ranching		38					38
ICE		-703.1	1821.6				1118.5
Irrigation				369.7	-1.5		368.2
Wetlands				-69.9	70.7		0.8
Fishermen				-121.2	1.3	121.2	1.3
Net Benefit	39.7	-703.1	1821.6	178.6	70.5	121.2	1566.5

(3 percent growth in dairying, high damage, 40,0000 ha irrigation)

This may be thought of as the worst-case scenario. Notice that the potential benefits from irrigation increase from 195 million in the baseline case to 370 million and the realized benefits from the region increase by about $150 million relative to the baseline case. However, the realized benefits from wetlands and fishing are nearly zero. The effects on the ecosystem are better explained when the effective life of the wetlands and fisheries under the alternative cases is examined below.

The results of sensitivity analysis with low and high damage scenarios and the planned expansion of irrigated area from 20,000 ha to 40,000 ha are summarized in Table 4.6 below.

Table 4.6—Downstream impacts of chemical pollution

Scenario	Irrigated Farms	Wetlands
Irrigated area 20,000 ha; Low damage		
Potential benefit	195.0	70.7
Externality costs:		
Irrigated farms	-	-20.1
Wetlands	-51.6	-
Fishermen	-111.6	16.9
Total	-163.2	-3.2
Net benefit	31.8	67.5
Irrigated area 20,000 ha; High damage		
Potential benefit	195.0	70.7
Externality costs:		
Irrigated farms	-	-3.1
Wetlands	-67.8	-
Fishermen	-121.2	4.2
Total	-189.0	1.1
Net benefit	6.0	71.8
Irrigated area 40,000 ha; Low damage		
Potential benefit	369.7	70.7
Externality costs:		
Irrigated farms	-	-26.0
Wetlands	-58.3	-
Fishermen	-116.9	12.7
Total	-175.2	-13.3
Net benefit	194.5	57.4
Irrigated area 40,000 ha; High damage		
Potential benefit	369.7	70.7
Externality costs:		
Irrigated farms	-	-1.5
Wetlands	-69.9	-
Fishermen	-121.2	1.3
Total	-191.1	-0.2
Net benefit	178.6	70.5

(constant dairy area)

The externality costs of irrigated farming are obviously higher under 40,000 ha but not by a significant margin. Benefits from increased crop production from acreage expansion equal $174.8 million. However, comparing the top and bottom cases, externality damages on wetlands increases by $18.3 million, and on fisheries by $9.6 million. Thus system benefits are much larger with expansion of irrigation. That is, the increased revenue from crop production outweighs the added environmental damage. Since the model does not have demand side effects, the benefits could be overestimated. It is possible that the output effect may reduce crop prices and reduce farm profits. On the other hand, this may also lead to added consumer surplus from lower food prices, which is not captured here.

The major impact of the chemicals can be seen from the estimated life of the wetlands and the coastal fisheries under these alternative scenarios, shown in Table 4.7. Additional runs were performed to see the effect of a 50 percent reduction in chemical use—because of Integrated Pest Management programs or other instruments such as taxes or quotas–on the life of the wetlands and fisheries ecosystems.

Table 4.7—Effective life of the wetland and fisheries in years

Scenario	Wetlands	Fisheries
Irrigated area 20,000 ha; Low damage	65	48
Reduced Chemical Use (50 percent)	135	99
Irrigated area 20,000 ha; High damage	9	5
Reduced Chemical Use (50 percent)	23	16
Irrigated area 40,000 ha; Low damage	38	28
Reduced Chemical Use (50 percent)	81	59
Irrigated area 40,000 ha; High damage	2	2
Reduced Chemical Use (50 percent)	12	8

Moving from low to high damage under 20,000 ha irrigation, the effective life of the wetlands declines from 65 years to 9 years and the fisheries from 48 to 5 years. Reduced chemical use under IPM and other alternative practices will increase wetland longevity from 65 to 135 years under the low damage case and 9 to 23 years under the high damage case. Under the planned expansion of irrigated area and assuming the high damage scenario holds, the wetlands die completely in 2 years. Even with reduced chemical use, it will last for only 12 years. The fisheries too survive for a much longer period (99 years) under reduced chemical use than in the business as usual scenario (48 years). Under high damage they survive for 8 years instead of 2 years.

The root cause of this divergence between the monetary and physical impacts from the model is the modest valuation we place on wetlands services at $200 per hectare. Higher valuations such as $2,000/ha will cause huge differences in the monetary payoffs from irrigation expansion or reduced chemical use. On the other hand, if the complete loss of the wetlands and coastal ecosystem in the near future is a socially unacceptable outcome, then the model suggests that immediate policy measures are necessary. The dollar estimates of benefits and costs obviously do not tell the whole story.

Table 4.8 shows the monetary impacts of policies that lead to a reduction in chemical use for 20,000 ha of irrigated farming. The base case is compared to two policies: a 40 percent tax on agricultural chemicals and IPM programs that reduce chemical use by 50 percent.

Table 4.8─Impacts of reduced chemical use (irrigated area, 20,000 ha)

Scenario	Irrigated Farms	Wetlands	Total
Irrigated area 20,000 ha; Low damage; No agro-chemical tax			
Potential benefit	195.0	70.7	265.7
Externality costs:			
Irrigated farms	-	-20.1	-20.1
Wetlands	-51.6	-	-51.6
Fishermen	-111.6	16.9	-99.7
Total	-163.2	-3.2	-166.4
Net benefit	31.8	67.5	99.3
Irrigated area 20,000 ha; Low damage; 40 percent agro-chemical tax			
Potential benefit	156.7	70.7	227.4
Tax revenue	31.2	-	31.2
Externality costs:			
Irrigated farms	-	-27.2	-27.2
Wetlands	-44.8	-	-44.8
Fishermen	-105.4	-20.7	-84.7
Total	-150.2	-6.5	-156.7
Net benefit	6.5	64.2	70.7
Irrigated area 20,000 ha; Low damage; IPM			
Potential benefit	195.0	70.7	265.7
Externality costs:			
Irrigated Farms	-	-32.5	-32.5
Wetlands	-39.8	-	-39.8
Fishermen	-100.2	-23.2	-77.0
Total	-140.0	-9.3	-149.3
Net benefit	55.0	61.4	116.4

Chemical taxes will reduce profits from irrigation by raising the cost of inputs. With a 40 percent chemical tax, net benefits from irrigation fall by $38.3 (from $195 to $156.7 million). Wetlands and fisheries benefits increase from reduced agro-chemical damage by $21.8 million but this is partly offset by an increase in bird damage on irrigated farms ($3.9 million). Adding up the change in net benefits and taxation revenue, there is a positive net economic benefit of 2.6 million. This gain arises because part of the externality cost of agro-chemical use has been successfully internalized under the taxation policy

We have assumed that IPM and other chemical reduction programs are costless, i.e., the government or the public sector bears all the costs of the programs. The table suggests that total gain in net benefit from IPM is $17.1 million ($116.4─$99.3 million). This estimate also gives an upper bound in terms of public funds that can be spent on a chemical reduction program.

The worst-case scenario to consider would be the 40,000 ha irrigated area with high chemical damage, shown in Table 4.9.

Table 4.9—Impacts of reduced chemical use (irrigated area, 40,000 ha)

Scenario	Irrigated Farms	Wetlands	Total
Irrigated area 40,000 ha; High damage; No agro-chemical tax			
Potential benefit	369.7	70.7	440.4
Externality costs:			
Irrigated farms	-	-1.5	-1.5
Wetlands	-69.9	-	-69.9
Fishermen	-121.2	1.3	-119.9
Total	-191.1	- 0.2	-191.3
Net benefit	178.6	70.5	249.1
Irrigated area 40,000 ha; High damage; 40 percent agro-chemical tax			
Potential benefit	262.9	70.7	333.6
Tax revenue	84.3		84.3
Externality costs:			
Irrigated farms	-	-5.4	-5.4
Wetlands	-68.1	-	-68.1
Fishermen	-121.2	3.7	-117.5
Total	-189.3	- 1.7	119.0
Net benefit	73.6	69.0	142.6
Irrigated area 40,000 ha; High damage; IPM			
Potential benefit	369.7	70.7	440.4
Externality costs:			
Irrigated farms	-	-8.7	-8.7
Wetlands	-66.6	-	-66.6
Fishermen	-121.2	5.8	-115.4
Total	-187.8	- 2.8	-190.6
Net benefit	181.9	67.8	249.7

Here the benefits of chemical reduction are less pronounced. This is because the externalities are so severe that reducing chemical use produces little benefit. Recall the earlier discussion of the impact of chemical use on the life of the wetlands in the high damage case. With taxation, irrigated farm profits go down by $106.8 million, and downstream benefits show a very small change. Even with tax revenues, system benefits under taxation decrease by $22.2 million. IPM programs increase overall benefits by only $0.6 million. These numbers of course hide the negative impacts on the ecosystem as measured by the life of the wetlands and fisheries discussed earlier.

Limitations of the Model

This chapter provides a simple framework for estimating economic values from pollution and sedimentation that can be coupled to a monitoring system for policy analysis for timely evaluation of trade-offs from policies that aim to control environmental degradation. The model has several limitations and may be sensitive to certain parameter values. For example, it is really not very clear what the precise effect of the siltation is on the life of each of the reservoirs. In particular, we need to better understand how silt moves in serially connected dams over time. The model is also sensitive to the assumed changes in land use patterns in the catchment area, but to a much lesser degree. For instance, as seen in the previous section, the 3 percent annual growth in dairying does not produce dramatically different results than an assumed continuation of the status quo. The model is quite sensitive to the low and high damage specifications for chemical use in the agriculture sector, especially in relation to the estimated life of the wetland and fisheries ecosystems. Under high damage scenarios, these services go to zero over a relatively short time horizon. This is in spite of the fact that we have allowed for self-cleansing of the wetland. Higher values of wetland services will increase the magnitude of environmental damages but not change the nature of results fundamentally. For instance, the externality impacts downstream of the dam may begin to approach those upstream of the dam, but even with relatively modest values for wetland services, the matrix of externality costs in the Gulf are significant enough to call for urgent policy attention.

The model results may be somewhat more sensitive to assumptions regarding the effect of pollution from the Tempisque river on the Nicoya Gulf. It is quite plausible that other sources of pollution such as from industrial wastes are more damaging than the chemicals flowing out of the wetlands. To that extent, the externalities may be overestimated. All these factors point to the severe data limitations of the study and suggest the need for collection of reliable time series data on the state of the resources in the watershed, which would be part of the monitoring system of which the model is but one component. However, the model is constructed in such a way that each module can be de-linked and upgraded or revised with new information over time.

IMPLICATIONS FOR THE MONITORING SYSTEM

The above numbers suggest that urgent steps need to be taken to monitor and control chemical use in the agricultural sector. Pending proposals for SENARA to increase the irrigated area are likely to have a serious adverse effect on the ecosystem. Measures need to be taken to develop indicators that isolate individual chemicals used in farming and rank the most damaging ones used in the region. These chemicals could be monitored on a periodic basis for information on any likely changes in their use patterns.

These model results also suggest the need for looking into technological fixes, such as adapting new pest resistant varieties of crops such as rice or more efficient spray methods, in lieu of the current inefficient method of spraying from the air.

What do the model results tell us about the monitoring system? In both the upstream and downstream reaches of the watershed, externalities impose very high costs. In both cases—siltation from the watershed and chemical use in farming—current activities need to be closely monitored for signs of worsening conditions and policies need to be developed for reduction in externality damages. In the watershed, policies that could make ranching and dairying less attractive would increase economic benefits. Technological fixes such as dredging of the reservoir or even building of additional reservoirs to take the silt load may be viable options.

In the downstream part of the watershed, policies must be adopted for farming with low chemical use. The need to consider such policies will lead to the possible development of new indicators for monitoring. Some possible indicators may involve monitoring the following activities: (i) grazing practices of upstream cattle (ii) prices of dairy products (iii) types of chemicals used in farming (iv) seed varieties and their fertilizer and pesticide requirements, and (v) inventory and measurement of biological prey and predators to pests. In Chapter 7, we revisit the model and explore in some detail, through a hypothetical illustration, how the model could be an integral part of the monitoring system.

Appendix 1:

LIST OF VARIABLES

The Catchment system

A_f	Catchment area under forestry
B_f	Aggregate social benefit per hectare of forest
C_f	Cost of maintaining each hectare of forest area
S_f	Weight (in tons) of sediment emissions per hectare of forestland per year
π_f	Net benefit from the upstream forests
π_{fj}	Net benefit from the upstream forests in the j^{th} year
A_d	Land area allocated to dairy operations
C_d	Annualized expenditure in the maintenance of each hectare of dairy farm
CH_d	Chemicals emitted per hectare of dairy farming
R_d	Revenue from each hectare of dairy farm
S_d	Sediment emission per hectare of dairy farming
π_d	Profits from upstream dairying operations
π_{dj}	Profits from upstream dairying operations in the j^{th} year
A_r	Land area devoted to cattle ranching
C_r	Cost of maintaining each hectare of ranchland
CH_r	Chemicals emitted per hectare of cattle ranching
R_r	Revenue from each hectare of cattle ranching
S_r	Sediment emission per hectare of cattle ranching
π_r	Profits from upstream cattle ranching
π_{rj}	Profits from upstream cattle ranching in the j^{th} year
π_u	Present value of profits from upstream land use

The ARCOSA hydroelectric complex

b	Aggregate transmission losses in the grid
C^i	Unit production cost for the i^{th} power plant
C_j^i	Unit production cost for the i^{th} power plant in the j^{th} year
n	Assumed life of the hydroelectric facility
P_e	Price of electricity
P_{ej}	Price of electricity in the j^{th} year
Q_e^i	Quantity of electricity produced by i^{th} power plant
r	Discount rate

W^i	Water flow per second through the ith power plant where i=1,2 and 3 represent the Arenal, Corobicí and Sandillal power plants
π_e	The present value of aggregate profits from electricity generation

(a) Dry season

Q_{ed}^i	Aggregate electricity produced in the dry season by i^{th} power plant
Q_{edj}^i	Aggregate electricity produced in the dry season by i^{th} power plant in the j^{th} year
N_d^i	Average number of operating days in the dry season for the i^{th} power plant
W^i_d	Water flow through turbines of the i^{th} power plant in the dry season
W^i_{dj}	Water flow through turbines of the i^{th} power plant in the dry season in the j^{th} year
π_{edj}	Profits from electricity generation in the dry season in the j^{th} year

(b) Rainy season

D_{er}	Demand of electricity in the rainy season
N_r^i	Number of days the i^{th} plant is operated in the rainy season
N_{rj}^i	Number of days the i^{th} plant is operated in the rainy season in the j^{th} year
Q_{er}^i	Aggregate electricity produced in the rainy season by i^{th} power plant
Q_{erj}^i	Aggregate electricity produced in the rainy season by i^{th} power plant in the j^{th} year
T^i	Daily operating time of the i^{th} power plant in rainy season
T^i_j	Daily operating time of the i^{th} power plant in rainy season in the j^{th} year
W^i_r	Water flow through turbines of the i^{th} power plant in rainy season
W^i_{rj}	Water flow through turbines of the i^{th} power plant in rainy season the j^{th} year
π_{erj}	Profits from electricity generation in the rainy season in the j^{th} year

The Arenal-Tempisque irrigation district

D_i	Demand function for the i^{th} crop
P_w	Water tariff per ha of land area
P_{wj}	Water tariff per ha of land area in the j^{th} year
π_i	The present value of profits from irrigation area

(a) Dry season

A_{id}	Area planted to the i^{th} crop in the dry season
A_{idj}	Area planted to the i^{th} crop in the dry season of the j^{th} year
C_{id}	Quantity of chemicals used per ha of the i^{th} crop in the dry season
C_{idj}	Quantity of chemicals used per ha of the i^{th} crop in the dry season of the j^{th} year
C_{Td}	The aggregate amount of agro-chemical used in the dry season
F_{id}	Average cost of planting the i^{th} crop in the dry season, excluding the cost of water and chemicals
F_{idj}	Average cost of planting the i^{th} crop in the dry season of the j^{th} year, excluding the cost of water and chemicals
k_d	Types of crops planted in the dry season
k_d^j	Types of crops planted in the dry season in the j^{th} year

P_{cid}	Price per dose of chemicals used for the i^{th} crop in the dry season
P_{cidj}	Price per dose of chemicals used for the i^{th} crop in the dry season of the j^{th} year
Q_{idj}	Production of the i^{th} crop in the dry season of the j^{th} year
$W_{i\,d}$	The volume of water used per ha of the i^{th} crop in the dry season
π_{idj}	Profits from irrigation in the dry season in the j^{th} year

(b) Rainy season

A_{ir}	Planted area for the i^{th} crop in the rainy season
A_{irj}	Planted area for the i^{th} crop in the rainy season of the j^{th} year
C_{ir}	Quantity of chemicals used per ha of the i^{th} crop in the rainy season
C_{irj}	Quantity of chemicals used per ha of the i^{th} crop in the rainy season of the j^{th} year
C_{Tr}	The aggregate amount of agro-chemical used in the rainy season
F_{ir}	Average cost of planting the i^{th} crop in the rainy season, excluding the cost of water and chemicals
F_{irj}	Average cost of planting the i^{th} crop in the rainy season of the j^{th} year, excluding the cost of water and chemicals
k_r	Types of crops planted in the rainy season
$k_r^{\,j}$	Types of crops planted in the rainy season of the j^{th} year
P_{cir}	Price per dose of chemicals used in the i^{th} crop in the rainy season
P_{cirj}	Price per dose of chemicals used in the i^{th} crop in the rainy season of the j^{th} year
Q_{irj}	Production of the i^{th} crop in the rainy season of the j^{th} year
$W_{i\,r}$	Volume of water used per ha in the i^{th} crop in the rainy season
π_{irj}	Profits from irrigation in the rainy season in the j^{th} year

The Palo Verde wetlands

A_w	Area of the wetland system
D_w	Damage to wetland services
D_{wn}	Aggregate damage to the wetlands in the n^{th} year
e^{CL}	Normalized CL concentrations that pass through the wetlands and enter the Nicoya Gulf
e^{N}	Normalized N concentrations that pass through the wetlands and enter the Nicoya Gulf
e^{p}	Normalized P concentrations that pass through the wetlands and enter the Nicoya Gulf
e^{S}	Normalized sediment concentrations that pass through the wetlands and enter the Nicoya Gulf
h_w	Damage parameter for wetland services
CL_{wn}	Quantity of CL in recharge in year n
N_{wn}	Quantity of N in wetland recharge in year n
P_{wn}	Quantity of P in recharge in year n
S_{wn}	Quantity of sediment in recharge in year n
o^{CL}	Normalized CL concentrations that decays in the wetland
o^{N}	Normalized N concentrations that decays in the wetland

o^P	Normalized P concentrations that decays in the wetland
o^S	Normalized sediment concentrations that decays in the wetland
q^{CL}	Normalized CL concentrations that remain in the wetland
q^N	Normalized N concentrations that remain in the wetland
q^P	Normalized P concentrations that remain in the wetland
q^S	Normalized sediment concentrations that remain in the wetland
U_{we}	Estimated annual value of wetland services per ha without chemical pollution in wetland water
V_{wn}	Value of wetland services in the n^{th} year
V_w	Net present value of the wetland
WW_n	Aggregate Volume of water entering the wetland in the n^{th} year

The Nicoya Gulf

D_{fi}	Demand of fish from the i^{th} zone
$H_i^{\,j}$	Harvest per year in zone *i* in the j^{th} year
$CL_{Ti}^{\,j}$	CL concentration in the i^{th} zone in the j^{th} year
$N_{Ti}^{\,j}$	N concentration in the i^{th} zone in the j^{th} year
$P_{Ti}^{\,j}$	P concentration in the i^{th} zone in the j^{th} year
$S_{Ti}^{\,j}$	S concentration in the i^{th} zone in the j^{th} year
P_{fi}	Price of fish caught in the i^{th} zone
$SR_{fi}^{\,j}$	Social returns to fishery from the i^{th} zone in the j^{th} year
$SR_f^{\,j}$	Social returns to fishery from the gulf in the j^{th} year
SR_f	Net present value of social returns to fishery from the gulf
t^{CL}	Normalized CL concentrations that remain in the gulf
t^N	Normalized N concentrations that remain in the gulf
t^P	Normalized P concentrations that remain in the gulf
t^S	Normalized sediment concentrations that remain in the gulf
W_q	Water quality in the gulf
$W_{qi}^{\,j}$	Water quality in the i^{th} zone in the j^{th} year

Appendix 2:

MODEL STRUCTURE AND EQUATIONS

Objective function:

The objective is to compute the discounted total benefits and costs of the system given by the discounted aggregate net benefits from each of the five modules: the upstream catchment, electricity generation, irrigated agriculture, wetlands and fisheries. These are given as (for notation and model description, please refer to Appendix 1 and the text, respectively)

$$\max\{\pi_u + \pi_e + \pi_i + V_W + SR_f\}$$

The profit from forestry operations is given by the net benefit per hectare times the area under forestry:

$$\pi_f = (B_f - C_f) * A_f$$

Similarly the profit from dairy farming and cattle ranching are given as follows:

$$\pi_d = (B_d - C_d) * A_d, \text{ and}$$

$$\pi_r = (R_r - C_r) * A_r$$

The present value of aggregate benefits from land use in the catchment area is then given by

$$\pi_u = \sum_{j=1}^{\infty} (\pi_f^j + \pi_d^j + \pi_r^j) / (1+r)^j$$

The production function for electricity produced in the dry and rainy seasons are given by

$$Q_{ed}^i = N_d^i * 24 * f_i(W_d^i)$$

$$Q_{er}^i = N_r^i * T_i(D_{er}) * f_i(W_r^i)$$

The main difference between the above specifications is that in the rainy season water is abundant and power plants do not need to operate 24 hours per day while in the dry season they do. The profits from electricity generation in the dry season are the total production in the three power plants times the output price of electricity net of transmission losses and the cost of power generation:

$$\pi_{ed} = P_e * (1-b) \sum_{i=1}^{3} Q_{ed}^i - \sum_{i=1}^{3} C^i Q_{ed}^i$$

Similarly, the profits from electricity generation in the rainy season are

$$\pi_{er} = P_e * (1-b) * \sum_{i-1}^{3} Q_{er}^{i} - \sum_{i=1}^{3} C^{i} Q_{er}^{i}$$

The present value of profits from electricity generation are given as the discounted sum of profits from both seasons over the entire planning horizon:

$$\pi_e = \sum_{j=1}^{n} (\pi_{edj} + \pi_{erj}) / (1+r)^{j}$$

The production function per hectare of the i^{th} crop in the rainy season is given by

$$Q_{ir} = F(W_{ir}, G_{ir}(C_{ir}))$$

where $G_{ir}(C_{ir}$ is the damage abatement function which suggests that the contribution of pesticides to yields increases at a decreasing rate. The production function *F* is assumed to be a Cobb-Douglas function. The dry season equations are similar.

The profit from irrigation in the rainy season is obtained by summing up the per hectare total revenue minus the costs of farming for each of the major crops times the area:

$$\pi_{Ir} = \sum_{i=1}^{k_r} \{D_i^{-1}(Q_{ir}) * Q_{ir} * A_{ir}\} - \sum_{i=1}^{k_r} A_{ir} * (P_W + P_{cir} * C_{ir} + F_{ir})$$

Dry season profits are computed analogously.

The present value of profits from irrigation are summed over both seasons:

$$\pi_i = \sum_{i=1}^{\infty} (\pi_{idj} + \pi_{irj}) / \ (1+r)^{j}$$

The aggregate damage to the wetlands in the n^{th} year is computed as a function of the chemicals accumulating in the system net the portion diluted in the wetlands and the volume that flows into the Gulf:

$$D_{Wn} = \{\prod_{i=1}^{n-1} [1 - H_w(N_{Twi}, CL_{Twi}, P_{Twi}, S_{Twi})]\} * A_w * V_{we} * H_w(N_{Twn}, CL_{Twn}, P_{Twn}, S_{Twn})$$

The economic value of the wetlands in the n^{th} year is given by the value of the wetlands per hectare times the effective area of the wetlands, which is the aggregate area net the area damaged by chemical pollution:

$$V_{wn} = A_w * (U_{we} - D_{wn}) \cdot$$

The present value of the wetlands is the discounted sum of wetland services over time:

$$V_w = \sum_{n=1}^{\infty} V_{wn} / (1+r)^j$$

The net benefits from fisheries in the i^{th} zone in the j^{th} year is given by

$$SR_{fi}^j = \int_0^{H_i^j} P_{fi}(H_i^j, W_q^j)\, d\ H_i^j - C_i(H_i^j, W_q^j)$$

Finally, the present value of the social surplus from fishery is obtained as follows:

$$SR_f = \sum_{j=1}^{\infty} SR_f^j / (1+r)^j$$

5. INDICATORS FOR A POLICY RELEVANT MONITORING SYSTEM

Lisa Segnestam

INTRODUCTION

This chapter develops appropriate indicators for monitoring the environmental health of the Arenal-Tempisque watershed. The indicators are intended to inform a policy relevant monitoring system for the watershed. As discussed in chapter 2, there are three types of indicators and they play a crucial role in a policy relevant monitoring system. Most of the time, only a small set of *alarm* indicators need to be monitored on a routine basis to check for any important changes in the environmental health of the watershed. As soon as any of the alarm indicators sound, a set of more detailed *diagnostic* indicators are activated to provide additional insights into the nature of the problem and its causes.

The diagnostic indicators also inform the model and the associated *Payoff Matrix* which can be used to more fully assess the consequences of the observed changes, and to explore alternative strategies for correcting the problem. Once the model and the Payoff Matrix have been used to compare the costs and benefits of alternative corrective actions, the relevant stakeholders are required to agree on a plan of corrective action. Again, the Payoff Matrix indicates which stakeholders should be involved in the discussions—either because they create the externality or because they are affected by externalities. *Response* indicators then come into play in monitoring whether the desired actions have been successfully implemented and whether these actions are having their intended impact. Following sections discuss possible indicators for each of these three functions, followed by discussion of data collection issues.

PROPOSED ALARM INDICATORS

Alarm indicators must be routinely monitored to detect important changes in the watershed. Ideally, they need to provide early warning of important changes so that decision-makers have adequate time to react to problems before serious damage occurs. Alarm indicators also need to be simple and relatively inexpensive if they are to be frequently monitored. Frequent monitoring is desired to reduce the amount of time taken between the occurrence of a problem and the implementation of an appropriate response.

For alarm indicators to be meaningful, they must have established *baselines* against which monitored values can be compared. Baselines for indicators are best determined through the monitoring of an “unspoiled” part of the watershed, or even another comparable but unspoiled watershed. For example, the status of the indicator proposed for the monitoring of agro-chemical use in the downstream areas—benthic macro-invertebrates—can be monitored in the irrigation canals above the irrigated areas. In doing so, unaffected benthic macro-invertebrates can be compared with the ones living in the polluted water downstream of the irrigated areas.

It is also necessary to establish *thresholds* for each alarm indicator, otherwise there is no way of knowing when the alarm should sound. Thresholds for some of the indicators suggested below can be based on previous research conducted within the Arenal-Tempisque watershed or in similar areas elsewhere. However, there are a few indicators for which such thresholds are not known and they would need to be established before the proposed indicators could become meaningful. Thresholds should be based on desired rather than existing standards of environmental health, otherwise current levels of environmental damage are likely to be institutionalized through the monitoring system even if they are already high. We turn now to a discussion of relevant alarm indicators for different segments of the watershed. The proposed alarm indicators are also summarized in Table 5.1.

Table 5.1—Summary table of alarm indicators

Issue and main impact	Proposed alarm indicator
Soil erosion in upstream areas - declining profits from electricity production - declining productivity on dairy and cattle farms	Land use changes planned by farmers in catchment area vs. appropriate land use (geo-referenced) Area forested vs. cleared land
Water availability in upstream areas - declining profits from electricity production	Land use changes planned by farmers in catchment area Area forested vs. cleared land
Water availability in downstream areas - declining profits from Tilapia, agricultural, and seafood production - damage to wetlands and loss in biodiversity	Water released by ICE Recommended (needed) water use for the different areas vs. actual water availability
Soil salinization in downstream areas - declining land productivity in irrigated areas	Electrical conductivity of the water
Bird infestation - crop damage in the irrigated areas	Hectares affected by feeding birds
Agro-chemical use in the irrigated agricultural areas - declining profits from seafood production - health impacts (agricultural areas and Nicoya Gulf) - loss in biodiversity in the wetlands and gulf	Condition of benthic macro-invertebrates in water channels
Soil erosion in irrigated areas - declining productivity of agricultural land - loss in biodiversity in the wetland and gulf	Levels of sedimentation at various points in the areas adjacent to the Palo Verde National Park

Catchment area and the Hydroelectric Power Complex

Soil erosion from the upstream areas. The modeling analysis in Chapter 4 has shown that soil erosion in the upper catchment area is potentially a serious problem because it leads to siltation of the reservoirs feeding the power plants, reducing ICE's power generation and profits. In the long term, soil erosion may also affect the productivity of dairy and cattle farmers in the catchment area. Further deforestation and increases in the area of more erosive crops planted by dairy and cattle farmers need to be monitored carefully.

An obvious alarm indicator is the amount of forest lost each year or the area of land put into more erosive uses (e.g. forage crops rather than pasture for more intensive dairy production). However, monitoring actual land use changes may not provide adequate warning time for decision makers concerned with slowing or preventing further soil erosion. A better approach that gives some early warning is to interview farmers located in the reservoir's watershed on a regular basis about any land use changes they are planning. Since the rate of soil erosion on agricultural land varies with the type of crop, soil depth, topography, type of soil, and other key characteristics, then threshold values for land use indicators need to be based on "appropriate" or "non-erosive" land uses, possibly for different locations within the catchment area. Planned land use changes could be geo-referenced (mapped) to show if and where serious amounts of additional soil erosion are likely and to facilitate scaling up of the total amount of additional silt that can be expected.

The required land use data could be collected through small sample surveys at relatively low cost. A potential problem, however, is that the dairy and cattle farmers may be reluctant to provide the required data if they think this will lead to corrective but uncompensated policies that reduce their farm incomes. Incentive issues are addressed in Chapter 6.

Water availability in the upstream areas. Lake Arenal is the main supplier of water for electricity production. At the moment, the lake seems to be adequately replenished on average (see Chapter 3) so water shortages have not been included as a constraint in the model. However, discussions with relevant stakeholders revealed growing concerns about water availability in the future, especially as national demand for electricity grows. It is, therefore, useful to think about relevant alarm indicators that might later be included in the monitoring system. The ARCOSA hydroelectric power complex and the irrigated farming system are both vulnerable to water shortages should the average water level in Lake Arenal eventually decline. The problems for irrigated farmers will also be aggravated by the planned extension of the irrigation scheme from 20,000 to 40,000 ha.

Since the recharge of Lake Arenal, and the amount of sediment entering the lake, both depend to a considerable extent on land use patterns in the catchment area, then the same alarm indicator can be used as for monitoring soil erosion, i.e. land use changes planned by farmers in the catchment area.

Although at present water shortages in Lake Arenal are not a management problem, it is possible that in the future annual demand for water from the reservoir might be more than annual replenishment and thus become an economically binding constraint. In that case, the reservoir catchment may need to be managed to maximize water production, rather than sediment control. Although the literature on this issue is mixed, some work in the Arenal watershed (Aylward and Echeverria, 2000) indicates that the value of increased water production associated with decreased forest cover may be greater than the soil erosion associated with the same decrease in forest cover. In any case, whether or not the watershed is managed to reduce soil erosion and sedimentation to the reservoir, or to maximize water inflow into the reservoir, appropriate alarm indicators can serve a valuable function in alerting analysts to important changes in the ecosystem. Threshold values for this indicator would need to be based on appropriate land uses for either sediment control or water production.

ARCOSA and the Irrigation District

Water availability in the downstream areas. Water users downstream of the ICE power complex are also dependent in the long run on the sustainable management of Lake Arenal. But more immediately, their access to water is controlled by ICE. ICE releases water when it generates electricity, and this leads to seasonal and hourly patterns of release that are not ideal for many downstream users. To monitor this problem would ideally require monitoring the amount of water entering key parts of the downstream watershed during periods of their greatest need. But this would not be easy. For example, there is no specific entry point through which water enters the Palo Verde wetlands, and neither does an unambiguous monitoring station for water supply exist for the Nicoya Gulf. A practical and low-cost indicator is the amount of water released by ICE to the irrigation canals, since these releases provide the lion's share of the water received in downstream areas. ICE already records this information on a routine basis, so no new data collection is necessary.

A more informative water availability indicator could also be developed for water planning purposes. One simple development would be to compare the water released by ICE to the recommended (or needed) water use for each area. The ratio of "recommended (needed) use to actual water availability" would reveal any potential inefficiencies in the use of water within the system. If the water released by ICE is more than the downstream areas need to function optimally, then the ratio becomes <1, showing that there are efficiency gains to be had in saving water in Lake Arenal for future use. If, on the other hand, the water released by ICE is not enough to meet current needs, then the ratio becomes >1, making it necessary for ICE to release more water if the downstream areas are to function optimally. Note, however, that the ratio may vary according to the time of day as well as by season since ICE releases water to the downstream agricultural areas on seasonal and hourly schedules driven by the demand for electricity generation. During peak-hours for electricity generation, the ratio may very well be <1 (that is, more water is released into the system than needed downstream), while during off-peak hours the ratio may be >1 (downstream needs are greater than releases). This feature makes it necessary not only to monitor the indicator at different times of the year, but also at different times of the day.

Information on recommended or needed water use may not exist for many of the downstream areas of concern. It is more easily obtained for the tilapia farm and irrigated farming system than for the wetlands and the gulf, since the water management needs of these activities have been widely studied.

The Irrigation District

Soil salinization in downstream areas. There is considerable evidence to show that irrigation often leads to increasing levels of salinity in soils (Umali, 1993). This in turn has a negative impact on crop yields. Although not yet a serious problem in the irrigated areas of the Arenal-Tempisque watershed (and hence is not included in the current version of the model), it may yet become so in the future. As such, it is useful to include a relevant alarm indicator in the monitoring system. We suggest the electrical conductivity of the water as a fairly straightforward indicator that gives an early warning before yields are negatively affected. It is also a quicker and more accurate way of measuring salinity than ion concentration methods (Cordero, 1999). SENARA already plans to monitor this indicator at five data collection points: at the exit point from the Sandillal power plant and before the water enters the irrigation canals; at two different places in the canals; and at two different places in the Río Cañas.

The Irrigation District and Palo Verde National Park

Bird damage. Damage to rice crops by birds coming from the wetlands to feed has become a serious problem for farmers located near the park. Monitoring the number of birds feeding in the rice paddies would be impractical and instead it would be simpler to rely on rice farmers to provide estimates of the amount of crop damage that they have incurred from birds. There are two stages in the crop season when rice crops are vulnerable to bird damage; for 2-3 weeks after seeding when the birds eat part of the seed, and later when the crop is maturing but before harvest. Farmers could be interviewed after these critical periods about the number of hectares that have been damaged or even perhaps about the estimated value of their losses. The former would be easier to verify, which could be important if farmers have incentive to exaggerate their losses in the hope of receiving compensation.

The irrigation district, Palo Verde National Park and the Gulf of Nicoya

Agro-chemical use in irrigated agriculture. Agro-chemical pollution of water is a major problem in the irrigated farming areas of the watershed, and as shown in the model results, has serious and negative impacts on the wetlands and the Gulf of Nicoya. It is also a potential hazard to human health through contact through spraying and, to a lesser extent, through contaminated water supplies. Because of the diversity of agro-chemicals used (different types of fertilizers, pesticides and herbicides) and their different impacts on the environment, direct monitoring would require frequent and extensive chemical tests at key points in the watershed. Even then, by the time threshold levels of particular chemicals are observed, it may be too late to prevent extensive damage.

Fortunately, a simpler and more practical alarm indicator can be based on the composition and health of benthic macro-invertebrates in the water, as demonstrated by researchers from the University of Costa Rica who have undertaken tests in the water channels of the Arenal-Tempisque watershed (Martinez Ocampo, 1998). The benthic macro-invertebrates are a large group of organisms, individual members of which are sensitive to different types of contamination (e.g. from pesticides, or fertilizers). They can be divided into groups according to how sensitive they are to pollution—very sensitive, sensitive, regular, tolerant, and very tolerant. These groupings provide a useful way to establish thresholds. Martinez-Ocampo (2000) suggests that when the ‘sensitive’ benthic macro-invertebrates constitute less than 15 percent of the total community then the threshold has been reached and the alarm should sound. Another attractive feature of this indicator is that it provides an early warning for negative impacts on birds, shrimp and fish.

It should be noted that SENARA is discussing the construction of a number of oxidation ponds between the irrigation district and Palo Verde National Park. If constructed, these ponds would help reduce the impact that agro-chemical pollution has on the wetlands, and thus reduce the need to monitor for benthic macro-invertebrates (see chapter 6).

Soil erosion in irrigated agricultural areas. Current soil management practices in the irrigated farming areas result in serious soil sedimentation in both the Palo Verde National Park and the Gulf of Nicoya. Current levels of soil loss must also eventually have a negative impact on agricultural productivity in the irrigated areas, although it is not clear if this has already happened. A suitable alarm indicator is the estimated sediment level at representative sites downstream of the irrigated farming areas. SENARA is already proposing to monitor sediment loads at ten different points, of which four are in areas adjacent to the Palo Verde National Park (Pineda Cordero, 1999).

Another soil monitoring method involves the placement and observation of erosion pins. Pins are driven into the soil so that the top of the pin gives a baseline from which changes in the soil surface level can be compared. The main advantage of this method is that it is cheap and simple, facilitating measurement at a larger number of sites within the irrigated area. Moreover, the method only requires modest skill levels and little maintenance (Hudson, 1993).

PROPOSED DIAGNOSTIC INDICATORS

Diagnostic indicators are needed to provide additional insights into the severity of emerging problems when an alarm indicator goes off, and to help determine the causes of the problem both in terms of identifying behavioral changes that have occurred (e.g. changes in land use) and the underlying factors that have led to the behavioral change (e.g. changes in market conditions). They also provide the data needed to conduct new simulations with the model to predict the likely consequences of emerging problems and the types of corrective action that may be needed.

Diagnostic indicators are likely to be more costly and difficult to measure than alarm indicators, and are therefore less suitable for routine monitoring. The choice of diagnostic indicators also needs to remain flexible since each emerging problem will likely have some unique characteristics. This may be in terms of the changes in behavior observed (e.g. introduction of a new type of crop or pest management approach) or in the underlying factors causing that behavioral change (e.g. it may be technologically driven on one occasion and market driven on another). In many ways, the collection of diagnostic indicators should be seen more as a process of investigation than a simple data collection exercise, and it may involve the sequential collection of different types of data as the investigation proceeds.

As with alarm indicators, we discuss relevant diagnostic indicators for different segments of the watershed. The proposed diagnostic indicators are summarized in Table 5.2.

Table 5.2—Summary table of diagnostic indicators

Issue and main impact	**Proposed diagnostic indicator**
Soil erosion in upstream areas - declining profits from electricity production - declining productivity on dairy and cattle farms	Interviews with dairy and cattle farmers Market conditions for important farm and forest products Changes in farm technologies and practices Changes in agricultural and forest policies
Water availability in upstream areas - declining profits from electricity production	As above
Water availability in downstream areas - declining profits from Tilapia, agricultural, and seafood production - damage to wetlands and loss in biodiversity	Land use practices in upper catchment area (see above) Electricity generation (annual and seasonal) Interviews with ICE and irrigated farmers Changes in irrigated area, cropping patterns, water management practices, etc Changes in market conditions and agricultural policies
Soil salinization in downstream areas - declining land productivity in irrigated areas	More spatially dispersed measurements of electrical conductivity and ion concentration to locate problem areas. Interviews with irrigated farmers Changes in cropping patterns and water management Changes in market conditions and agricultural policies
Bird infestation - crop damage in the irrigated areas	Changes in bird populations, feeding sources and bird scaring practices Interviews with irrigated farmers and park managers
Agro-chemical use in the agricultural areas - declining profits from seafood production - health impacts (agricultural areas and Nicoya Gulf) - loss in biodiversity	More spatially dispersed measurements of benthic macro-invertebrates and chemical tests to locate source of problem and type chemical Interviews with farmers and spraying firms Changes in cropping patters, crop varieties, cultivation and pest management practices, chemicals used, water management, spraying methods, etc Changes in market conditions and agricultural policies
Soil erosion in agricultural areas - declining output from agricultural lands - loss of biodiversity in wetland and gulf	More spatially dispersed measurements of sedimentation and soil movement to locate source of problem Interviews with irrigated farmers Changes in cropping practices, cultivation practices and water management Changes in market conditions and agricultural policies

Catchment Area and ARCOSA

Soil erosion and water availability in the upstream areas. If the recommended alarm indicator (planned land use changes by farmers) exceeds a threshold level, then additional information will be needed about the reasons for these planned changes. One source of information should be participatory discussions with a sample of farmers about the reasons for their planned changes in land use. Other useful indicators would include changes in market conditions (e.g. changes in market access and product collection, changes in prices for milk, cattle, coffee and timber, and changes in interest rates), changes in dairy farming technology, and changes in government policies affecting forestry and dairy and cattle farming.

ARCOSA and the Irrigation District

Water availability in the downstream areas. Should future water scarcities emerge in the downstream areas, then it will be important to determine whether the problem is due to insufficient recharge of Lake Arenal, or to the water release polices of ICE. If the former, then ICE itself will be affected, and this should be easy to determine. The problem may then be because ICE is required to generate more power than can be sustained by the watershed, or because land use changes in the catchment area are reducing the amount of water reaching the lake. Relevant diagnostic indicators should therefore include seasonal observations on Lake Arenal's depth, annual and seasonal data on electricity generation, and the same indicators described above for diagnosing the extent and causes of land use changes in the upper catchment area.

If the water shortages are not caused by shortages in the catchment area and Lake Arenal, then possible causes could be changes in ICE's own water release policies, expansion of the irrigated area, a switch to crops requiring more water, less efficient water management practices, increased water losses from canals, etc. In this case, interviews with ICE management and irrigated farmers will be appropriate, as well as collection of information on changes in electricity generation and water release patterns, changes in cropping patterns and water use practices, on any changes in the engineering structures, and on causal variables such as changes in key crop and farm input prices (fertilizer and chemical prices, wages, interest rates, etc), and changes in agricultural policies that impact on the irrigated farms.

The Irrigation District

Soil salinization in downstream areas. If the alarm indicator (electrical conductivity) flags a problem, then it will be important to first locate the areas that are most affected. This may require more widespread testing (electrical conductivity or ion concentration readings) in the irrigated farming areas. These results can be mapped in a GIS framework to facilitate interpretation. Diagnosing the cause would require collecting information about changes in cropping patterns and water management practices, using participatory interviews with farmers and some of the same indicators as mentioned in the previous paragraph.

The Irrigation District and Palo Verde National Park

Bird infestation. If bird damage to crops reaches critical levels then it will be important to determine whether this is due to more birds, loss of alternative food sources, increased area of rice near the park, or to less diligent bird scaring practices. Participatory interviews with park managers and farmers should quickly resolve these issues.

The Irrigation District, Palo Verde National Park and the Gulf of Nicoya

Agro-chemical use in the agricultural areas. If the levels of agro-chemicals in the water is increasing, as monitored by the benthic macro-invertebrates indicator, then it would be important to identify the farming areas from which these additional chemicals are coming and the types of chemicals involved. Water testing at more sites around the irrigated farming system would be an obvious first step, using both the bethnic macro-invertebrates indicator and chemical tests to identify individual chemical pollutants.

Additional diagnostic indicators may be needed to determine the cause of the increased chemical use. Participatory interviews with farmers and professional spraying firms would help, combined with information about changes in cropping patterns (for example, fruits and vegetables demand more chemicals than rice), crop varieties, cultivation and pest management practices, water management and spraying technologies. Additional information about changes in crop and chemical prices and agricultural policies that impact on irrigated farming practices may be useful for identifying underlying causes.

Soil erosion in agricultural areas. As with agro-chemical runoff, once an increase in soil sedimentation from irrigated farming has reached threshold levels, it would be important to pinpoint more precisely the area from which the sedimentation is emanating. This may require additional measurements of soil movement and sedimentation at a larger number of sites in the irrigated farming area, perhaps using GIS techniques to map the data to facilitate interpretation. Participatory interviews with the farmers concerned would be helpful in pinpointing underlying causes, as well as information on changes in cropping and cultivation practices, water management and the like.

PROPOSED RESPONSE INDICATORS

Response indicators are used to determine whether corrective actions agreed amongst the stakeholders for resolving a problem have been successfully implemented, and whether those actions have had their intended impacts. It is only after the response indicators show that a problem has been solved that the monitoring system can revert back to the routine monitoring of the alarm indicators. If the problem is not solved, then data on the response indicators can help guide further corrective actions, and provide valuable feedback for improving the system in the future (see Chapter 7).

As with diagnostic indicators, the selection and collection of response data needs to be flexible to adapt to the specifics of a particular problem. No two situations are likely to be identical, even if the same environmental problem occurs more than once in time or space.

Monitoring the implementation of agreed actions by stakeholders can be done through participatory means (e.g. direct interviews with farmers who have agreed to refrain from certain land use or chemical use practices, or follow-up meetings with all the key stakeholders at which each reports on their progress). This approach is intrusive but can help create peer pressure for stakeholders to honor their commitments. It also allows for some flexibility in stakeholder responses when there are alternative ways of achieving the same goal (e.g. erosive land use practices might be suitably modified through ridge plowing or tree planting along contours to reduce soil erosion without having to revert to less profitable land uses). Allowing individual stakeholders to figure out the best strategy for meeting their promised goals can be more efficient and sustainable than trying to impose uniform solutions on all.

Another and less direct approach is to simply monitor whether the promised changes have occurred (e.g. observe whether land use practices have changed as promised, or whether “banned” chemicals are still sold and used). This approach also goes part way to monitoring the impact of the agreed action. Unlike the participatory approach, this method is more rigid in its view of successful implementation. It may also inadvertently contribute to a mind set in which stakeholders do not feel they have to follow through on their commitments.

Monitoring the impact of corrective actions requires use of some of the same alarm and diagnostic indicators discussed earlier. For example, agreed actions to reduce agro-chemical pollution would need to be followed up with additional monitoring of water quality (using the bethnic macro-invertebrate indicator or specific chemical tests) until the readings fall below their threshold values. Similarly, agreed actions by dairy and cattle farmers to reduce soil erosion in the catchment area may need to be monitored through observation of land use practices and perhaps measurement of the silt loads entering Lake Arenal and the hydro-electric power complex.

Table 5.3 provides examples of plausible response indicators for some of the major problems found in the Arenal-Tempisque watershed. But it is impossible to give a definitive list of indicators because of uncertainties about the appropriate actions that might be agreed for meeting particular problems. In most cases there will a wide choice of possible actions, including perhaps the introduction of new technologies, changing incentives through price, tax or subsidy policies, and direct attempts to educate and change the behavior of certain individuals or stakeholder groups. The model can help analyze the more cost effective ways of solving important environmental problems, but as indicated above, enough flexibility should be left for individuals to work out the best strategies for own situations.

Table 5.3—Examples of response indicators

Issue and possible corrective actions	**Examples of response indicators**
Soil erosion in upstream areas - Constraints on land use - Soil conservation investments - Subsidy for retained forest - Tax on milk and beef produced in the catchment area	Interviews with farmers on changes they have made Monitoring of land use changes and soil conservation investments from the air or via ground inspection of sample farms and/or along sample intercepts in the catchment area Monitor subsidies paid for retained forest and whether sample of farmers who receive them are retaining agreed forest.
Water availability in upstream areas - Constraints on land use - Subsidy for retained forest	See above.
Water availability in downstream areas - Minimum water flows agreed with ICE - Volumetric water charges for irrigated farms - Investments in drip irrigation and other water saving technologies - Tax on high water using crops	Water released by electricity company (quantities and timing) Revenue from water charges. Interviews with irrigated farmers on changes they have made, supplemented by inspections on sample of farms
Soil salinization in downstream areas - See above	See above
Bird infestation - Investments in bird scaring technologies - Develop alternative feed sources in wetland	Interviews with irrigated farmers near park and with park managers Ground inspection of bird scaring equipment in place and of alternative feed sources
Agro-chemical use in the agricultural areas - Introduce more pest resistant varieties - Introduce Integrated pest management - Tax on helicopter spraying - Tax on selected agro-chemicals - Construct oxidation ponds for treating irrigation drainage water before it enters wetland	Interviews with farmers and spraying firms on changes they have made, supplemented by inspections on sample of farms Monitor sales of selected chemicals that are being taxed or which farmers and spray firms have agreed to reduce or eliminate. Monitor quality of water at selected points through bethnic macro-invertebrate counts and chemical testing Check progress on construction oxidation ponds
Soil erosion in agricultural areas - Laser leveling of paddy fields - Improved land preparation techniques	Interviews with farmers on changes they have made, supplemented by inspections on sample of farms Monitor sedimentation loads in water at selected points

COLLECTION OF DATA

The data needed for the indicators can be collected different ways. For example, external companies or institutions specializing in resource monitoring could be contracted, or organizations representing stakeholder interests could be involved using their vested interests as an incentive, or schoolchildren could participate as part of their education, or the local population —farmers, residents, researchers, fishermen—could be encouraged to take part as a way to promote their interest and responsibility in the social, environmental, and economic health of their surroundings.

Using an external company or institution is likely to be the more expensive option, and may best be limited to specific and more technically demanding functions such as chemical testing of water. Involving local stakeholders is not only likely to be cheaper, but can be an important way of obtaining their participation in, and ownership of, the monitoring system. This in turn is crucial for sustaining the system over time and for obtaining agreement on corrective actions when required. Developing appropriate incentives for stakeholders to participate is important for the success of a policy relevant monitoring system.

Figure 5.1 shows how three sets of the proposed indicators map into the Payoff Matrix. This is a useful exercise for understanding a) which stakeholders have incentive to participate in monitoring specific environmental problems and which ones do not, and b) the feasibility of stakeholder participation from a spatial perspective. For example, the first column of Figure 5.1 shows that land use indicators need to be monitored in the catchment area where soil erosion originates, but because the costs of soil erosion occur downstream, then dairy and cattle farmers have little incentive to participate. ICE’s power system, on the other hand, is adversely affected by soil erosion in the catchment area hence ICE should want to participate in land use monitoring. Since ICE also has a presence in the catchment area (e.g. through its control of rivers, Lake Arenal and watershed protection areas), it is also well placed to participate in land use monitoring.

Figure 5.1—Links between indicators and the Payoff Matrix.

	Dairy/cattle farms	Irrigated farms	Wetland
CATTLE FARMS	**Land Use indicators**		
Irrigated farms		**Water quality indicators**	**Bird damage indicators**
Wetland		**Water quality indicators**	
FISHERMEN			

Key:

denotes cells in which environmental costs occur.

denotes cells in which environmental costs originate.

Water quality needs to be monitored in the irrigated areas and at irrigation drainage entry points into the wetland. Since the damage from agro-chemicals occurs in the wetlands and the gulf, irrigated farmers have little incentive to participate in monitoring these indicators. But the wetlands managers and fishermen who are adversely affected by agro-chemicals should be interested in participating. There are opportunities for the wetland park managers to participate in monitoring the quality of the water entering the wetland, but the fishermen are located too far downstream to be effectively involved. Wetland managers also have the incentive to monitor water quality that drains towards the gulf because by demonstrating the cleansing function of the park will empower their conservation lobbying efforts.

Monitoring bird damage to irrigated crops presents a contrasting situation in which the problem that needs to be monitored is located in the same location as where the damage occurs. In this case, the irrigated farmers have incentive to participate in monitoring the damage and, since it occurs on their farms, they are also strategically placed to participate.

A number of other data collection issues (credibility, cost effectiveness, and knowledge gaps) are discussed below.

Credibility

In order for the indicators to play their role in the policy relevant monitoring system, then the data collected must be credible to all concerned. This implies that the stakeholders involved in the collection of data must also be credible. If the results are not credible, either explicitly (because of poor quality data) or implicitly (because the data are collected by a stakeholder with vested interests) then the data is unlikely to be acceptable.

There are two aspects to credibility that come into play: *trustworthiness* and *capacity*. It is important that even though a stakeholder has, by definition, a stake in what happens in the project area, they can non the less be trusted by other affected groups to provide reliable and accurate data. But even if indicators are monitored by a trustworthy agency, the results may still be misleading if that agency does not have the capacity to undertake the job properly. In many cases, the best approach is to create "monitoring teams" consisting of one agency that collects the data, and another that undertakes quality control. In this way, it is possible to achieve trust and capacity, even in cases where one single agency does not possess both characteristics.

Cost Effectiveness

Cost-effectiveness is important if the monitoring system is to be socially attractive and if the resources to sustain it over time are to be found. In addition to choosing relatively simple and low cost indicators, two other factors can contribute to maintaining a low cost system: participation of the local population and building on existing monitoring efforts.

Participation of the local population. A couple of the proposed alarm indicators—benthic macro-invertebrates and hectares damaged by feeding birds—are best collected in a participatory manner. Even though the actual analysis of the chemical loads in the macro-invertebrates needs to be done in a laboratory, the collection of samples is simple enough to be carried out in a participatory manner. School children can be involved, farmers can be asked to collect samples while working in the fields, or the National University (UNA) could be hired to do the work since it already has experience in developing and applying these methods. One option could be to contract the university to teach a group of local farmers or schoolteachers in the methods for collecting and analyzing samples, and then they could organize school children and/or farmers to undertake part of the work. Since some external expertise is needed to undertake supporting tests in laboratories, then the same external experts could also provide quality control for the data collection.

The alarm indicator for monitoring bird infestation—hectares damaged by feeding birds—is most easily and cheaply obtained by asking farmers to report this information. SENARA, which represents the interests of irrigated farmers is well placed to collect and compile this information. A representative from the national park could also be involved to help ensure that the results of the monitoring are credible, and to provide useful diagnostic information about changes in bird populations or other sources of feed for the birds.

Once an alarm indicator has flagged a problem and the monitoring system has moved into a diagnostic phase, the participation of local stakeholders will often be important for achieving a proper understanding of the causes of the problem. Participatory interviews with groups of farmers, for example, will be important for understanding why land uses, cropping patterns and farming practices are changing. Interviews with ICE managers may be important for understanding why water releases to the lower watershed are changing, and interviews with spraying firms may help explain changes in pesticide runoff.

Existing monitoring efforts. Some of the indicators that have been proposed are already being monitored by various organizations in the Arenal-Tempisque watershed, or there are plans afoot to monitor them in the future. These indicators include actual water availability in Lake Arenal and in the downstream area (water released by ICE), electricity generation, estimated sediment levels at various points in the areas adjacent to the Palo Verde National Park, and the electrical conductivity of the water. In these cases the interest and resources are already in place, and as long as the developers of those indicators are reliable and trusted by the other stakeholders, then there is no reason to start developing the same indicators within a different organization.

Some other indicators require information that is already collected for other purposes. For example, indicator data on changes in cropping patterns in the irrigated areas can probably be obtained from SENARA because this is basic information that they need for their own planning purposes. Credibility should not be an issue in this case since there is no reasons for SENARA to report false numbers.

Filling Knowledge Gaps

Any comprehensive monitoring system for the Arenal-Tempisque watershed must inevitably begin with less than perfect information about the problems to be monitored, and suitable threshold values for key indicators. These knowledge gaps can be filled over time as the monitoring system generates new data and experience in tracking and correcting problems. Some key areas where improved knowledge is required are as follows.

Soil erosion in the upstream areas. Available estimates about the severity of the siltation problems affecting the hydropower complex vary widely, particularly estimates of the useful life of Lake Arenal. To arrive at more precise knowledge about these issues will require further research on the current rate of siltation and links to land use and farming practices in the upper watershed.

Water availability in the catchment area. Although not currently a problem, there is growing concern that changing land use patterns in the catchment area will affect the amount of water recharging Lake Arenal each year, and hence the prospects for future water shortages for ICE and the irrigation system. There is conflicting evidence about these relationships. Some researchers are suggesting that deforestation increases the amount of available water (Aylward and Echeverria, 2000). But this result may depend on whether deforested land is planted to permanent pasture or to forage crops for dairying. Additional research is required to resolve these issues, and to quantify the relationships between water and silt flows for different land uses.

Agro-chemical use in the agricultural areas. At present it is difficult to determine meaningful threshold values for agro-chemical contamination in the irrigation drainage canals because there has been too little research to quantify the relationships between this contamination and human sickness in the watershed, damage to the wetland park and the wildlife in it, and damage to the shrimp and fishing grounds in the gulf.

Soil erosion in agricultural areas. There is also insufficient knowledge at present about the rates of soil sedimentation moving into wetlands and the gulf from the Arenal-Tempisque watershed, and the damage that it causes to mangroves, navigation, and fish and shrimp production. Nor is much known about the impact of this soil erosion on agricultural productivity in the irrigated areas.

As the monitoring system progresses, new knowledge gaps are likely to become apparent about existing and future problems and their causes. The monitoring system will need to have the flexibility to adapt to new environmental problems in the watershed and to changes in the economic environment that impact on stakeholders' behavior. It will also need to have sufficient resources to develop and test appropriate indicators to handle these changes.

CONCLUSIONS

This chapter has discussed relevant alarm, diagnostic and response indicators that would be needed by a policy relevant monitoring system for the Arenal-Tempisque watershed. These indicators would be informative in their own right, but many also provide input to the regional model and the Payoff Matrix which have a key role to play in assessing the consequences of observed changes in key indicators and in developing appropriate corrective actions. The way in which the indicators and model would interact is discussed in some detail in Chapter 7. It is important to involve local stakeholders in the collection and use of the monitoring data to encourage them to take ownership of the monitoring system and to use it to improve their combined management of the watershed. This will require that there be an appropriate system of incentives in place. This issue is taken up in the next chapter.

6. INSTITUTIONAL FRAMEWORK FOR A RESOURCE MONITORING SYSTEM IN THE ARENAL-TEMPISQUE WATERSHED

Rafael Celis and Peter Hazell

INTRODUCTION

The modeling analysis in Chapter 4 shows the high economic and environmental costs associated with the way the Arenal-Tempisque watershed is currently being managed. Soil erosion, sedimentation, and pollution of soil and water, are the most visible manifestations of a trend initiated in the early eighties. The Payoff Matrix shows explicitly how these impacts translate into economic costs affecting many of the stakeholders in the watershed. Yet, despite growing awareness of these problems amongst key stakeholders, and despite pressure from bilateral and multilateral development agencies and from local and international environmentalist groups, these trends appear to continue unchecked.

Because of the large number of assumptions that have had to be made for this analysis, these findings should be considered as “indicative results” and interpreted with caution. Nevertheless, the preliminary findings reported in Chapter 4 indicate that these environmental costs have now reached an astonishing $0.61 per dollar of realized social benefits. Part of this cost is avoided in practice because ICE dredges the silt from its smaller reservoirs on a regular basis, but there is still ample room for stakeholders to explore, negotiate and undertake remedial actions to their mutual benefit. Why has this not happened and what can be done to bring about such action? These are key questions that this chapter attempts to address, and the answers leads into a discussion of the kinds of institutional structure that might be needed to develop and manage a policy relevant monitoring system for the watershed.

INSTITUTIONAL ISSUES

Market and Institutional Failures

Environmental problems of the type encountered in the Arenal-Tempisque watershed arise from classic externality problems. The agents who cause the environmental damage do so because their actions are profitable and because they do not have to bear or pay for the downstream costs resulting from their actions. Moreover, since they do not bear the downstream costs, then the prices at which they are willing to sell their outputs do not reflect the true costs to the watershed. These are fundamentally market failure problems, and they lead to inferior social welfare outcomes for the watershed and the nation. The externalities are identified and quantified in the off-diagonal elements of the Payoff Matrix—and they are found to be pervasive and often large in absolute amounts.

There are several possible reasons for the existence and continuance of these kinds of market failures. One is the offsite nature of the damage; it does not occur on the property of the people who cause the damage. This problem is aggravated by spatial separation from those who are affected. With sufficient distance, those who cause the damage may not even be aware of the costs they impose on others, or they may feel little social pressure to do anything about it. Stakeholders may also be separated in time; for example future generations of Costa Ricans cannot make their voice heard to change the behavior of any of the stakeholders whose actions are putting the watershed at risk. There are also instances in which the affected party cannot be properly represented at the bargaining table; this is the case of many plant and animal species in the watershed whose future depends on how successful environmentalist are in voicing their fate.

In theory, if appropriate property rights systems could be defined over the different natural resources in the watershed and if transactions costs are not too high, then the different stakeholders might be able to negotiate market solutions to these environmental problems (Coase 1960). “With well-defined property rights and no transactions costs, there is a market and a price for everything. All externalities are automatically internalized” (Law and Clemens, 1998). Unfortunately, defining appropriate property rights can be quite elusive in the presence of externalities (e.g. the right to “clean” water, not just water), and the transactions costs of negotiating solutions can also be formidable. It is not therefore surprising that adequate solutions to these problems have not yet been found in the Arenal-Tempisque watershed, as is the case in many other watersheds around the world. In addition to property rights, information is needed on what is happening if informed decisions are to be made. This aspect highlights the importance of a monitoring system and information disclosure for effective action.

Past Experience with Institutional Arrangements

In terms of institutional development, the Arenal-Tempisque watershed has been one of the most dynamic areas in Costa Rica. Institutions developed in response to the dramatic changes that have taken place there in the last 20 years. The driving forces behind that institutional evolution range from modest private production and conservation initiatives that have consolidated and expanded over time, to the need to create government entities to undertake and administer large investment projects. Examples of the first are the Cheese factory and the Monte Verde Conservation League; examples of the latter are ICE and SENARA.

In the initial stages, the creation of institutions responded to specific management needs in different sections of the watershed. Lack of communication infrastructure and poor knowledge about the links among those sections contributed to the creation of a culture of “institutional territories” that has proven difficult to overcome and hinders any serious attempt to manage the entire watershed in a more integrated way. This is still true, despite the fact that communications and knowledge have improved, and a new generation of institutions—like the National System of Conservation Areas (SINAC), has emerged that are aimed at fostering institutional coordination and cooperation.

Despite these problems, some attempts have been made by different stakeholders to cooperate and improve the overall management of key resources in the Arenal-Tempisque watershed. Some of these efforts have been successful and some have not. For instance, the Monteverde Conservation League (MCL) and the Monteverde Dairy Producers Association (MDPA) agreed on the need to prevent soil deterioration and deforestation. Using funds from international donors, plus their own technical capabilities and labor, they embarked on an agroforestry project to plant windbreaks. The windbreaks can be seen everywhere; but when the external funding ended no more trees were planted. Another example of stakeholder negotiation is the agreement between ICE/SENARA and Aquacorporación, the tilapia farm. ICE agreed to continuously release at least the minimum of water that is essential for the survival of the fish, even at times when ICE is not generating electricity (and hence when the water has a direct opportunity cost to ICE and the nation). In this case, Aquacorporación lobbied successfully to make the agreement possible, and has expanded to become the largest aquaculture operation of its kind in the Western Hemisphere. Critics of the agreement contend that tilapia prices should reflect the cost of all electricity production lost as a result of these minimum water releases; something that should be part of future negotiations.

The negative environmental impacts caused by institutional and policy failures have prompted other positive reactions from key stakeholders. For instance, SENARA jointly with other stakeholders has established an environmental commission. This was the result both of their own initiative and in response to loan conditions imposed by the Interamerican Development Bank (IDB), the main financial source for construction and maintenance of irrigation infrastructure. Similarly, private farms, like Taboga and Pelón de la Bajura, have created environmental departments in charge of devising and implementing programs to recycle plastics and to reduce agro-chemical pollution. Smallholder associations in the settlement areas have also developed education campaigns to increase awareness of environmental problems.

OPTIONS FOR NEGOTIATING SOLUTIONS

While some of these past developments are encouraging, the fundamental problem of negotiating successful solutions to the major environmental problems in the watershed still remains. In this section we explore the nature of these negotiation problems in more detail, and suggest possible solutions.

The Payoff Matrix in Table 6.1 is a condensation of the Payoff Matrices discussed in previous chapters. It combines a verbal description of the meaning of the coefficients in each cell and their dollar values as derived from the model's baseline solution.

The clustering of environmental costs in the matrix shows that there are really two sub-problems in the watershed, and that because the stakeholders involved are different in each problem, then they can for most practical purposes be conceived as separate negotiating problems. These two problems are soil erosion in the catchment area and agro-chemical pollution in the irrigated areas and below. We discuss them in turn.

Table 6.1—Payoff matrix of stakeholder interests.

	Forest Reserves	Dairy/ Cattle Farms	ICE	Irrigated Farms	Wetland	Fishermen	Realized Benefit
Forest Reserves	Maximize forest area (39.7)						(39.7)
Dairy/Cattle Farms		Maximize dairy & cattle income (37.5)					(38.0)
ICE		Siltation of reservoirs (-703.1)	Optimize electricity production (1,821.6)				(118.5)
Irrigated Farms				Maximize crop income (194.9)	Bird damage to crops (-20.1)		(174.9)
Wetland				Agro-chemical pollution and soil runoff (-51.6)	Maximize conservation (70.7)		(19.1)
Fishermen				Agro-chemical pollution and soil runoff (-111.6)	Reduced Agro-chemical and soil runoff (16.9)	Maximize fish income (121.2)	(26.5)
Net Benefit	(39.7)	(-665.1)	(1,821.6)	(31.8)	(67.5)	(121.2)	(1416.7)

Note: NA means not applicable

Erosion in the Catchment Area

Soil erosion in the catchment area is caused by dairy and cattle farmers and it already imposes externality costs on ICE because of the silting of the small reservoirs that feed the Corobicí and Sandillal hydroelectric power plants. Siltation also reduces the useful life of Lake Arenal which will have much more serious consequences for all downstream users in the long term (current estimates give the lake a useful life of another 500 years). Expansion of forage crop production for dairying may also reduce the amount of water recharging Lake Arenal, and this may eventually impact on ICE and irrigated farmers though it is not yet perceived to be an important issue. The model ignores water scarcity issues and, while the impacts of siltation on the useful life of Lake Arenal is considered the damage is too far in the future to affect the discounted benefit streams today. But even without factoring in the costs of future water scarcities, the externality costs imposed on the system through siltation by the dairy and cattle farmers are enormous ($703.1 million) and it is all borne by ICE. This cost far exceeds the economic value of dairy and cattle production. Given that the two activities together only generate income of $38 million, then their net social benefit is negative, $-665.1 million. On strict economic grounds, there is no justification for dairy and cattle farming to be practiced in the catchment area, at least if they continue with current land use management practices.

The payoff matrix also suggests that the negotiating partners for solving the soil erosion problem in the catchment area should be ICE vs. the dairy and cattle farmers. The forest preserves do not contribute to the problem, nor are they negatively affected. But the managers of the forest preserves cannot be expected to remain neutral since they appreciate the environmental benefits that they bestow on downstream users through the soil erosion that they prevent by retaining primary forest. Moreover, since they have to continuously find the funds to protect their preserves, it is no secret that they are interested in seeking financial compensation from ICE for part of the environmental benefits they generate. The preserve managers would undoubtedly consider it very unfair if the dairy and cattle farmers received compensation for adopting less-erosive land uses if they did not also receive compensation for protecting forest.

The model results in Chapter 4 suggest that the current levels of soil erosion in the catchment area are now so high that any further increase will have little impact on ICE’s current siltation problem. This is because it is the silting of the smaller, downstream reservoirs that feed the individual power plants that is causing the current problems for ICE, and these already fill up on a frequent basis. In order to change the situation, it is necessary to substantially reduce erosion on existing agricultural land in the catchment area, not just to contain any further forest conversion.

There are several options for approaching the problem. The easiest is for ICE to invest in more dredging equipment and to simply keep cleaning the small reservoirs that feed the power plants. They are already doing this on a regular basis. But this is an incomplete solution to the problem because a) it is costly to undertake on a regular basis; b) it does not deal with the increasing severity of soil erosion as more land in the catchment area is put into erosive uses, c) it does not address the longer-term silting problem that is affecting the useful life of Lake Arenal, and d) it does not address the associated water catchment problem; more forage crop land in the catchment area may mean that less water will be captured in Lake Arenal leading to eventual downstream water shortages.

More effective solutions to the problem need to focus on reversing the decline in the forested area, and in getting cattle and dairy farmers to adopt non-erosive land uses and farming practices.

Banning any further deforestation through government fiat would be difficult to legislate and enforce given that most of the land is privately owned. A better solution might be for ICE to buy up more of the most critical parts of the catchment area and to manage these as protected areas, but this would have to be a long term strategy. Another strategy that could have broader and quicker impact is for ICE to compensate holders of forest land by paying a per hectare subsidy. Compensation might also be paid for new land that is put back into forest, though perhaps at a reduced rate until the trees have fully grown (e.g. payments could be tied to the estimated amount of total carbon that is standing in the forest in similar vein to the payment for environmental services that is already practiced under provisions of the Kyoto Protocol by the Costa Rican Office for Joint Implementation). At the same time, it would be necessary to implement changes that reduce soil erosion on agricultural land. This requires promotion of technology and land use practices for dairy and cattle farms that are less erosive. Some types of agroforestry (e.g. coffee) are non-erosive and can be quite profitable. Permanent pasture also causes little erosion if properly managed and if cattle tracks are protected against soil erosion. On the other hand, frequent plowing and soil exposure associated with forage crop production can be very erosive, especially in these hilly landscapes. Farmers could be compensated financially for adopting environmentally sound land use practices that are less profitable. With some initial technical assistance and training and help in accessing new markets, these alternatives might even prove to be more profitable in the long run, and the financial compensation could be phased out. For this strategy to work, it would also be necessary to ensure that agricultural policies do not inadvertently subsidize or favor inappropriate land use practices (e.g. through credit, exchange rate misalignments or forest, milk or beef pricing policies). The Ministry of Agriculture would have to be a partner to some of the negotiations.

ICE would have to raise additional revenue to buy additional protected areas or to pay for compensation to farmers and the forest preserves. There are two obvious ways of doing this. One is for ICE to charge more for its electricity (essentially adding an environmental cost). But electricity prices are regulated by the Government and may be difficult to change. ICE could also consider charging SENARA and/or the irrigated farmers a volumetric water fee (this would also help address emerging water scarcity issues). But again ICE does not have the authority to charge for water without the government's agreement (in this case, it would require approval from Congress and the MINAE and the oversight of the Regulatory Authority of Public Services, ARESEP). Because preserved forest bestows environmental benefits that extend well beyond the watershed (e.g. conservation of unusual biodiversity in the cloud forest and carbon sequestration offer national and international benefits) it may be appropriate for the government to contribute to the levels of compensation paid. This would reduce the burden on ICE and other downstream beneficiaries.

ICE seems to be the natural stakeholder for initiating a solution to the catchment area problems. It has strong incentive, and is large and powerful enough to organize and bring considerable pressure and resources to bear on the problem, including perhaps some supporting government action. But ICE cannot afford to commit itself to paying financial compensation without first raising the additional revenue. Before entering into negotiations ICE needs to determine whether it can a) obtain approval from ARESEP to charge higher electricity prices, b) charge SENARA and/or the irrigated farmers for water, c) recover part of the costs of protecting the catchment area directly from the government, and d) buy up larger parts of the catchment area for itself. ICE also needs to obtain some bargaining leverage over the managers of the forest preserve and the dairy and cattle farmers to keep any agreed compensation levels at reasonable levels. The managers of the forest preserve should in general be expected to identify with and support ICE's objectives in any negotiations, but at the same time they will want to negotiate a level of compensation for themselves. The irrigated farmers currently are not yet affected by land use changes in the catchment area, and undoubtedly they would not want to pay more for their water. Eventually, if the land use problems in the catchment area are not resolved, then water may become more scarce, and SENARA and the irrigated farmers would have more incentive to join ICE in negotiating with stakeholders in the catchment area. At that time they might also be willing to contribute to paying for the higher effective cost of supplying water.

A fundamental problem in this negotiating problem is that ICE (and all other down stream stakeholders for that matter) has very little leverage over the managers of the forest preserve or the dairy and cattle farmers. As the payoff matrix in Table 6.1 shows, these groups do not depend on ICE and other downstream users in any way, but at the same time their actions do affect ICE and other downstream users. If soil erosion eventually proves costly to dairy and cattle farmers because their own land productivity falls, then it may be in their own self-interest to correct the problem. This would open up opportunities for "win-win" strategies, whereby improved land management practices would be beneficial to these farmers and ICE. But there is no evidence that such win-win opportunities currently exist. So ICE's only effective bargaining chip is to pay compensation.

Under these circumstances, how can one get the negotiations off the ground? ICE is reluctant to initiate action because it cannot afford to offer any compensation to upstream stakeholders without first securing additional revenue to pay for it. ICE is also rightly concerned that without some leverage over these stakeholder groups, then the amounts of compensation that they could demand would be unrealistic. Somehow the process needs to be kicked started from outside. One possibility would be for the government, perhaps acting through MINAE, to introduce land use regulations for the catchment area, and to implement these through inspections and fines. The mere threat of such an intervention may be enough to bring the relevant parties to the table to negotiate more reasonable and less costly solutions to the erosion problem. Finding and orchestrating the appropriate "threat" would be a prime function for any institution managing a policy relevant monitoring system for the Arenal-Tempisque watershed.

Agro-Chemical Pollution in the Irrigated Area

Agro-chemical pollution of the water leaving the irrigated area is a major problem for the wetlands and the fishing industry in the Gulf. As the payoff matrix in Table 6.1 shows, these costs amount to $51.6 million for the wetlands and $111.6 million for the fishermen. The total cost of these externalities is equivalent to 84 percent of the realized income generated by the irrigated farms. This large environmental cost is also likely to worsen in the future if the planned expansion of the irrigation system is undertaken without any change in pest and cultural management practices.

The payoff matrix suggests that the negotiating partners for this problem should be SENARA and the irrigated farmers vs. the wetland park managers (including MINAE and supporting environmentalists) and the fishermen and the Costa Rican Fisheries and Aquaculture Institute (INCOPESCA).

The model results in Chapter 4 show that it will take more than a minor adjustment of current farming practices to make a big impact on the discounted value of the environmental damage caused, but even moderate changes should lengthen the expected life of the wetlands. One solution is for SENARA to build oxidation ponds at the edge of the wetland to treat the water coming out of the irrigation drainage ditches. This could solve part of the problem but is unlikely to be sufficient, particularly if the irrigation project is expanded. The ponds would also become silted quite quickly because of the level of soil sedimentation carried in the drainage canals under existing rice cultivation practices. (At the time of writing, SENARA had already built two one-hectare by 1.8 meter deep oxidation ponds in the vicinity of the park, but their design appears to have created some controversy and MINAE has sued SENARA alleging damage to the park).

Another solution is to change the technology and management practices of irrigated farmers, through offering better technologies or changing incentives. There is good news in that the current technologies (especially the rice varieties grown and pest control practices) are old and inefficient and modernization could bring real cost savings to farmers as well as significant reductions in agro-chemical use. This situation seems to stem from the demise of the public agricultural research and extension system in the 1990s as a result of cutbacks in public expenditure and policy reforms. Even modest investments in adaptive agricultural research and training and extension might reverse this perverse situation. Encouragingly, one of the largest rice producers, Pelón de la Bajura, has already made it’s own private investment in developing new varieties. And some other rice farmers are experimenting with alternative methods of weed, pest and disease control and fertilization.

Changing incentives is also a viable option. Compensation is not appropriate in this case because it is a classic “polluter pays” problem. If farmers were compensated for not polluting then they would have an open invitation to threaten further pollution if they are not paid more money. Some existing agricultural policies need to be reformed to remove perverse incentives. For example, banks credit for farmers is still tied to the adoption of the old technological package and to compulsory crop insurance. To make matters worse, the insurance company (a state-owned monopoly) only indemnifies farmers in the event of a serious yield loss if they can demonstrate that they followed the calendar of activities and applied the chemicals and cultural practices indicated in the old technological package. The Ministry of Agriculture, the banking system, and the insurance company would need to be party to any negotiations aimed at resolving the agro-chemical pollution problem so that they could rectify these disincentives. But even these changes may not be enough to fully solve the problem, and there may still be need for the government to legislate water quality standards and to impose fines on farmers when they exceed these limits.

As with the previous negotiation problem in the catchment area, there is a fundamental imbalance in the negotiations because the fishermen and environmentalists do not have any bargaining leverage over the irrigated farmers who are causing the problem. As the payoff matrix in Table 6.1 shows, the only reverse impact is bird damage to rice fields. Unfortunately, the damage increases with the health of the wetlands, and hence works in exactly the wrong direction to provide any useful leverage to the wetland park managers.

SENARA would seem to be best positioned to take the lead in negotiating a solution. It is large and powerful enough to marshal the required resources and influence, and it already has a track record in initiating such action. On the negative side SENARA does represent the interests of the irrigated farmers but it is also accountable to the Ministry of Agriculture and to the donors (e.g. the Interamerican Development Bank) who finance the irrigation scheme. Environmental groups could also bring pressure to bear on SENARA. The fishermen are seriously affected by agro-chemical pollution from the Arenal-Tempisque watershed, but they are not very effective negotiators. They are poorly organized for this purpose and anyway have to contend with several other major sources of pollution in the Nicoya Gulf which diffuses their efforts. However, INCOPESCA, which represents their interests should be a negotiating partner.

How can the negotiations be initiated? Again, there needs to be some kind of bargaining "threat" to SENARA and the irrigated farmers. If the government, perhaps through MINAE, were to legislate water quality standards and to fine SENARA and/or farmers who violate them then they might have incentive to negotiate less costly local solutions to the problem. Again, finding and orchestrating a credible "threat" would be a prime function for any institution managing a policy relevant monitoring system for the Arenal-Tempisque watershed.

INSTITUTIONAL DESIGN FOR THE PRMS

As we have seen, there are currently two distinct environmental problems in the watershed that need solving. In both cases the chances of a successful negotiation among stakeholders within the watershed is hampered because those who suffer from the environmental damage do not have any real bargaining leverage over those who cause the damage. There needs to be a higher level intervention that can create a "threat" to the polluters if they do not sit down and negotiate a local solution to the problem. This implies that any institution mandated to manage a PRMS for the Arenal-Tempisque watershed must have strong government support as well as the participation of the local stakeholders.

There are a number of institutional options that might work for this watershed, but we illustrate with only one. This option would entail the creation of a single watershed management committee (hereafter called the Watershed Management Committee, or WMC) comprising representatives of all the important local stakeholders (managers of the forest preserves, dairy and cattle farmers, ICE, SENARA, irrigated farmers, the wetland park managers, environmentalists, INCOPESCA and fishermen). Moreover, since strong government support is needed, both MINAE and the Ministry of Agriculture could be full members of the WMC. The WMC would have five major functions:

1. To setup and manage the monitoring system in a participatory way. This might involve having ICE lead the monitoring of the catchment area, SENARA lead the monitoring of the irrigation area, and the park managers lead the monitoring of the wetland and gulf areas. Leadership would entail making sure that all appropriate data are collected and made available at the right times, but a lead organization would not necessarily collect all

the data themselves. As discussed in Chapter 5, it is often desirable to involve other stakeholders or groups of stakeholders in data collection in a participatory way. Farmers and school children might be involved, for example, in monitoring water quality within the irrigated areas, or research organizations working in Palo Verde National Park (e.g. the University of Costa Rica, the National University and the Organization for Tropical Studies (a consortium of over 50 national and US organizations that conduct training and research within the park) could be involved. Some more specialized data collection work (e.g. chemical testing of water) could be contracted to specialized agencies or private firms. The upkeep and operation of the model could be undertaken by ICE after some staff training, or perhaps it could be contracted out to a local university.

2. To organize meetings of relevant stakeholders to negotiate solutions to environmental problems as they arise. Given that most environmental problems only involve a subset of all the stakeholders involved in the watershed, then negotiations for corrective actions might best be delegated to sub-committees of the relevant stakeholders. However, all decisions might need to be endorsed by the full WMC to give them legitimacy and to help ensure that they are implemented.
3. To monitor the implementation of agreed corrective actions and their impacts and to make sure that the problem is finally resolved. The same leadership structure as indicated above might be relevant, though having a professional WMC staff member oversee the process may be necessary to assure all participants of the objectivity and credibility of the process.
4. To make recommendations to the government as needed about electricity and water pricing in the watershed, land use regulations and fines in the catchment area, fines on agro-chemical pollution in the irrigated farming area, and other policy changes that require governmental action.
5. To educate people living and working in the watershed about the linkages between their actions and the health and stability of the entire watershed, and the need for improved collective management.

The WMC would need to be given realistic level of resources to do its job, including at least one full time professional staff member with relevant technical and managerial skills. While the government might reasonably pay part of the cost, greater ownership by and participation of local stakeholders is more likely if they are also required to help cofinance its operations. The WMC would need to be legally empowered and accountable to some appropriate national entity. This might require that it be authorized by the Congress or MINAE.

CONCLUSIONS

This chapter has used the Payoff Matrix to identify the clusters of stakeholders who are impacted by each major environmental problem in the Arenal-Tempisque watershed, and to identify potential coalitions of gainers and losers who would share common objectives in any negotiations to resolve these problems. The Payoff Matrix provides both qualitative and quantitative insights that are valuable for resolving these issues. Qualitatively it identifies the gainers and losers in each problem and the more obvious coalition partners for negotiations. Quantitatively it provides information about the dollar value of each stakeholder's interests, and shows where their largest gains and losses arise and hence which problems and coalitions most merit their attention.

Environmental problems flow downstream with the water in a watershed, hence the damage caused by agents upstream tends to affect only on those further downstream. In the Arenal-Tempisque watershed, for example, soil erosion caused by dairy and cattle farmers in the catchment area adversely affect the hydro-electric power system downstream, and chemical use in irrigated agriculture adversely affects the wetlands and gulf at the end of the irrigation drainage system. The lack of reverse feedbacks creates perverse incentive problems that bedevil attempts to negotiate solutions. The agents who cause damage and do not suffer its consequences have little if any economic incentive to take corrective action. At the same time, the agents who must bear the cost of the damage have little if any effective bargaining leverage over the agents upstream who cause the problem. Under these conditions, the chances that solutions can be negotiated purely by local stakeholders are not favorable, as indicated by the poor track record that has been achieved to date in the Arenal-Tempisque watershed. An institutional framework that is to resolve these problems will not only have to involve all the key local stakeholders, but it will also have strong support from government and the active participation of key Ministries like Agriculture and the Environment that can bring new pressures to bear on those who cause the damage. A possible institutional structure for a policy relevant monitoring system for the Arenal-Tempisque watershed has been proposed that incorporates these key features.

7. OPERATIONALIZING THE MONITORING SYSTEM FOR THE ARENAL-TEMPISQUE WATERSHED

Ujjayant Chakravorty and Peter Hazell

INTRODUCTION

In this chapter, we provide an integration of the main pieces of the Policy Relevant Monitoring Systems (PRMS) for the Arenal-Tempisque watershed and demonstrate through a hypothetical example, how it might work in practice. These pieces involve the system of alarm, diagnostic and response indicators, the economic model, and the institutional and decision-making structure described in previous chapters.

We begin with the operational cycle of the monitoring system described in Chapter 3. Recall from Figure 3.1 that the cycle begins from the top and goes clockwise. At the top of the cycle are the alarm indicators. These give an early warning when a problem arises. If there is no alarm, then the monitoring agency continues to monitor on a routine basis. However, if an alarm indicator crosses a key threshold, then the monitoring agency activates a set of diagnostic indicators to enable more in-depth analysis of the causes of the alarm. Once information from the diagnostic indicators is available, this provides input into the model which is then used to generate information about the impact of the problem on the watershed and, if the threatened damage is high enough to warrant action, to help identify and evaluate appropriate corrective actions.

The model has limited capacity to undertake causal analysis since it takes land uses, cropping patterns, technology choices, etc., as given. In many cases, the source of a new problem might have originated from changes in some of these exogenous parameters and relationships, in which case they cannot be explained by the model. While the model could be extended to make more decisions endogenous, this would add to its cost and complexity, making it harder to use and maintain. However, given diagnostic data on changes in key model parameters, the model can be used to undertake an assessment of their effects, including providing dollar values for economic benefits and costs as well as estimates of the future economic services from the ecosystem, such as the future value of wetland services and its economic life. These numbers can then help determine whether corrective action is worthwhile and provide upper and lower bounds for the costs that society could bear to provide a solution. Model runs can be informed through participatory interviews with affected stakeholders. For example, this would provide information on whether they will behave in the way expected if proposed corrective policies change their incentive structures.

The next step in the cycle calls for dialogue among the key stakeholders leading to an agreed plan of corrective action. The institutional structure plays a key role in promoting this dialogue, especially when there are conflicting interests among different stakeholders, as highlighted in Chapter 6. The model can also play an important role in helping to evaluate alternative courses of action, providing detailed information about their likely effects and the costs and benefits to different stakeholders (as revealed in revised Payoff Matrices).

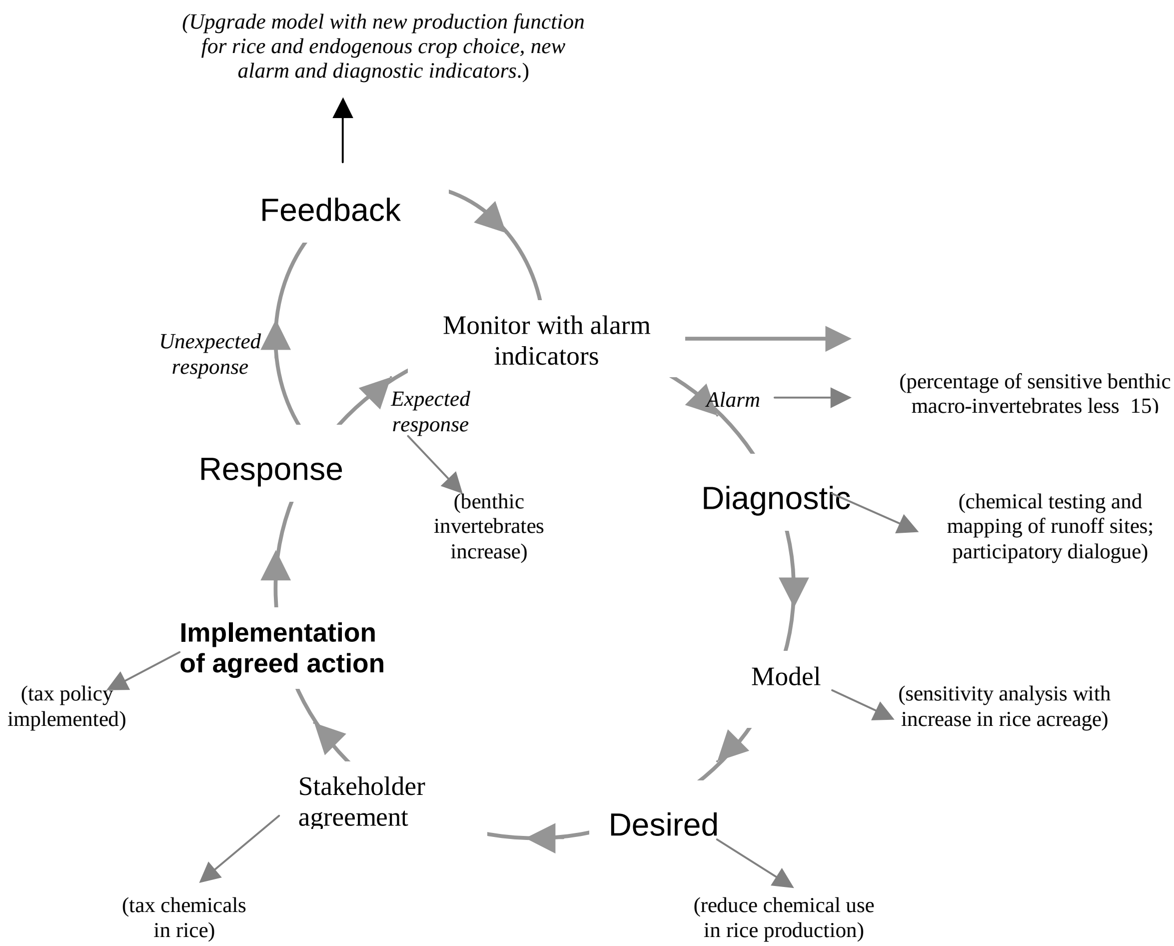
Once a plan of corrective action has been agreed and implemented, then appropriate response indicators are activated to monitor its impact and to determine whether it has successfully corrected the initial problem. If the impact is successful, then the monitoring agency resorts back to the routine tracking of alarm indicators as a precaution against any future problems. But if the impact is not successful in correcting the problem then the monitoring agency engages in a learning process. This involves evaluating why the expected response did not occur and making any necessary corrections to the institutional structure or the indicators and model to avoid the same problem in the future. This phase of the monitoring cycle will disclose whether the monitoring system is properly designed or whether there are changes to be made in order to achieve the expected results in the future. The expected impact may not have been realized because one or more stakeholders did not follow through on the agreed plan of action, or because the expected response was incorrectly identified through the diagnostic and modeling frameworks. Once the cause of the unexpected response has been identified, appropriate modification to the indicators, model or institutional structure may be required. This built in learning process should, over time, lead to continuous refinement in the data collected at the alarm and diagnostic stages, more accurate specifications of the biophysical and economic relationships in the model, and to strengthening of the institutional process for effecting corrective actions.

ILLUSTRATION OF THE OPERATIONAL CYCLE OF THE MONITORING SYSTEM

The Operational Cycle can be illustrated with a hypothetical example for the Arenal-Tempisque watershed. Let us assume that a monitoring system is already in place and alarm indicators with established baselines are being monitored on a regular basis for the various components of the watershed, as described in Chapter 5. In particular, the composition and health of the benthic macro-invertebrates are being measured periodically. As suggested by Martinez Ocampo (2000), assume that during one such monitoring exercise it was discovered that the sensitive benthic invertebrates consisted of only 10 percent of the total community, which is below the threshold level of 15 percent. As shown in Figure 7.1, which is the operational cycle of Chapter 2 adapted to this hypothetical example, the alarm bells sound off and a host of diagnostic indicators kick in as we move clockwise from the top right hand corner. The alarm suggests that the wetland ecosystem may be subject to stress from chemical pollution, possibly from the agricultural sector. However, the alarm could be false, say due to measurement error, or episodic, because of some localized or temporary adverse conditions (e.g., a chemical spill in the area or a low probability storm runoff event) or some other factor. The task of the diagnostic indicators will be to develop more reliable and detailed information on the state of the wetlands, verify whether the problem is indeed serious and attempt to establish the cause of the change. The term “attempt” is used here because for some changes, no cause may immediately be found and an elaborate expert consultation and research effort may be necessary.

A combination of several diagnostic indicators could be activated at this stage. Further readings of the macro-invertebrates may need to be taken at other sites in the wetlands and irrigation drainage canals to identify the extent of the problem and the areas from which additional agro-chemical pollution may be originating. Use of GIS mapping

Figure 7.1—lllustration of the operational cycle



approaches might help in pinpointing the source of the problem and the parts of the wetlands that are likely to be damaged. More elaborate chemical testing of irrigation runoff may also be needed to determine which chemicals are present and in what concentration. Several stakeholders could be involved at this stage, but in particular, there needs to be close institutional collaboration between the wetland managers and SENARA at this stage. SENARA's knowledge of the irrigation and drainage system and the cropping patterns in the area could be brought to bear to determine what may be the cause of the problem. The results of further testing and chemical analysis could then be discussed in a participatory setting with farmers, agronomists, agricultural extension personnel, wetland scientists and managers, and other people who may have local or scientific knowledge pertinent to the problem.

Let us assume for simplicity, that one possible cause discussed in the above dialogue was a recent increase in rice prices in the world market and a possible switching of cropped area from sugar to rice because of a change in relative prices. Participants in the dialogue pointed out that they had interviewed farmers during extension visits and several had increased or were considering an increase in their rice acreage at the expense of sugarcane. They were also planning to grow more rice during the rainy season on non-irrigated land. The participatory dialogue upon further deliberation, developed a consensus estimate for the possible model simulations that could be done with rice acreage. The participants wanted to know how the wetland and fisheries environmental services would be impacted if indeed there is a trend towards increased rice production in the area at the expense of sugarcane. What would be the magnitude of externality damages and how would this new development affect the effective life of the downstream ecosystem?

The dialogue concluded that they would like to see the results for a model run with an increase of rice acreage by 10 percent a year for the next 5 years. The Watershed Management Committee (WMC) obtained new model runs for this scenario shown in Table 7.1. This table shows the payoff matrix with annual values (in million dollars), assuming a rice area increase of 10 percent per year for 5 years in a row. The table compares two scenarios: scenario 1 in which rice area displaces sugarcane at the rate of 10 percent a year for 5 years and scenario 2 which provides the business-as-usual case of rice area remaining constant. Notice that these numbers are annual values for the first five years, since the discounted present values aggregate over an infinite horizon and may not really capture the short-run shock to the system.

Table 7.1—Annual irrigation, wetland and fishery benefits when rice area displaces sugarcane (million dollars)

	Year 1		Year 2		Year 3		Year 4		Year 5	
	Scenario		Scenario		Scenario		Scenario		Scenario	
	1	2	1	2	1	2	1	2	1	2
Profit from Irrigation	11.5	9.1	12.0	9.4	12.3	9.6	12.8	9.8	13.3	10.0
Benefit from Wetland	3.6	3.6	3.1	3.1	2.6	2.7	2.2	2.3	1.8	2.0
Profit from Fishery	6.2	6.2	5.1	5.2	4.1	4.2	3.2	3.4	2.4	2.7

Scenario 1. Rice output price increase by 10% leading to rice acreage expansion by 10% per year for 5 years, substituting into sugarcane.
Scenario 2. Baseline case: rice output price and area remain constant.

The table shows that there is a clear a divergence between the two scenarios that shows up in higher annual benefits from the second year on with the increasing rice acreage. The model also computes the reduction in the effective life of the ecosystem from this 5-year shock. Wetland services will decrease to zero in 52 years under the shock relative to 65 years in the base case. Similarly, fishery benefits will decline to zero in 38 years, relative to 48 years in the base case. Once again, these numbers reveal the importance of looking at longterm effects and not just the dollar values of ecosystem benefits.

The model results suggest a clear need for corrective action in this case. We next move to the “Desired Action” phase of Figure 7.1. A whole range of policy measures can be considered to reduce the impact of increased rice production and pesticide use. These could be briefly listed as follows: (i) a tax on the output price of rice that restores the pre-shock relative price between rice and sugarcane; (ii) a tax on chemicals used in rice production; (iii) a new program for Integrated Pest Management in rice; and (iv) develop new pest-resistant varieties of rice that could be grown without heavy application of chemicals. Options (i) and (ii) could be problematic since a tax on rice or chemicals in the Arenal region and not in other rice producing regions may be politically infeasible and create tension between regions. Option (iii) and (iv) raise the issue of who will pay for the IPM or plant breeding programs. Would the intended beneficiaries such as the wetlands and the fisheries sectors pay? Should public moneys be used, perhaps justified on the grounds that increased rice production has social benefits such as cheaper food prices for urban consumers, and increased self-sufficiency and national food security? Does one apply the 'Polluter Pays' principle in this context? Other questions may also arise about options (iii) and (iv). How long will such programs take to produce results and what may be the cost? Who will undertake the plant breeding option? Does the country have the capacity for a scientific research program? Does it need external scientific assistance?

Many other policy actions could be considered, although not discussed here. These alternatives could be discussed at length among the stakeholders, which may include the WMC, as well as any other parties that may have important information or could provide useful input in the discussions. For example, if one of the options is to develop or adapt pest-resistant varieties of rice, then plant breeders and agronomists from the international scientific community could be invited to provide input on the feasibility of the program or whether such rice varieties may already be available off the shelf.

The model could be used to evaluate the most promising courses of action. The results would show the relative effectiveness of different approaches in correcting the pesticide runoff problem, and the associated costs and benefits to different stakeholders. The results would be used to inform the discussions among key stakeholders in deciding on their course of action. Table 4.8 in Chapter 4 shows, for example, the effect of introducing a pesticide tax on rice, and similar results could be obtained for the increasing rice area scenario. Some of these simulations may require some upgrading of the agriculture component of the model to better reflect technology and pest management choices as a function of the different varieties, fertilizers and pesticides used. The model may also need to allow for acreage responses to rice or pesticide taxes, as well as inter-regional responses. That is, if the taxed rice grown in the region cannot compete with rice grown elsewhere, rice production will shift to other regions, and farmers in the watershed may switch back to sugarcane or experiment with other crops. In short, examining this problem in all its dimensions may require a model with a more sophisticated specification of the farming sector. It is important to note that the model is a tool that is used only when stakeholders ask for answers. This avoids the problem of a monitoring system which is driven by the model, and the possibility of over-investing in the model, making it too complicated and cumbersome, and therefore opaque in terms of generating insights on key monitoring and policy questions.

Let us assume that the stakeholders agree upon a common course of action involving the imposition of a pesticide tax in the region. From the circular flow diagram, the next step in the monitoring cycle is ‘Implementation.’ The next stage involves developing response indicators to verify if the policy action is having the desired effect. In this case, participatory approaches could be undertaken to determine if rice growing has become less economically attractive as a result of the tax. It is quite possible that unintended consequences may occur, such as the illegal importation of cheap pesticides that may cause even greater damage on the downstream ecosystem. This also means that new alarm indicators may need to be developed, such as the precise type of chemicals rice farmers use. Since each pesticide or fertilizer may have differential impacts on the environment, the model could be upgraded by specifying separate damage functions for each major category of chemicals.

If the expected response to the tax is the gradual decrease in chemical use, we expect to see a gradual resurgence in the number of sensitive macro-vertebrates in the wetlands. This may only happen slowly and the system may have to be on “red alert” for a period of time. Once the indicators see a drop in the value of the alarm indicators, the monitoring system can over time, go back into a periodic checking of the alarm indicators.

If the expected response fails to occur, the monitoring system needs to trigger the feedback response to see what went wrong. There are many possible reasons for a mismatch between expected response and actual response. These may include incorrect assumptions used in the model, conditions and policies not captured by the diagnostic indicators; a failure in the implementation of the desired actions and a lack of capacity or knowledge within the relevant institutions and stakeholders. Another possibility is misconceptions or lack of knowledge about the causal links within the watershed. In that case, a learning or research component needs to be added to the monitoring program cycle.

The feedback mechanism included in the policy relevant monitoring system also plays a role in detecting necessary changes in the assumptions and causal relationships in the model and the selection of relevant alarm and diagnostic indicators. For instance, after the above cycle, one may decide that the previous alarm indicator system needs strengthening. That is, the measurement of invertebrates is insufficient and needs to be supplemented by new alarm indicators that measure specific chemicals in the runoff and at strategic points in the area. If the originally selected alarm and diagnostic indicators are proved to be irrelevant, or insufficient, they could be replaced.

Concluding Remarks

These same principles apply to other parts of the watershed such as soil erosion from the upstream areas and water availability in the upstream areas. The corresponding alarm indicators could be the land use changes that show an increase in land converted from forests to cultivated land, or an increase in forage crops that goes beyond the established threshold. The model is activated, analyzes what the damage is of the land use change, whether stakeholders should react to it or not considering the various costs (e.g. reduced electricity production) and benefits (e.g. increased profits from dairy farming), and in that case in what direction the actions should go. When the analysis has been carried out, the specific actions still need to be determined. For example, if the outcome of the analysis is that the planned land use change needs may impose serious externality costs on the downstream environment, several key questions need to be asked and answered, through a similar process of stakeholder dialogue and learning by doing. In this case, the modeling of the catchment may need to be upgraded with detailed specification of land use decisions.

8. POLICY RELEVANT MONITORING SYSTEMS: LEARNING LESSONS AND LESSONS LEARNED

John A. Dixon

The art of sustainable resource management is the art of identifying conflicts and trade-offs, and taking decisions that balance the needs of the present generation against the future, and the gains to individuals against the gains to society at large. As demonstrated in this study, these issues are clearly seen in the management of watersheds and the competing demands from different users of the ecosystem's resources, from the top of the watershed to the coastal and marine areas at the bottom. The complexity of these systems is multi-layered—from the physical links between the various components, to the economic interactions via the generation of externalities, to the institutional and social dimension that ultimately determines what changes (or compromises) are possible.

As seen in this application to the Arenal-Tempisque watershed in Costa Rica, this type of resource system is one where normal market forces will lead to a sub-optimal outcome. Because most of the impacts of resource use decisions are unidirectional—and flow from top to bottom due to the force of gravity—externalities are common, and there is little or no incentive for the various stakeholders to work together. The rancher in the area above the reservoir has no incentive to take steps to control erosion or change patterns of water flow to benefit the various downstream users—including the power generating authorities, mid-level irrigated agriculture or tilapia fish farms, or the downstream coastal wetlands or coastal fishery. In fact, the coastal wetland and artisanal fishermen are potentially the most affected by all of the upstream actions, and yet have no economic (nor usually institutional) way to influence any of the decisions that affect their ecosystem, their wellbeing, and their wealth.

Hence the importance of the linked environmental-economic analysis that is presented here, and the role for indicators to help monitor what is happening, and elicit policy responses, when problems arise. We call this a Policy Relevant Monitoring System (PRMS) and the intention is to both inform and empower the various stakeholders (and decision makers) within the watershed so that serious problems can be avoided, and the social welfare of the watershed as a whole can be maximized. Identification of potential problems, and their solutions, is only the first step. Implementation of new policies requires consultation and the coming together of different parties (stakeholders), many of whom have no personal (nor economic) interest in co-operating. Thus the importance of the role of Government or organized stakeholder or management groups.

The analysis presented here of the application of this approach in the Arenal-Tempisque watershed in Costa Rica indicates both the potential for (and limitations of) this methodology. It is based on available data and our understanding of the functioning of the watershed and the various stakeholders. The process of developing the model and the associated indicators involved much learning and also highlighted the remaining areas of uncertainty. Hence, the results should not be seen as a concrete management proposal. Rather, the results are indicative of the types of answers this PRMS approach can produce, and identifies areas deserving of closer attention and additional work.

Nevertheless, there are some important lessons that can de drawn from this study and that have wider applicability. The major findings of the application of the PRMS in the case of the Arenal-Tempisque watershed follow.

Major Findings

A strength of this approach is the explicit linking of the physical–economic–institutional systems within a single framework that uses indicators to transmit information and serve an early warning function. The analysis is simplified by the fact that this is a watershed where the force of gravity (and flowing water) means that most effects are unidirectional (from the upper watershed to the coast). The same approach can be used in other settings (such as an urban area, or within a marine environment); but will normally require additional work to clearly specify the nature, size, and direction of externalities.

The associated economic model and the payoff matrix explicitly identify the winners and losses of any change in the management system, and the size and location of external effects (the economic externalities). In essence this allows both a traditional private analysis of actions (sometimes referred to as a financial analysis) as well as a social-welfare analysis (also called an economic analysis) of outcomes. The Payoff Matrix also provides a great deal of other useful information:

- The diagonal elements of the Payoff Matrix represent the private (usually financial) perspective while the off-diagonal elements indicate the externalities associated with each diagonal element. And the externalities can be either positive or negative. In essence, the diagonal elements show what the net benefit from any activity are estimated to be, and the off diagonal elements show how much externalities are affecting the bottom line. When summed across all activities in the watershed, the Payoff Matrix therefore represents the total social welfare of the ecosystem, and indicates where there are important opportunities for gains to be made.

- The Payoff Matrix helps identify those impacts and links in the economic/ecosystem being studied, and this information helps inform the selection of alarm and diagnostic indicators for both monitoring and evaluating possible policy responses. This continuous learning process helps to more efficiently use scarce resources, both in identifying what to monitor (the important externalities in the Payoff Matrix), and how to do it (the alarm and diagnostic indicators).
- The analysis of links and the use of the Payoff Matrix allow the identification of potential "partners" or natural allies in any negotiations between groups, and also identifies the monetary amounts at stake (especially from the private, financial perspective as seen in the diagonal elements) of any proposed management change. Although this information does not guarantee better outcomes, it definitely identifies those who should be involved in management discussions, and the likelihood for potential success.

Since each **diagonal element** represents the private benefit obtained from an activity, then in the absence of enforceable property rights (or "rights to pollute/ create externalities") the diagonal value also represents the MINIMUM that those involved in the activity will be willing to accept to stop carrying-out that activity. Similarly, the off-diagonal elements in each **column** represent the externalities created by the activity on the diagonal. (These off-diagonal elements in each column are usually negative, but in some cases may be positive.) The sum of these externalities, therefore, represents the collective MAXIMUM that others will be willing to pay to "buy-out" the activity on the diagonal, and thereby avoid these externalities. Depending on the relative size of the diagonal value versus the column values for the same diagonal activity, one can see whether or not social welfare is increased by allowing any activity to continue at the present scale, or to reduce its scale or even completely eliminate it. (Of course, if an activity creates positive externalities, the socially desirable outcome is to **increase** the scale of the activity).

There is a parallel analysis of the activities on the diagonal and the values in the **row** associated with each diagonal activity. As before, the value on the diagonal represents the private benefit from the activity and these benefits are determined by both what goes on within the activity and by any externalities that affect the activity. The externalities that affect the diagonal activity are seen in the row associated with each diagonal element—and just as before, one can compare the value on the diagonal with the externality values in the row to see whether or not it pays for the activity on the diagonal to try to negotiate with, or prevent, other activities that affect net profitability.

The Payoff Matrix clearly shows why people at the top of the system may have major impacts, for good or for ill, on others at all levels within the system (seen in the values in the column below the diagonal element), and yet these same stakeholders have little or no incentive to change their individual, profit-maximizing behavior, regardless of the size and sign of any externalities generated. Even though the Payoff Matrix clearly indicates the potential for a Coasian solution, institutional rigidities and information problems usually prevent this from happening.

If the example of the Arenal-Tempisque watershed illustrates the potential for this approach, it also highlights a number of limitations:

First, the approach is fairly data-intensive. A major contribution of the approach is the attempt to develop an efficient, and effective, monitoring system that is built around the concept of alarm—diagnostic—response indicators. Previous efforts to develop indicator systems for monitoring have often failed to make the link to policy responses, and have ignored the basic principle of cost-effectiveness and that often “less is more”. The approach presented here provides a way to identify different sets of indicators to monitor, and their explicit role in the analytical and policy response process. The “alarm” indicators are designed to be transparent, low cost and easy to monitor. If an alarm is sounded, then the more complex diagnostic indicators come into play, and later the policy response indicators are used to measure impact of the changes made. Still, considerable knowledge is often required to understand the causal links between actions and impacts in different parts of the watershed.

Second, the analytical demands and complexity of the analysis increase dramatically with the scale of the area being studied. The larger the area included, the more the different types of users (stakeholders), the more different types of activities taking place within the watershed (or system), the harder it is to understand the causal links, and identify and fill in the off-diagonal cells (the externalities) in the Payoff Matrix.

Third, and perhaps most importantly, the identification of the externalities and the potential actions to correct or minimize them is an essential, but not sufficient step. Taking effective action so that the individual stakeholders will change their individual welfare-maximizing behavior usually requires intervention by some higher authority that can force individuals to accept some modest private cost in the name of a larger social gain. To accomplish this requires information on the size of these potential costs and benefits (as derived from the Payoff Matrix) as well as political will to enforce the improved management pattern.

The approach presented here can be a powerful tool for helping this process, and helping to inform the general public and the political process. This is not always easy to do, however, especially if some of the stakeholders, who are being asked to make these changes, are “rich and powerful”. There may be a way around this problem, however. One other potential outcome from the PRMS and Policy Matrix approach is that the various stakeholders in the system being studies (both large and small stakeholders) are *themselves empowered* by the information presented. Even in the absence of government or other outside intervention, the fact that the principal actors have information on the size and direction of externalities opens up the possibility that coalitions can be formed, and negotiations can take place between the different groups, hopefully leading to an improved outcome. The results of the analysis also highlight the interdependencies between different groups in the watershed (a farmer may also be a part-time fisherman and thus one activity [use of chemicals in agriculture] has direct effects on the other [the health and productivity of a downstream fishery].) Recognition of these links helps promote a search for co-operative solutions.

Both monitoring and economic data can thus help to reduce the “informational asymmetries” commonly found in such ecosystems. While not guaranteeing a Pareto superior outcome, the increased level of information and transparency certainly can be powerful forces to get the various agents together “around the table” to seek ways to minimize externalities and thereby increase the generation of net benefits. These net benefits are then seen on the diagonal of the Policy Matrix, which serves a valuable feedback function as various management options are discussed.

BROADER APPLICABILITY OF THE PRMS APPROACH

Although the example presented here is based on the study of one watershed in Costa Rica, the approach has much broader applicability. The basic elements can be used in most natural systems, whether they be temperate forests, African savannas, or Pacific coastal ecosystems. What is required is some “boundary of the analysis” that permits an understanding, and modeling, of an ecosystem. As seen here, it is important that one can identify and quantify the links between actors in the system, and in this way estimate the type, location and scale of externalities. The policy responsive monitoring system then flows from this understanding of the physical/ economic system.

The same approach can also be applied in urban areas. This will be more challenging in many cases since the links between different actors may be quite complex and therefore creating a Payoff Matrix may require considerable scientific and technical information. Air pollution, for example, comes from many different sources, is “mixed” in the airshed, and has many different types of impacts. Water pollution, since the flows are easier to monitor and gravity does play an important role, may be easier to model. In either case, the application of this approach to an urban resource management problem will promote explicit consideration of the links between the major actors, the importance of externalities, and the indicators that are needed to monitor and manage the system.

Scale is always an issue, but should not limit the application of the approach. Although smaller systems may be easier to model and the linkages between actors may be more transparent, there is conceptually no reason why this approach could not be applied at a broad geographic scale. In fact, there may be some global environmental issues (ozone depleting substances, pollution of international waters, maybe even green house gas emission) where one could consider using this approach to construct a rough Payoff Matrix.

In sum, the methodology illustrated here presents a roadmap to a better, more inclusive analytical approach to resource management by explicitly highlighting and quantifying the “stakes” involved in this process, and why improved resource management decisions (from a systems perspective) are always so difficult to implement. By quantifying the magnitudes of both the net benefits and the externalities, the Payoff Matrix highlights the potentials for improvements in overall social welfare. The explicit linking of indicators to issues of concern to policy responses, is also an important contribution to improved resource management. However, political will is often ultimately needed to make improved resource management happen.

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