THE ON-SITE AND DOWNSTREAM COSTS OF SOIL EROSION

by

Wilfrido Cruz
Herminia A. Francisco
Zenaida Tapawan-Conway

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Wilfrido Cruz (University of the Philippines at Los Baños)
Herminia A. Francisco (Benguet State University)
Zenaida Tapawan-Conway (University of the Philippines
at Los Baños)

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OVERVIEW

This report presents a practical methodology for the asssessment of the economic impact of soil erosion, illustrates the methodology with results from recently completed case studies, and proposes a framework for incorporating this methodology for upland resource policy and management programs. The motivation for the study of economic assessment of environmental effects should not only be for the purpose of extended project benefit-cost analysis. Valuation efforts should be properly put in the the context of improving resource pricing policy. The reason is that it is this set of potential government policy instruments that rivals project-oriented watershed management efforts in terms of making immediate and widespread impacts in the reduction of soil erosion.

There is a need to explicitly recognize the development context for upstream conservation activities in terms of their implications for downstream impacts -- especially on the food production program in general and on irrigation development in particular. This is not meant to imply that on-site economic impacts are unimportant. Indeed they are expected to be substantial; the problem is that in the socio-political arena of policy-making, the welfare of upland interests are primarily appreciated only through their downstream inter-relations.

Chapter I presents a detailed exposition of the methodologies for estimating erosion: gross erosion from

Universal Soil Loss Equation-based approaches as the basis for on-site effects and reservoir sedimentation measurements as the basis for off-site effects. Data availability for such efforts is the constraint, and the problem is much worse for off-site impact evaluation.

Chapter I also discusses the private decision-making perspective that requires conservation benefits to be judged vs. perceived losses in upland production. This highlights the problem of government watershed management projects that are presented to upland farmers or forest users as once-and-for-all propositions. Since the erosion process is gradual and its on-site effects occur in the future, the timing of adoption of conservation practices cannot be restricted to the start of official projects. The private decision for soil conservation is therefore spread out over time and recursive in nature. Clearly, with this kind of decision-making, the timing of adoption of less erosive practices should be itself part of the optimizing decision. This further supports our view that, beyond the project-oriented approach, it is general government policy that can introduce changes in the incentive structure to allow social valuations to enter the private decision-making process.

In Chapter II, on-site environmental losses from erosion are evaluated for the Magat and Pantabangan watersheds. Erosion leads to a reduction in organic matter and nutrients from the land and subsequently to a decline in crop production unless nutrients are replaced in the soil. Therefore the measure of the economic loss may be based on the cost of replacing these nutrients.

For the Magat watershed where sheet erosion is in the order of 88 tons/hectare/year (t/ha/yr), soil loss carried with each ton nutrients with a combined value of about ₱15, using 1985 prices. On a per hectare basis, the combined loss is about ₱1,000. In the Pantabangan case, we present a more detailed procedure that derives nutrient loss for each 5-cm layer of soil, up to a depth of 50 cm. On-site cost of erosion (using 1977 prices) from the top soil layers is in excess of ₱7 per ton, and this declines to about ₱4 when erosion occurs from the lower soil layers.

Chapter III evaluates the downstream cost of soil erosion. The off-site economic impact of erosion centers on the sedimentation of the Pantabangan and Magat reservoirs which reduces their potential irrigation and hydroelectricity benefits. This reduction is in terms of (a) a shorter reservoir and dam service life, (b) the opportunity cost of providing for excessive sediment storage capacity, and (c) a reduction in useful storage capacity of the reservoir.

In Magat, increased sedimentation from the expected 20 to more than 34 t/ha/yr leads to foregone benefits associated with the loss of 40 years of reservoir operation. In addition, the requirement for constructing an excessively large sediment storage capacity due to erosion means that potentially irrigable area downstream cannot be serviced. This accounts for losses of about ₱18/ton of sediment (in 1985 prices). In Pantabangan, sedimentation increased from the design 20 t/ha/yr to about 81 t/ha/yr. With the practical assumption that only 75 % of sediment deposition actually settles in the dead storage, with 25 % being deposited along the active storage of the reservoir, the operational life of the reservoir will be reduced to about 61 years. The 3 sources of off-site losses, (a) to (c) above, are estimated for Pantabangan. These losses exceed ₱30/ton of sediment (in 1977 prices).

In Chapter IV, we use the on- and off-site costs of erosion as a measure of potential benefit once abatement programs are in place. A pricing policy approach to setting conservation subsidies is illustrated, based primarily on the marginal loss per ton of erosion which may be computed from Pantabangan data.

Finally, in Chapter V we conclude by focusing on the general policy implications of the study for commercial and social forestry. The contribution of the analysis to (a) the economic assessment of watershed management projects, (b) to an operational definition of a "critical" watershed, and (c) to improving land classification (especially for identifying areas for disposition under the land reform program) are also discussed.

CHAPTER I
THE ENVIRONMENTAL EFFECTS OF SOIL EROSION: ECONOMIC VALUATION ISSUES FOR PHILIPPINE UPLANDS

I. INTRODUCTION

A. The Need for Policy Priorities

The complex concerns of upland resource management in the Philippines requires broadness in research scope if the output of policy research is to be relevant. Because of the encompassing problems of commercial timber harvesting, agro-forestry activities by upland communities, as well as extensive downstream effects of soil erosion, the traditional tendency of conventional single-discipline studies to focus on specialized components of the resource management problem and to assume relatively site-specific research perspectives is no longer sufficient. Indeed the growing appreciation of the magnitude of upland resource degradation or over-exploitation (e.g., in World Bank, 1978) and the extent of the environmental effects of watershed modifications (e.g., in Hufschmidt et al., 1983; David, 1984; and NEPC, 1979) has led to a demand for analytical work from which more general inferences may be derived. This means that research should increasingly and explicitly incorporate the upland resource sector within a national policy framework.

Within such a framework, there is a pressing need to respond to the challenge of establishing priorities for government action since the needs of the sector are many and the resources of government are severely limited. This challenge probably cannot be more complex than it is in the field of environmental and natural resource management. In all its key dimensions, environmental and natural resource management requires fundamental and difficult policy choices. Indeed the growing popularity of the term sustainable development to describe the basic objective of resource management tends to understate the conflicts that consistently arise when we think of specific resource-related issues such as the following: (a) development vs. conservation; (b) present vs. future resource uses; (c) on-site benefits vs. off-site costs; (d) underprivileged vs. commercial users of resources; and (e) private vs. social interests.

A focus on valuation of environmental services associated with resources is an important contribution toward a more systematic response to the needs of the policy choice process. The reason is that it allows the decision-maker to explicitly include within the resource pricing system, on- and off-site externalities of resource exploitation activities.

The potential contribution of valuation methodologies for the environmental effects of soil erosion to benefit-cost analysis (BCA) is apparent. In spite of this, the absence of good estimates of such environmental effects (for example, in the economic appraisal of irrigation development and watershed management projects) continues to be a critical weakness in the project evaluation process. In this context, valuation methodologies have the purpose of determining proper shadow prices for project outputs that have significant environmental effects.

Beyond this shadow-pricing objective, however, is the more basic goal of improving resource pricing for national resource policy making in general. This less apparent role of resource valuation is nevertheless more important than its BCA role. The impact of government projects (which are the objects of BCA valuation), though individually large and expensive, are limited to specific sites so that their contribution can only be limited compared with the effect of general policies. Examples of the latter are policies that govern input pricing, such as timber cutting charges and incentives for soil conservation to upland farmers. This means that, while government should not abandon the use of projects in its upland management program, it must recognize that the most substantial and immediate impacts that may be made on resource exploitation and conservation are determined by input and output pricing, taxation, and trade policies -- all of which depend on reasonable resource valuation.

B. Government Policy and Economic Incentives

Elsewhere (Cruz et al., 1987), we have pointed out that traditionally official or administrative resource pricing tends to underestimate the true value of natural resources -- both in terms of their development contribution as well as conservation role. This undervaluation of resources leads to fundamental problems of resource management, including the creation of excessive rents, promotion of over-exploitation, and the institutionalization of rent-seeking as the main mode of economic behavior.

The economic activities associated with the exploitation of natural resources are characterized by an over-dependence on formal or discretionary pricing of key resources (such as standing timber) or licensing of access to others (as in the case of coastal fishery resources). Because the prices assigned to such resources do not even start to approximate their true market values (much less their true social values which may include beneficial environmental effects), the tendency is to create excess demand for the exploitation of these resources.

In forestry the rents that are earned by those firms that gain the right to exploit the resource are unusually large. It is well known that the effect of such unearned surpluses is to motivate widespread rent-seeking behavior since these rents, by definition, represent returns above that which is actually required to attract or keep firms in an industry. Over time, the persistence of such rents lead to overexploitation of the resource as private interests scramble to partake of the windfall. At the same time, the accompanying bias for actors within the industry to be motivated not by productive objectives but by rent-seeking introduces a continuing stimulus to corrupt the administration of resource management, which from the very start has already been discretionary and arbitrary in orientation.

The problem therefore of corruption in government administration and the problem of continuing tendency for resource over-exploitation spring from the same foundation -- the institutionalization of excessive surpluses in the use of forestry resources.

Indeed, the widely recognized problem of inequity in the social sharing from the benefits of the use of natural resources is also ultimately related to this institutionalization of excessive rents because the existence of discretionary and corrupt resource administration plus the competition to penetrate bureaucratic red-tape and fulfill difficult requirements to capture those elusive licenses, concessions, and claims almost ensure that small-time operators or community interests will be squeezed out by the big and influential concerns.

In addition to the unrealistic discretionary pricing in the case of commercial forestry, for upland farming, proper valuation is constrained by the property rights context within which the small upland farmer's decision-making is done. In the first place, rational economic behavior dictates that processes and effects that are not circumscribed within the physical boundary of one's farm are ignored. Thus the conservation services of environmentally appropriate agro-forestry systems are not incorporated in the individual farmer's decision-making calculus. This means that off-site environmental effects of upland agriculture (through soil erosion) are not viewed as relevant and are therefore not priced.

On top of this, the property rights situation is such that the farmer, because he has no secure and permanent claim on the land that he cultivates, has no stake in ensuring the sustainability of land beyond what limited cropping time frame he perceives to be reasonable. This indicates that while he may respond to conservation motivation whose pay-offs are fairly short-term in nature, he will normally shirk from undertaking investment or land improvements (such as terracing) that are permanent in nature.

To sum up the thrust of this paper, the underlying motivation for our study of valuation methodologies is not primarily for the purpose of making a contribution toward better economic analysis of specific projects. In fact, such a study has its potential contribution to project analysis as pointed out by proponents of extended BCA -- the explicit extension of economic appraisal to include environmental externalities of development projects. (See, for example, Hufschmidt et al., 1983; Dixon and Hufschmidt, 1986; and Easter et al., 1986). However, the relevance of environmental valuation is much more general, and it is important to point out that *the more basic challenge* to meet *is proper pricing for economic policy*. As far as upland resource management is concerned, the domain of economic policy covers the entire spectrum of policy instruments, including timber harvesting charges (input pricing), subsidies for conservation efforts, and trade policies for forest products.

II. AN ECONOMIC PERSPECTIVE TO WATERSHED MANAGEMENT

A. The Watershed as Focus of Assessment

In this discussion, a watershed is defined as the area whose surface run-off water drains into a common point or reference with respect to a river or stream (David, 1984). There are many accounting or assessment perspectives that may be adopted for an economic valuation study of soil erosion and conservation. One way might be to look at specific logging and reforestation projects as these contribute toward erosion abatement. This kind of approach would mean that the results of the study would be site- and technology-specific, and inferences for the valuation of other abatement or conservation projects would be quite limited.

In this study, the valuation perspective will assess particular activities as they occur within the watershed as a physical system. One advantage of this approach is that it may be directly applied to the appraisal of management projects for specific watersheds which, by the sheer magnitude of government investment in them, as well as the amount of downstream externalities that they generate, deserve the description "critical."

Another advantage of this approach is that, while it will evaluate different economic activities occurring in various biophysical components of the watershed, the environmental effects are viewed in terms of an integrated soil erosion and sedimentation process. For example, various economic activities are undertaken within a watershed by different decision-making units -- e.g., timber cutting by logging concessionaires, shifting cultivation by upland farmers -- the environmental effects of their different activities all contribute to a common process or system of soil erosion and downstream sedimentation. Since the estimation methods for determining these watershed erosion externalities are advanced and the bio-physical and management information for these estimation methods are available, this approach has relevance for making inferences beyond the site-specific results.

B. The Management of Watersheds

Watershed management is seen as the "process of formulating and carrying out a course of action involving manipulation of the natural system of a watershed to achieve specified objectives" (Hufschmidt et al., 1983:1).

According to Hufschmidt et al. (1983:4-5), the components of the process are the following:

(1) resource management actions, involving allocations of land use, schemes for resource utilization, and on- and off-site practices related to different types of resource

(2) implementation tools, such as regulations, licensing systems, price changes, loans; and

(3) institutional arrangements, including both non-organizational (tenure, legal codes, informal

arrangements) and organizational (public agencies and other institutions).

Integrated or comprehensive watershed management follows from these basic notions and attempts to address multiple objectives with a variety of activities. In this section our concern is to highlight the development context in which such efforts will increasingly be attempted in the Phlippines. At the same time we introduce an explicit economic policy perspective to balance an incipient management style that has tended to emphasize direct government intervention in resource allocation.

Management Goals and the Context of Development

It is useful to emphasize the irrigation-orientation or focus that has motivated much of the history of water resource management in the Philippines. In this sense, the management of watershed resources may be interpreted within the general problem of agricultural intensification in economic development. In addition, the development context helps establish the boundaries or priorities among the many objectives and activites in the watershed management approach presented by Hufschmidt et al. (1984).

The initial concern of government planning was primarily on water resource utilization from the dam-site to downstream farms. This emphasis on farm-level water use has been justified given the transition, during the early 1960s, in agricultural development programs from land expansion toward intensification of production technology with the closing of the land frontier (ILO, 1974). Similarly, during this period there was limited concern for the protection of watershed resources above the dam-site because of the availability of numerous sites suitable for dam construction and irrigation development. With increasing population pressure on the uplands and resource degradation from commercial over-exploitation of forests and their consequent effects in terms of downstream flooding and reservoir siltation, there has been a growing concern on management issues of resources located from the dam-site to the uplands.

With respect therefore to resource management actions to be undertaken, this background indicates that the major motivation for the management of dam-to-upland resources is the concern for the "off-site" or dam-to-farm effects of watershed modifications. (Note that the term "off-site" here is not entirely accurate since some, if not most of the downstream effects of upland resource degradation, will still be within the watershed.) There will therefore be a bias to make cost efficiency the main criterion for the choice of soil cover or management practice for watershed protection.

This means that traditional forestry-oriented goals of keeping specific proportion of watersheds under forest cover will be replaced (in practice, even if not in terms of official policy). Indeed while forest conservation and the amenity-related benefits of forest protection have beneficial implications for watershed protection, the availability of competing and possibly less expensive forms of soil conservation may make reforestation and establishment of protection forests a less attractive choice for watershed management. To emphasize this important point, the critical objective from the downstream or off-site perspective is the control of soil erosion and the availability of water for downstream uses; thus the particular form of on-site soil cover or modifications to be used to achieve this goal will increasingly be viewed as of secondary importance.

Indeed the nature of the vegetative cover itself (or its substitution with man-made structures) becomes important only in so far as it is efficient from the perspective of catching, absorbing, and eventually draining rain water. This is especially so where such watersheds have become part of major investments such as multipurpose dam projects and irrigation systems. In these instances, watershed degradation often leads to sediment build-up at the dam-site during the wet season and limited water supply during the dry season, both of which have very high social costs.

Management by Rules Vs. by Prices

In general when we talk of how to manage resources, there are really only two basic tools available to policy in effecting changes in resource use: rules and prices. Rules refer to formal or informal regulation aimed at structuring the behavior of individuals, with compliance achieved through the use of sanctions or enforcement. Management by prices, on the other hand, refers to the use of both market prices or non-market valuations to change the incentive system on which individual decision-making is based.

Both approaches have the objective of re-directing individual actions toward socially beneficial results. While rule-making has, of course, always been the concern of government, natural resource management through price intervention has had a much shorter history in public administration. Indeed the tradition of public administration of Philippine forest and upland resources has generally followed a rule-oriented approach, and the current experiments in watershed management offer opportunities for moving into more effective combinations of these two implementation tools.

While pricing policies may offer, in general, the least cost solution to erosion abatement (Baumol and Oates, 1978), it should be recognized that when we deal with the wider concerns that confront policy in respect of the whole watershed the management system will have to resort to combinations of both types of tools. This will be especially important when we consider the multiple use/user nature of watershed resource exploitation and the crucial implications of management for economic activities external to the sector. For example, the three major users of watershed resources are the commercial sector (composed of logging firms), the informal forestry users (made up of households or communities whose livelihood is significantly dependent in some form of forest exploitation), and the government (which presumably represents the social interest). Within forestry, the output of commercial forest firms is primarily timber. The informal sector, however, includes many other users with alternative activities undertaken on land presently under forest.

From this perspective on watersheds, the scope for applying both rule-making and price intervention in managing the system needs to be established. On the one hand, it is clear that the government may be able to significantly control the activities of forest firms or even to completely exclude them from the watershed. On the other hand, the non-formal sector and its activities may be much more difficult, to detect and to control with the use solely of regulation. This means that re-directing the resource use pattern by changing the incentive structure may be the only practical approach.

III. THE ENVIRONMENTAL EFFECTS OF EROSION

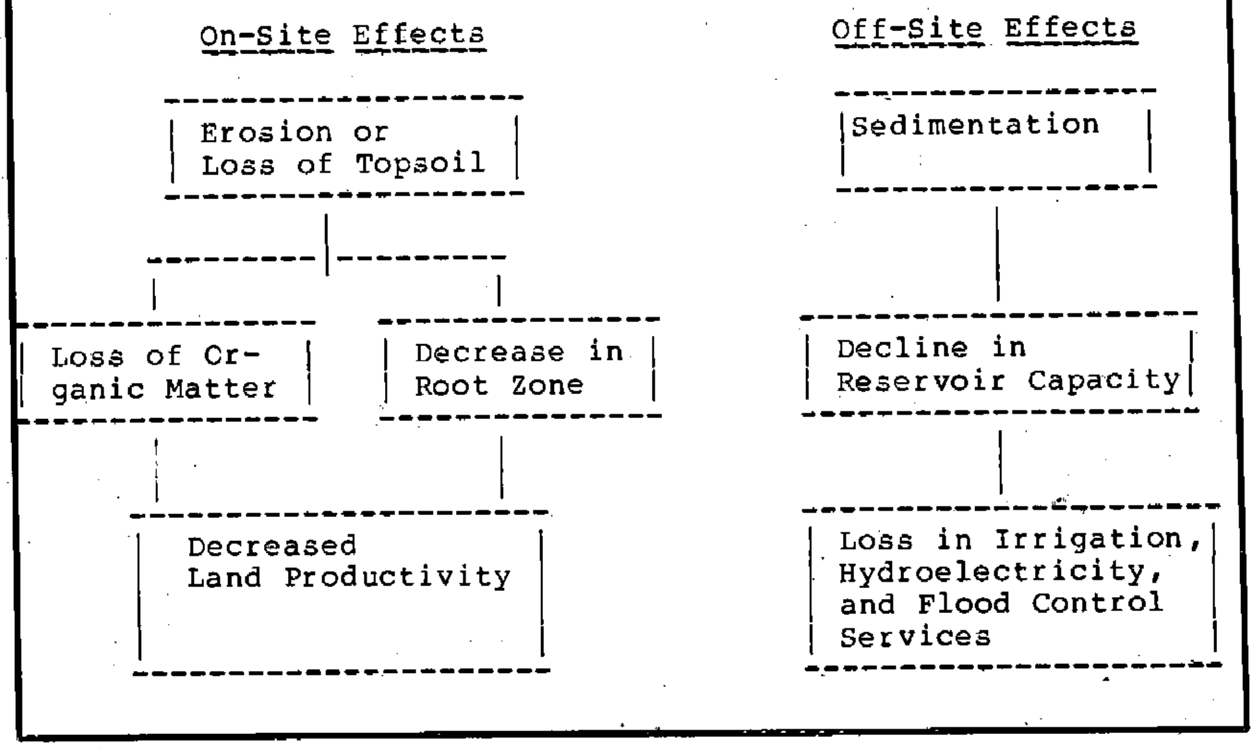
A. Estimating Erosion and Its Effects

Wischmeier (1976) describes the process of erosion as the "wearing away of the land surface" by water and the elements while sediment is defined as "solid material, both mineral and organic, that has been moved from its original source by these agents and is being transported or has come to rest on the earth's surface." The immediate environmental relevance of soil erosion is on its on-site effects on land productivity while the impact of sedimentation is primarily off-site.

Figure 1 simplifies the complex effects associated with erosion and sedimentation by identifying the basic effects that will be used in our valuation framework. Erosion in terms of loss of topsoil leads to (a) loss of organic matter and nutrients and (b) a reduction and degradation of soils for plant roots. These both contribute to a decline in on-site productivity.

For off-site effects, sedimentation (vs. soil erosion itself) is the more directly relevant process. Sedimentation may occur all along the waterway down to reservoirs, natural water bodies, and even croplands. Sedimentation affects water quality and often degrades downstream lands where it is deposited (Wischmeier, 1976). Where the watershed drains into a major dam and reservoir system -- which provides irrigation, hydroelectricity, and flood control services -- most of the impact of sedimentation may be captured by focusing on reservoir sedimentation and its effects on the multiple services provided by the dam project. In the following sections, we look at the basic methods for assessing erosion and sedimentation.

Figure 1.1 Effects of Soil Erosion and Sedimentation



Estimates of Erosion from the USLE

The standard methodology for estimating erosion from large areas is with the use of the universal soil loss equation (USLE). The USLE views gross sheet and rill erosion as a function of several determinants (Wischmeier, 1976): $A = f(R,K,L,S,C,P)$, where:

A is tons of soil loss per hectare (usually the average for the year);

R is a rainfall and run-off erosivity index, based on the product between the kinetic energy and the maximum 30 minute intensity (or amount) of rainfall;

K is the soil erodibility factor, usually computed as the average soil loss in tons per hectare per unit of R for a standard "unit plot" (which is 72.6 feet long, with 9 percent slope, continuously fallowed, and tilled parallel to the land slope);

L is the slope-length factor, which is the ratio of soil loss from a given slope length to that of soil loss from a slope length of 72.6, with all other factors constant;

S is the slope-steepness factor, which is the ratio of soil loss from a given slope to that of soil loss from a 9 percent slope, with all other factors constant;

C is the soil cover and management factor, which is the ratio of soil loss from a given cover and agronomic condition to that of soil loss with continuous fallow, with all other factors constant;

P is the conservation practice factor, which is the ratio of soil loss with a given conservation practice to soil loss with tillage parallel to the slope, all other factors constant.

The L and S factors are usually combined into a slope-length index in standard practice in the United States (Wischmeier, 1976).

Using long-term erosion plot data, soil scientists have estimated the form and coefficients of the USLE, and there is widespread agreement that this approach now represents the standard in estimating gross erosion. The procedure is to use available data for rainfall, slope-length, soil erodibility, soil cover, and conservation practice with the estimated coefficients from the USLE to determine the amount of erosion for given areas. There is still some debate about the need to modify some of the coefficients in the USLE although soil scientists have by the early 1980s already agreed on the basic applicability of the approach (Crosson, 1985).

David (1986) has also argued that erosion estimates from the USLE are more generally applicable especially for large watershec areas than data isolated plot experiments and stream measurements. However, he emphasizes the need for modification of the equation for Philippine conditions. In the first place, some of the data needed for the determinants of the USLE, while generally available in the United States, are not generally locally measured. For example, the computation of R, the rainfall erosivity index, requires data on 30-minute rainfall intensities. Since local rainfall measurement is usually done without the use of recording rain gauges, only daily intensities are available. This means that construction of the R index will need to be modified. This problem of data constraints is also found, in case of the other indices.

While the use of the USLE is clearly not independent of the need for site-specific data and modifications of both the indices of erosion determinants as well as the coefficients for prediction, it nevertheless represents a comprehensive approach to estimating erosion that has potential for generalization and inference. Estimates using this method may therefore be useful for policy-making. This should not preclude the conduct of plot experiments and stream measurements. Indeed, more site-specific data are needed. The qualification, however, is that to optimize the usefulness of these data-collecting efforts they should be done within a generalizing and predictive framework such as that offered by the USLE model.

Estimates of Sedimentation

Materials that are lost from erosion upstream eventually end up as sediment downstream. Our focus (in Figure 1) is on sedimentation of reservoirs due to the critical role that this process plays in terms of harmful downstream effects. In fact, the transport of material downstream leads to the deposition of sediment along the waterway -- much of which will entail either beneficial or harmful results. However, because of the presumption that the net effect of this sedimentation is small relative to the reservoir sedimentation effect, our procedure abstracts from waterway sedimentation.

Focusing on reservoir sedimentation, there are two relevant methods for estimation. The first is to estimate incremental deposition by taking depth sounding of the reservoir. However, this requires expensive, case-to-case estimation for each reservoir of interest. The other method is to estimate the relationship between computed soil loss from the USLE and downstream or reservoir sedimentation to determine a sediment delivery ratio (SDR).

Wischmeier (1976) defines the SDR as the ratio of sediment at the point where run-off enters a continuous stream system or body of water to the gross erosion in the drainage area above that point. The SDR ratio will generally be less than one since most eroded materials will be deposited along the waterway before they reach the reservoir area. Once an SDR is estimated from a series of relevant areas, this ratio can be useful to approximate sedimentation of reservoirs once upstream erosion has already been determined.

Caution needs to be exercised with respect to the use of these SDRs since specific watershed reservoirs may possess characteristics that may make the estimate inappropriate. For example, it has been shown that SDR estimates for large watersheds will generally be smaller than for small watersheds since the larger drainage areas in the bigger ones allow more sediment deposition before the run-off reaches the reservoir (Wischmeier, 1976).

B. On-Site Economic Effects

On-site environmental losses from erosion lead to decline in land productivity. There are two basic approaches for estimating these losses in productivity. The first is to directly estimate the relationship between crop yield and soil depth. Because of the many factors that may intervene between these variables, the simple correlation may produce counter-intuitive results. For example, there is the possibility that flat portions of a generally sloping terrain may form hard water pans where plant growth will be slow. In this case, minimal erosion from such flat areas may correlate with low crop yields (Lal, 1985).

Complex variations of the yield-soil depth model have been attempted. The USDA Resource Conservation Assessment (1980), with the results of the first U.S. National Resource Inventory, evaluated crop yield as a function of the following: (a) depth of topsoil, (b) depth of two sub-soil horizons, (c) average land slope, (d) USDA land capability sub-class, (e) soil texture, (f) presence of irrigation, and (g) land characteristics.

Another study, by Larson et al. (1983), used a two-step approach to the problem. They first estimated a crop-rooting model where an index of crop yield was specified as a function of the soil's bulk density, available water capacity, permeability, and acidity. Erosion measures were then used to reduce the yield index. Note that nutrient supply was not included as a determinant because this was not primarily a soil characteristic but the result of farmers' management practice.

A third study, using the U.S. National Resource Inventory data was done by Crosson and Stout (1983) at Resources for the Future (RFF). Their main contention was that in the evaluation of potential productivity loss due to continuing soil erosion, the determinants should include the trend for technology and management from the past. In this case, they looked at these trends for the past 30 years. By doing this, the researchers attempted to put the problem of soil degradation within the context of technological and resource management techniques that have essentially provided substantial substitution for soil loss at acceptable cost.

There are two important conclusions that may be derived from these different studies. First, as Crosson (1985) points out, the most important result of these three crop yield-soil depth exercises was that the estimates of agricultural productivity decline due to soil erosion fall only within the range of 2.5 to 10 percent, even with the various assumptions used. (Please see Table 1.)

Secondly, the importance of continuing technological and management changes should be a critical component of any soil erosion or agricultural production modelling. For this reason, the RFF study is especially important since it alone explicitly adopts the view that the economic effect of declining productivity of the soil leads to changes in the cost of crop production, with increasing production cost expected. However, the development and adoption of new land-substituting technology is expected to avert this cost inflation.

Crosson and Stout (1983) argue that if technological change, such as that associated with hybrid corn, proceeds at post-World War II rates, then the productivity effects of erosion may not be constraining at all. However, there is a need to assume that technological change slows down as has been observed in the decade by decade trend. The other problem here is that technological and management changes are not socially costless, and it is not clear that Crosson and Stout (1983) have allowed for this in their study. This indicates that their 2.5 percent yield-reduction effect of erosion may be an underestimate.

Table 1.1 Estimates of Yield Reduction Due to Soil Erosion.

Study	Yield Reduction (%)	Time Frame (years)
USDA (1981)	8	50
Larson et al. (1983)	5-10	100
Crosson and Stout (1983)	2.5	30 (1960-80)

Replacement Cost Methods for Estimating Economic Effects of Soil Erosion

The preceding methodologies directly attempt to estimate losses from soil erosion based on yield reduction as the soil resource is degraded. In the replacement cost method, the economic valuation of losses from soil erosion is accomplished indirectly, by looking at what society has to pay to retain land productivity at levels prior to soil erosion. As Figure 1 indicates, soil erosion leads to a reduction in organic matter and nutrients from the land. This will lead to a decline in crop production unless nutrients are replaced in the soil. Therefore the measure of the economic loss may be based on the cost of replacing these nutrients. The usual procedure is to calculate the amounts of nitrogen (N), phosphorus (P), and potassium (K) that will need to be incorporated in the soil and to value these at realistic prices.

To be able to use this procedure, good estimates of on-site erosion and nutrient loss associated with this level of erosion are needed. Kim and Dixon (1986) have used this method for assessing an upland agriculture project in South Korea. In two locations, Ichon and Gochang, soil loss was 40.35 tons per hectare, which was close to the predicted 39.9 tons per hectare with the use of the USLE. With the use of a lysimeter, it was further determined that nutrient losses (in kilograms per hectare) were of the following magnitudes: (a) N -- 15.7, (b) P -- 3.6, (c) K -- 14.6, (d) Ca -- 10.6, (e) Mg -- 1.6, and (f) organic matter -- 75.4.

They then estimated what the relevant losses would be when alternative management techniques are applied to help reduce soil erosion. It should be noted that the replacement cost approach does not necessarily mean that alternative management programs should completely eliminate soil loss. Indeed most programs can only attempt partial replacement. The difference between losses without management and losses with management were then taken as the benefit of management, and the cost of the alternative management programs was used as the cost of partial replacement of eroded soil (since erosion is not completely eliminated).

In other studies where less data is available, no direct comparison between reductions in soil loss and therefore nutrient loss with or without management is possible since there is limited actual data on the erosion reduction using alternative management schemes. In these cases, a couple of options are available. The simpler option is to just assume that the relevant nutrients can be directly replaced in the soil with the use of inorganic fertilizer.

The other option is to use predictive models such as the USLE to estimate how different C and P factors will reduce the soil loss. In the first technique, the major difficulty is that it implicitly makes the assumption that the physical loss in soil and reduction in rooting depth have not reached such critical levels as to make irrelevant the application of inorganic fertilizer. The second procedure is thus preferrable, presuming that in the absence of site observations on the effects of alternative management schemes, a relevant USLE model, together with average data to use in the model, will be accessible. If this is available then the procedure of Kim and Dixon (1986) may be followed.

C. Off-site Economic Effects

To arrive at an implementable methodology for assessing off-site effects of soil erosion, the most important challenge is to be able to pinpoint the erosion processes that have economically significant effects from among the many processes and interconnections arising from erosion in the uplands. For this purpose, the general agricultural development context is important to use as the initial basis for focusing on relevant off-site effects. Since irrigation development is a major component of the agricultural or food production program, the logical starting point for assessing the economic impact of watershed erosion is in terms of the irrigation dam and reservoir. The major off-site effects therefore are those that affect crop production through the irrigation system. Since most of the big dam projects are multi-purpose, a second important impact has to do with the hydro-electricity generating function of the dam.

Sedimentation of the reservoir is the physical process that links upstream erosion to off-site effects. Where reservoirs are clearly delineated and depth soundings are economically feasible, the estimation of erosion for off-site effects (by this method) may be, for practical reasons, separated from the use of the USLE to determine upstream erosion and its on-site effects. Otherwise the reasonable range of SDRs will have to be established as a general guide to the determination of reservoir sedimentation.

In either case it is important to distinguish between sedimentation that takes place within a reservoir's dead storage vs. that which occurs in active storage. While there has been no question that sedimentation of the active storage reduces both irrigation capability and hyrdro-power output, there has been some concern on the correct treatment of dead storage. Some approaches have tried to address this issue by attempting to assess incremental sedimentation losses. This is done either by

(a) valuing how a reservoir's life expectancy decreases when actual sedimentation goes beyond the projected rate or by (b) presuming that some proportion of sedimentation (presumably that going to dead storage) generates no off-site losses. The latter procedure, for example is utilized in Ruandej and Hufschmidt (1986).

The problem with such an approach is that sedimentation of dead storage also entails a social cost. David (personal communication) has argued that the fact that provision has been made in dam construction for dead storage adds to the cost of the reservoir. The difference therefore between sedimentation of dead storage vs. that of active storage is that the cost of absorbing the former has previously been included in the capital cost of the project -- i.e., at the time of construction. On the other hand, the cost of the sedimentation of the active storage will arise once the dead storage has been filled up. Indeed, since construction of dead storage capacity has been included in the construction phase and therefore among costs that occur up front, the effect of discounting of future values, in the case of estimating the sedimentation of active storage, does not arise. Thus from a present value perspective those cost will be quite important.

IV. THE OPTIMAL RATE OF EROSION AND THE FACTORS AFFECTING THE CONSERVATION DECISION

> It may seem surprising that over a 40-year period the nation would devote the efforts of tens of thousands of people and spend billions of dollars to deal with a problem about which essentially nothing was known. The explanation, perhaps, is that the people providing leadership to the soil conservation movement were possessed by a missionary zeal to protect the land. For these people, anecdotal and casual empiricism provided sufficient evidence that erosion presented the nation with a major problem.
>
> -- Crosson (1985)

A. The Optimal Rate of Erosion

What Crosson (1985) has pointed out above for the United States is also true for the Philippines. We often hear of complaints that erosion rates are too large and that drastic control measures are required. The numbers that are normally cited, however, lack accuracy for policy making. For example, according to David (1984) the two studies that are most often mentioned, Kellman (1969) and Veracion and Lopez (1979), give erosion rates that are either unusually low or unrealistically high. (Please see Table 2.)

Beyond the data problem on how much erosion is actually occurring is the fundamental policy question of whether the benefits of erosion abatement will outweigh the cost of conservation programs. Crosson and Stout (1983), for example, point out that, even with reasonable data (as generated for the United States by their natural resource assessment surveys), policy purposes are not sufficiently served by the use of a purely technical criterion of erosion. They propose that erosion T values (which set tolerable limits for erosion based on maintaining land productivity) need to be interpreted within a wider framework that will include individual and social decision-making concerns.

The economic analysis of erosion (E) requires an understanding of two types of costs. On the one hand, there are the losses that society will have to bear due to soil erosion; we refer to this as Total Damage Cost (TDC). These will be both in terms of upstream productivity losses and in terms of damages downstream due to sedimentation or flooding. It has been suggested that such costs are positively sloped with respect to rate of erosion, with the slope increasing as the erosion rate becomes larger (Hufschmidt et al., 1983):

Table 1.2 Estimates of Erosion Rates

Type of Cover:	Erosion Rate (tons/ha/year)
A. Kellman (1969)	
Primary forest	0.09
Softwood fallow	0.13
Imperata or cogon grassland	0.18
New rice kaingin	0.38
12 year old kaingin	27.60
B. Veracion and Lopez (1979) (Estimates for kaingin crops)	
Pineapple	308.0
Coffee	318.0
Tiger Grass	396.0
Castor bean	360.0
Banana	414.0
Banana/coffee/pineapple intercrops	421.0
Undisturbed areas	251.0

Source: David (1984:Table 3).

$$TDC = f(E), \quad f_E > 0, \quad f_{EE} > 0 \tag{1}$$

However, we do present an alternative specification below, using a negative second derivative for TDC.

On the other hand, the abatement or control of erosion itself can be fairly costly, especially if infrastructure modifications need to be installed. These can be represented by a Total Abatement Cost curve (TAC). Presumably such abatement costs increase with the reduction in erosion that society wishes to achieve, and such costs will be infinitely high as the rate of erosion is made to approximate zero:

$$TAC = g(E), \quad g_E < 0, \quad g_{EE} > 0 \tag{2}$$

These concepts of costs are illustrated in Figure 2 as total erosion damage and abatement cost functions, TDC and TAC. We use the specification of Hufschmidt et al. (1983) for TDC in this diagram. The vertical summation of these two curves gives us total social cost (TSC) at each rate of erosion:

$$TSC = TDC + TAC \tag{3}$$

The optimal rate of erosion may then be defined with reference to the minimum point of total social cost. Very clearly this occurs at a positive level of soil loss (Hufschmidt et al., 1983). Note, however, that the problem is one of cost minimization with the relevant social cost curve, TSC, with respect to E.

Contrary to Hufschmidt et al. (1983), the point at which TSC is minimized is when the marginal increase in damage cost just equals the decline in abatement cost:

$$dTSC/dE = f_E + g_E = 0 \quad (4)$$

$$\text{or } f_E = -g_E . \quad (5)$$

Thus, the optimal rate of Erosion, E*, occurs where the marginal damage cost (MDC) equals the decline in the marginal abatement cost (MAC). (Please see Figure 2.)

B. Off-site Damage Estimates and Implications for Total Damage

The state of empirical knowledge on off-site damages from erosion is limited. This is the case even for developed countries. In the U.S., for sediments that are deposited before the run-off reaches a body of water, which is about 60 percent (Crosson, 1985), the economic effect is generally presumed to be negative (e.g., when it clogs up irrigation ditches). It should be reasonable, however, to expect that some of its effect might be positive, such as when silt fertilizes crop lands. For the rest that reaches water bodies, the effects are generally negative. It tends to increase water turbidity, leading to a decline in the water's productivity, its value for human consumption, as well as increases in pumping costs. It also leads to sedimentation of water bodies, causing not only shortened reservoir life but also affecting irrigation, decreasing water carrying capacities of rivers (thus increasing the possibility of flooding) and changing fish-spawning patterns (Crosson, 1985).

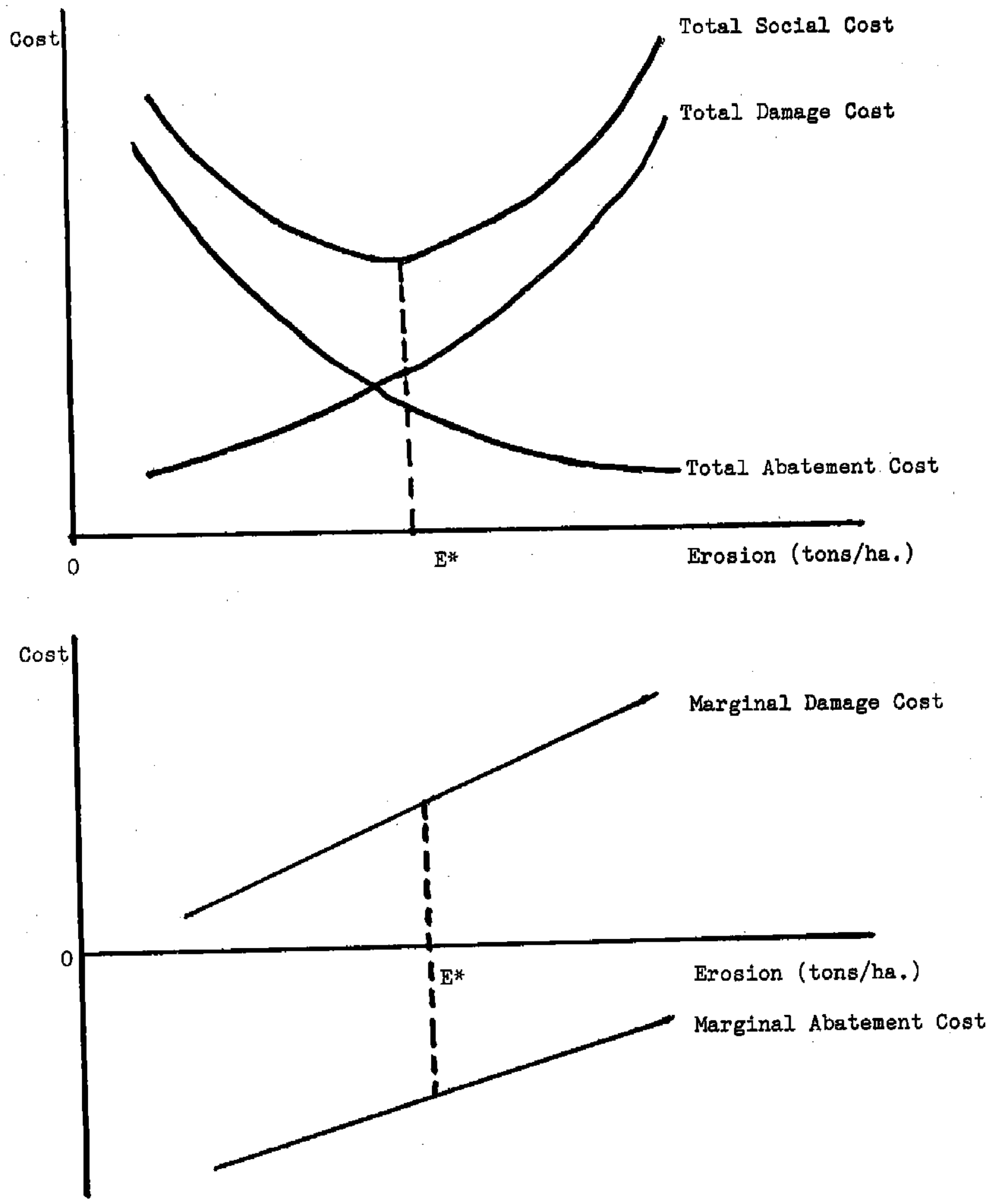


Figure 1.2 The Optimal Rate of Erosion

The situation with respect to the estimation of off-site effects of erosion is therefore even more fragmentary than that for on-site effects. We may therefore conclude that any attempts to ascribe any specific characteristic (beyond its first derivative) to an off-site damage function is a bit premature. The implication here is that the second derivative of the total damage function should therefore depend primarily on on-site damages.

C. The On-site Damage Function

As indicated earlier, the total damage function, TDC, is positively sloped with respect to erosion rate. The reason is apparent: as more erosion occurs (soil is lost), yield will decline and therefore the losses become greater. Now we have argued above that the shape of the on-site damage function dominates the shape of the TDC. From this, can we still accept the presumption due to Hufschmidt et al. (1983) that the TDC's slope increases at an increasing rate? In Equation (1), this is specified by $f_{EE} > 0$.

This can happen only if the yield progressively declines as erosion increases or soil depth decreases. However, the opposite result should be expected. For example in Klock's (1983) study, the rate of increase in the damage declines as erosion increases. This means that the slope of TDC increases at a decreasing rate. We may therefore specify an alternative form for TDC:

$$TDC = f(E),\ f_E > 0,\ f_{EE} < 0 \qquad (6)$$

The difficulty that this introduces is that the optimal solution in Figure 2 is clearly unique if MDC is positively sloped. It will also be unique if MDC is flat. However, if MDC is negatively sloped, there could be an infinite number of values that will satisfy the condition MDC = -MAC. In Figure 3, we present an example of a TDC that follows the specification of Equation (6). Here we observe that there may be an infinite number of erosion rates (to the right of E*) which will satisfy the TSC minimizing condition given in Equation (5).

V. FACTORS AFFECTING THE CONSERVATION DECISION

While government agencies may evaluate erosion abatement costs then compare these with erosion damages as a basis for decision-making on the adoption of conservation practices, the conservation decision from the private perspective will normally focus on production vs. conservation trade-offs.

Production Potentials of Philippine Uplands

Potential upland productivity may be substantial and at the same time sustainable. Omengan (1981) reports that rice output in Bontoc terraced fields averages about 124 cavans (approximately 6 tons) per hectare. For the Antique Upland Development Program (AUDP) sites in Hamtic, Antique, Tapawan (1980) reports that in non-terraced residual soil up to 1.2 tons per hectare could be produced, while terraced fields could yield 1.7 tons per hectare. In terraced alluvial soils, yield was 2.37

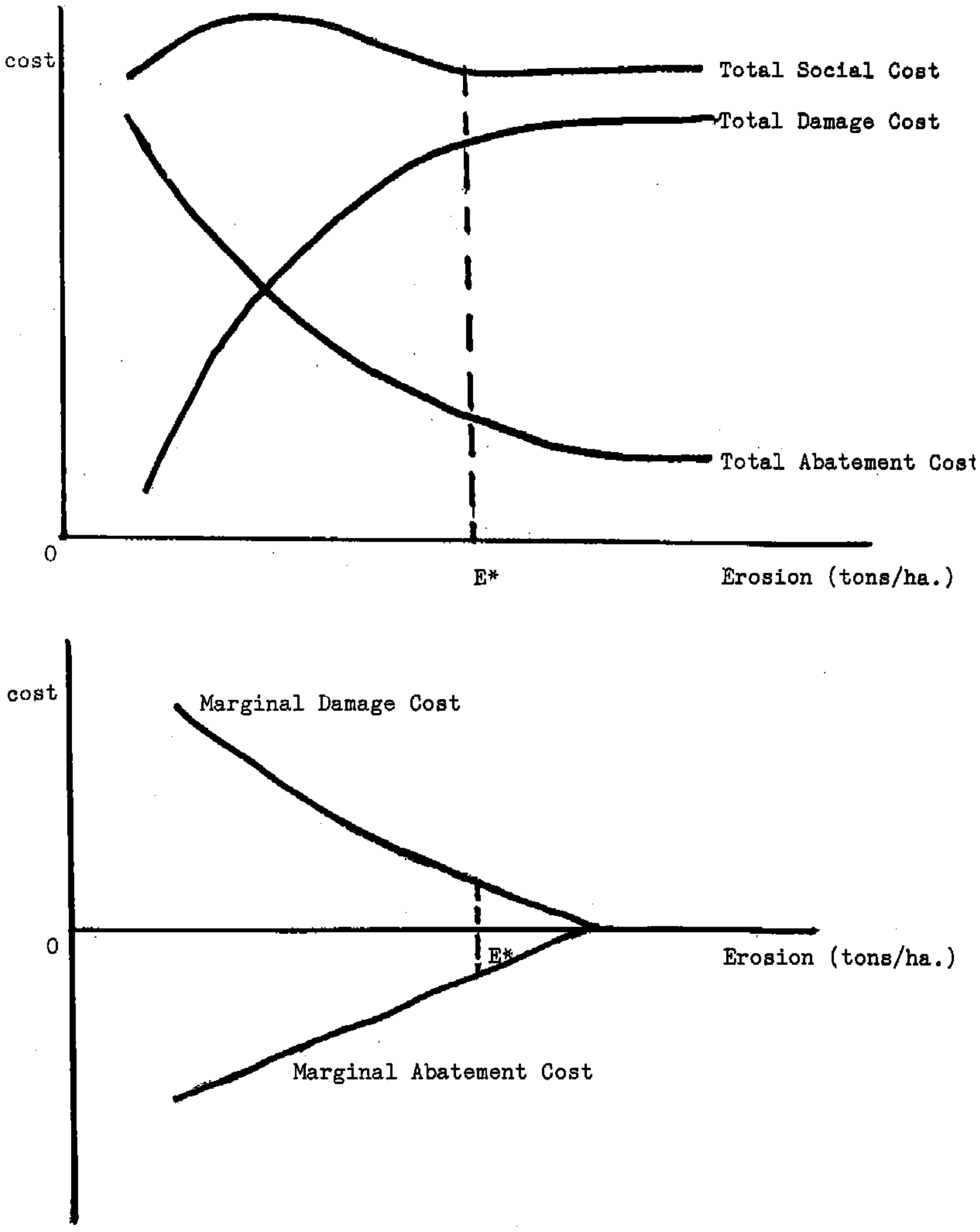


Figure 1.3 New Specification of Total Damage Cost

tons per hectare. These high yields, however, were dependent on fertilizer application: where no fertilizer was applied yields were only about 0.85 to 0.89 tons per hectare.

These figures indicate the large potential productivity of terraced-field upland farming. However, these estimates must be viewed with some caution since they usually represent very small planting areas where intensive cultivation is undertaken. For larger plots, the Magat study by Madecor (1982) reported that 3.5 tons per hectare could be produced in the social forestry areas with proper management. It has been pointed out that this is too optimistic and the terraced field data suggests that the reasonable range of production will not be substantially greater than one ton per hectare (David, 1987).

For corn, the data is even more variable. Cruz et al. (1985) report that sites in Buhi and Cebu were producing 0.84 and 0.89 tons per hectare, respectively. Tapawan, however, reports for AUDP non-terraced field output of only 0.27 tons per hectare and, for terraced alluvial soil, 0.64 tons per hectare. The conservative conclusion therefore is that while crop production may be widespread in upland areas and while such production may in fact be sustainable, with given varieties and technologies, the uplands will generally have limited yield potentials.

Critical Trade-off from the Private Perspective

In addition to the environmental and technical constraints leading to poor upland productivity, there are critical trade-offs that the private upland decision-maker has to make if he is to adopt conservation methods. The most obvious are losses in production of traditional staples. Other less apparent constraints, have to do with the immediate cost of undertaking conservation practices in contrast to the limited and gradual losses from allowing erosion to continue.

The multi-site upland production systems study by Cruz et al. (1985) has quantified the losses in staple crops that follow the introduction of soil conservation practices within the traditional cropping system. Using a production function with conservation indicators for corn in Cebu and Buhi upland sites, the study determined that farmers' corn output declines by about 12 percent for those farmers who have adopted inter-cropping and similar conservation practices in their cropping system. This study, however, stopped short of attempting to assess if the output from intercrops was sufficient to outweigh the losses in corn, and it is clear that an assessment with a whole-farm perspective still remains to be done.

With respect to the hesitation of farmers to immediately adopt conservation practices, Walker (1982) has pointed out that losses from erosion are gradual while expenses for conservation are current. The rational reaction therefore can include a postponement of adoption of conservation practices. The problem is that most conservation and watershed management programs in the Philipppines, because they are being promoted by government, are organized as once-and-for-all propositions: farmers are required to participate at the start of the program or they cannot participate at all.

We can use Walker's (1982) proposition to highlight the severe constraint of this kind of project-organized conservation programs. Since these projects cannot achieve the required flexibility due to the government's own administrative rules as well as timetables required by funding sources, other approaches to conservation promotion that are less restrictive on the decision-making process are called for. The class of government intervention, having to do with changing the incentives for conservation, may be the relevant alternative.

Perhaps government should introduce policies that will affect farmer decision-making in general and over the long-term to allow farmers on their own to slowly undertake the adoption process. Giving farmers full titles to exploit as well as conserve their lands, and introducing a system of subsidies for conservation as well as penalties for erosion, are ways of directly changing the farmer's decision-making context. Undertaking extension or education programs can be a complementary effort that does not directly change the incentive structure but attempts to change the farmer's perception and valuation of a given economic choice situation.

Finally, there are also general social and long-term factors that need to be considered in evaluating the production-conservation trade off from the national perspective. In line with the need to comprehend the realistic alternatives that policy can consider, there should be a rejection of total physical productivity criteria on which soil erosion targets have traditionally been based. In the U.S. this approach has led to a misplaced emphasis on the attainment of tolerable soil loss targets (T-values). For U.S. croplands, for example, these T-values range from 4.4 to 5 tons per hectare on deep soils. As Crosson (1985:235) has pointed out:

> T-values are an expression of the conservation ethic, that the productivity of the soil should be maintained in fact from one generation to the next. The presumption is that if we fail to do this we impose higher costs for food and fiber on the next generation. But this fails to recognize that society can and does develop technological substitutes for the soil, which make it possible for us to maintain constant (or even declining) production costs despite declines in the productivity of the soil.

VI. SUMMARY

In this paper, we have presented in detail the critical concerns, the state of technical and economic estimation methods, and the data constraints attendant to the economic valuation of the environmental effects of soil erosion. We started by motivating the study of economic assessment of environmental effects not only for the purpose of extended project benefit-cost analysis. Valuation efforts should be properly put in the context of improving resource pricing policy. The reason is that it is this set of potential government policy instruments that rivals project-oriented watershed management efforts in terms of making immediate and widespread impacts in the reduction of soil erosion.

We then proceeded in Part II to establish the development context for upstream conservation activities in terms of their implications for downstream impacts -- especially on the food production program in general and on irrigation development in particular. This was not meant to imply that on-site economic impacts are unimportant. Indeed they are expected to be substantial; the problem is that in the socio-political arena of policy-making, it is our impression that upland activities and the welfare of upland interests are primarily appreciated only through their downstream inter-relations.

In Part III, we went into a detailed exposition of the methodologies for estimating erosion: gross erosion from USLE-based approaches as the basis for on-site effects and reservoir sedimentation measurements as the basis for off-site effects. Data availability was found to be limited, and it was much worse for off-site impact evaluation.

In Part IV, the economic model for determining the optimal erosion rate was presented, and we suggested changes in the specification of damage functions to conform to what is known from on-site economic effects of erosion. It turns out that, with this new specification, fundamental questions about the determination of an optimal erosion rate are brought up. Our conclusion is that previous optimism about our capacity to establish erosion rate targets may have been misplaced. Indeed, it now seems that the process of approximating a socially optimal level of erosion, even presuming that the data limitations have been overcome, may be accomplished only through primarily iterative procedures.

We concluded (in Part V) with a discussion of the private decision-making perspective that requires conservation benefits to be judged vs. perceived losses in upland production. This highlighted the problem of government watershed management projects that are presented to upland farmers or forest users as once-and-for-all propositions. Since the erosion process is gradual and its on-site effects occur in the future, the timing of adoption of conservation practices cannot be restricted to the start of official projects. The private decision for soil conservation is therefore spread out over time and recursive in nature. Clearly, with this kind of decision-making, the timing of adoption of less erosive practices should itself be part of the optimizing decision. This further supports our view that, beyond the project-oriented approach, it is general government policy that can introduce changes in the incentive structure to allow social valuations to enter the private decision-making process.

CHAPTER II
THE ON-SITE ENVIRONMENTAL COST OF SOIL EROSION

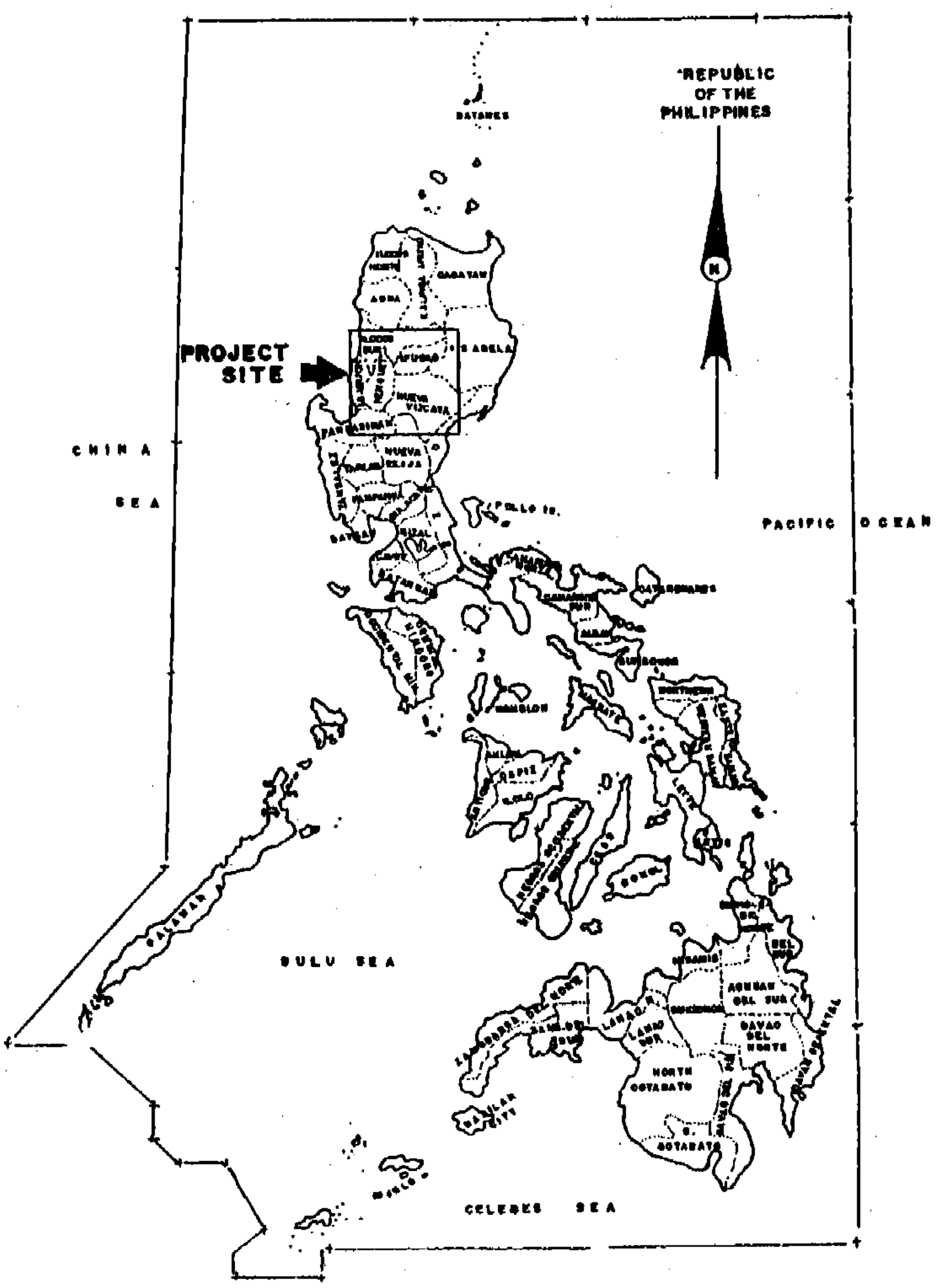
I. INTRODUCTION

Maps 2.1 and 2.2 indicate the location of the two watersheds that are discussed in the following sections. The general procedure for estimating the value of soil fertility that is lost through the erosion process is illustrated in Figure 2.1. The two basic data sources required are (a) the delineation of the site into soil or land mapping unit with as much data as possible on soil analysis for various land uses (in Box A) and (b) estimates of erosion rate per mapping units (through the universal soil loss model) given data on cover, rainfall, slope, soil erodibility (in Box B).

Since part of the objective of this study is to present the potentials as well as the limitations of methodologies for the assessment of economic impact of erosion, we undertake in the case of the Magat watershed a general assessment while in the case of Pantabangan the method is much more detailed. Thus for Magat, we assume linearity in the soil nutrient content throughout the profile, and a weighted average of the nutrient content of the two upper soil layers (with weights based on the relative depth of each layer) is used. In the case of Pantabangan, soil analysis for regular depth intervals are utilized so that this detailed procedure explicitly recognizes the non-linearity of nutrient content in the soil profile. The method uses 5-cm intervals up to a depth of 50 cm in measuring nutrient content.

For Box B, the erosion rates utilized for Pantabangan are based on a detailed application of the modified USLE model from David (1987c) so that the assessment is able to focus on four key land uses in the area. For Magat, where erosion data are based on the watershed management feasibility studies, our quick assessment just focuses on the open grassland area since it is the major land use type, and it is the most problematic with respect to accelerated erosion.

From the soil analysis of the land or soil mapping units (in Box A), data on the soil organic content (used for estimating N) and for available P and K are converted into N,P, and K fertilizer equivalents in Box A1. (Appendix 2.1 outlines the conversion procedure.) Given the fertilizer equivalents, in the soil and the rate of erosion per ton of soil loss, the amount of N, P, and K actually lost may be derived (Box C). From Box C, we can assess the implications for land use classification (Box D) in Pantabangan because of the more detailed methodology utilized. In the Magat case, we illustrate how price information (in Box E) may be combined with physical nutrient loss estimates (in Box C) to get the on-site costs associated with erosion (Box F).


REPUBLIC
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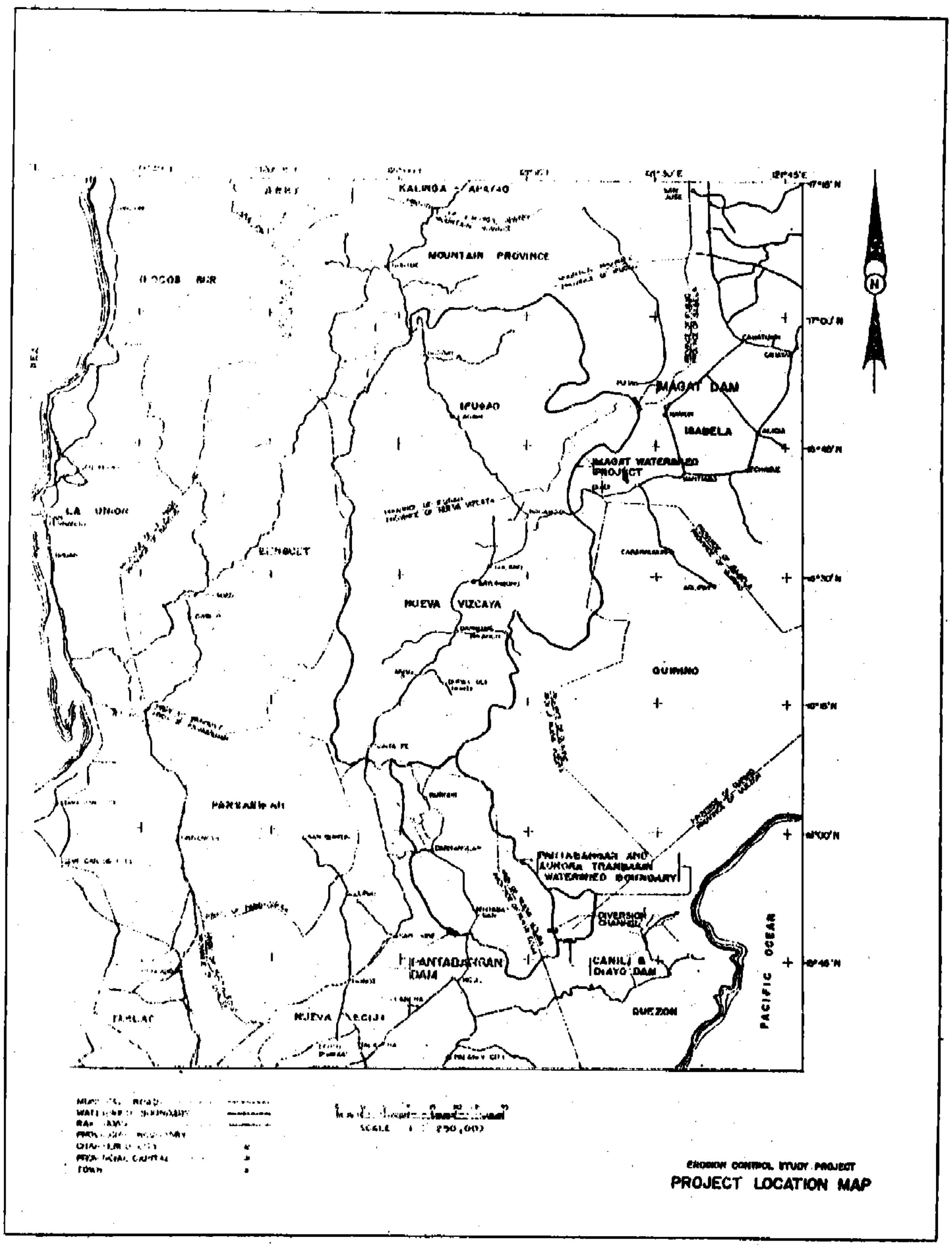
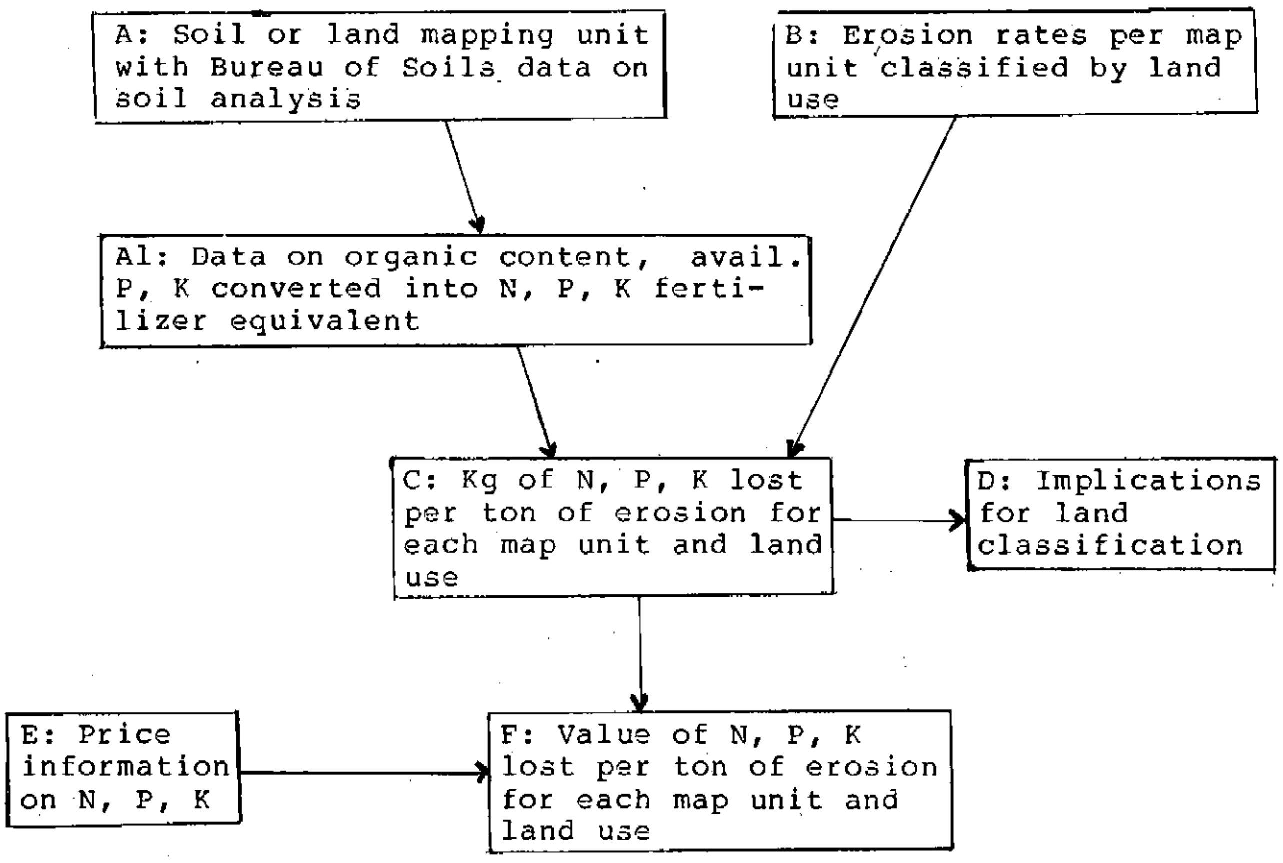
ABRA
ISABELA
IFUGAO
NUEVA VIZCAYA
PANGASINAN
NUEVA ECIJA
PAMPANGA
RIZAL
BATAAN
POLILLO IS.
CATANDUANES
ALBAY
SORSOGON
MASBATE
LEYTE
BOHOL
CAPIZ
ILOILO
PALAWAN
AGUSAN DEL SUR
DAVAO DEL NORTE
NORTH COTABATO
S. COTABATO
SULU

Map 2.1


KALINGA - APAYAO
ABRA
MOUNTAIN PROVINCE
ILOCOS SUR
LA UNION
BENGUET
IFUGAO
MAGAT DAM
ISABELA
MAGAT WATERSHED PROJECT
NUEVA VIZCAYA
QUIRINO
PANGASINAN
PANTABANGAN AND AURORA TRANSBASIN WATERSHED BOUNDARY
DIVERSION CHANNEL
CANILI & DIAYO DAM
PANTABANGAN DAM
TARLAC
NUEVA ECIJA
QUEZON
PACIFIC OCEAN
121°30'E
121°45'E
17°15'N
17°00'N
16°45'N
16°30'N
16°15'N
16°00'N
15°45'N
N
MUNICIPAL ROAD
WATERSHED BOUNDARY
RAILWAY
PROVINCIAL BOUNDARY
CHARTERED CITY
PROVINCIAL CAPITAL
TOWN
SCALE 1 : 250,000
EROSION CONTROL STUDY PROJECT
PROJECT LOCATION MAP

Map 2.2

Figure 2.1 Basic Application of the Replacement Cost Method to Assessment of On-site Effects of Erosion



II. THE ON-SITE ECONOMIC EFFECTS OF SOIL EROSION IN THE MAGAT WATERSHED

The Magat Watershed Management Project

In 1983, the Magat dam was put into operation as a part of the Magat River Project Plan which was started in 1975. The dam, together with existing small-scale irrigation systems in the area, was designed primarily to serve as water storage for irrigation of downstream farms situated in Isabela. The command area envisioned was 104,000 hectares. As a secondary purpose, it was planned that the dam would also provide 300 megawatts of power supply at full capacity.

During the design stage of the dam sometime in 1973, the reservoir's sedimentation was estimated at 20 tons per hectare per year (t/ha/yr). Using this rate, the dam's service life was projected to be 95 years, 50 years of which was the economic life. In 1982, however, the Mandala Agricultural Development Corporation (Madecor) came up with a higher rate of sedimentation of 34.5 t/ha/yr.

Land Use and Soil Erosion

Since actual downstream sedimentation is only a proportion of erosion at the source, this increased rate of sedimentation is indicative of a very high rate of erosion taking place upstream of the reservoir. One of the most important factors determining the rate of soil loss, using the universal soil loss equation model, is the crop cover. This factor provides information on the use to which the land is put, a use which is either natural or has already been altered by man.

Table 2.1 shows the general land use data for two periods, 1980 and 1983, in the Magat watershed. A comparison of these two sets of figures reveals the substantial rate of change that has taken place in the area over a short period of time. Referring to the 1983 data, the areas under primary and secondary forest are 102,212 hectares (25% of total) and 91,102 hectares (22%), respectively. Together forest lands account for 47% of the total land area in the Magat watershed. This is still an acceptable proportion to ensure environmental protection but the existence of very large open grasslands (about 39% or 159,517 hectares) complicates the situation in the area.

Table 2.1. Land Use Changes in the Magat Watershed.

Land Use	Hectares	%	Hectares	%
Primary forest	123,780	30.7	102,212	24.79
Secondary forest	123,479	30.7	91,109	22.10
Open grassland	102,265	25.4	159,517	38.69
Agricultural land				
irrigated rice	25,470	6.3	34,145	8.28
non-irrigated rice	4,191	1.0	986	0.24
bench-terraced rice	14,620	3.6	15,087	3.66
diversified crops	2,260	0.6	2,142	0.52
orchards	25	0.0	272	0.06
Residential land	2,647	0.7	2,270	0.55
Riverwash	4,090	1.0	4,570	1.11
Total	402,827	100.0	412,303	100.00
Reservoir	4,900			

Source: Madecor (1985).

In fact, the increased rate of erosion is attributed mainly to the increase in open grassland areas (Madecor, 1985). These areas consist of (a) lands left under fallow after slash and burn operations of upland farmers, (b) areas left barren from continuous and non-discriminating grazing activities, (c) those pasture areas still covered by grasses, (d) newly reforested areas, and (e) alienable and disposable lands. Agricultural land use constitutes the third largest form of land use in the watershed, covering 52,632 hectares (or about 13% of total). Specific agricultural land uses include irrigated and non-irrigated rice, bench-terraced rice, diversified croplands (mostly planted to vegetables), and orchard lands.

The highest rate of sheet erosion is associated with the open grassland areas. Table 2.2 lists the estimates of sheet erosion for various land uses.

By major land use category, the highest erosion rate was obtained for open grasslands, with an average erosion rate of about 88 t/ha/yr. For all the other land uses, the average erosion rate is about 28 t/ha/yr. For the entire Magat watershed, the estimated rate of sheet erosion alone is about 52 t/ha/yr. If we use the Madecor (1985) assumption that sheet erosion is 40% of the gross erosion rate then the latter must be about 219 t/ha/yr for open grasslands and 71 t/ha/yr for all other areas, excluding riverwash and residential lands. For the entire watershed, gross erosion would be about 129 t/ha/yr (Madecor, 1985)[2].

Table 2.2. Estimates of Sheet Erosion for Various Land Uses

Land Use	Mean Erosion (t/ha/yr)
Primary forest (with small patches of clearings)	3
Secondary forest (with patches of shrubs and clearings)	12
Open grasslands	
hillside farming	100
overgrazed pastures	250
slightly grazed pastures	48
newly reforested areas	30
alienable and disposable areas	48
Cultivated areas	
lowland and bench-terraced rice	1.8
diversified upland crops	48

Source: Madecor (1982).

These high rates of erosion and sedimentation are serious resource use problems, with potentially large social costs. Watershed management is therefore required. However, the development of an acceptable watershed management approach requires an acceptable evaluation of the economic effects of soil erosion.

Table 2.3 presents the soil types and topographic characteristics of lands in the watershed according to a survey by the Bureau of Soils (1983). Appendix 2.2 lists the 37 Land Mapping Units (LMUs) devised by the Bureau of Soils to represent the basic unit of land resource information. This LMU classsification is based primarily on soil characteristics, degree of dissection, rock outcrop, and relief and drainage.

Figure 2.2 illustrates the procedure used for the Magat watershed. Of the 31 LMUs with open grassland areas, 19 were selected on the basis of availability of information on soil nutrient content. These LMUs are listed in Table 2.4 which also provides information on the depth of the first two soil layers and the organic carbon, phosphorous, and potassium content of the soil. The sheet erosion rate data for selected LMUs are listed in Table 2.5. Appendix 2.1 provides the step-by-step procedure for the conversion of soil analysis and erosion rate data into equivalent quantities of inorganic fertilizers N, P, and K that are lost per ton of soil erosion.

Table 2.3. Slope Category and Soil Types in the Magat Watershed.

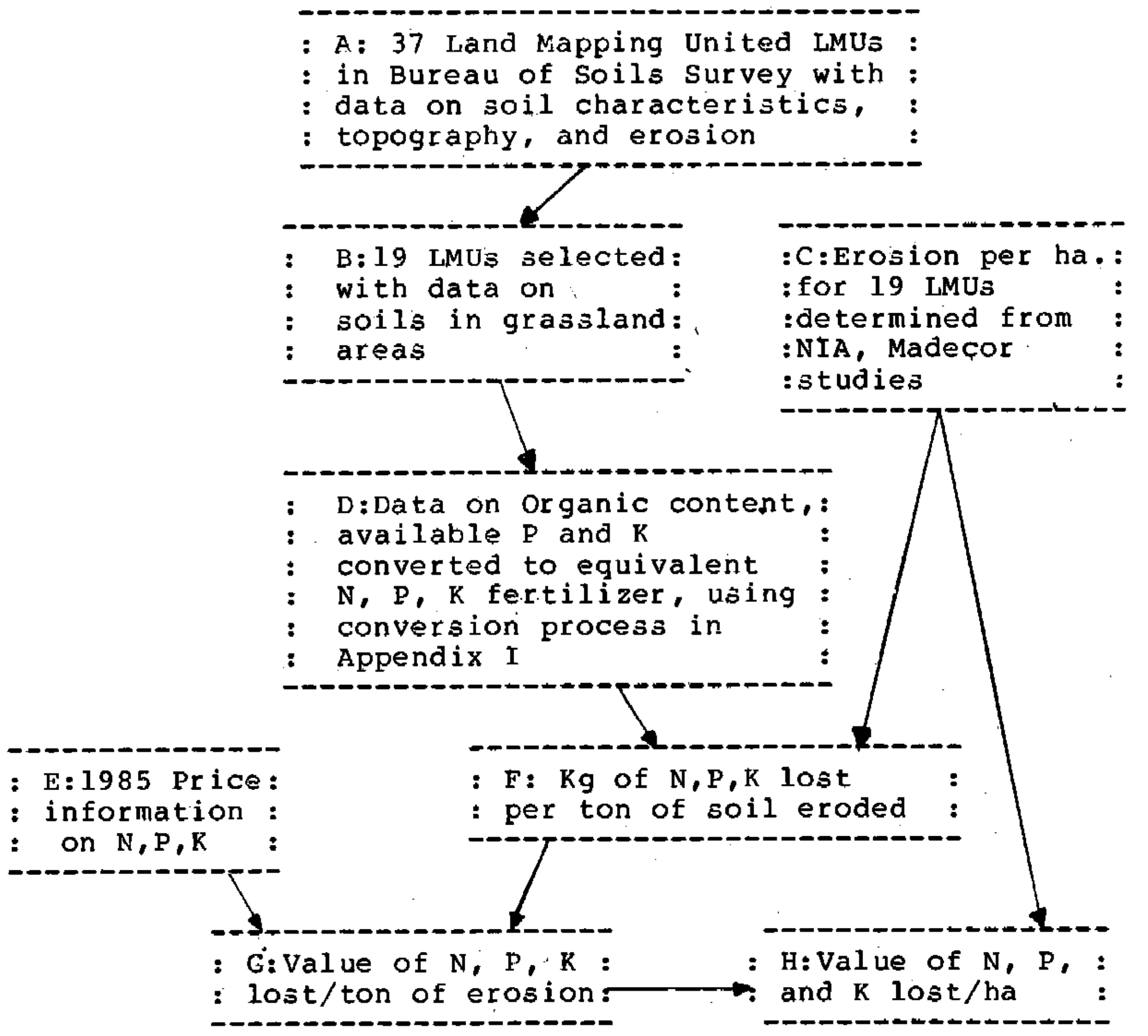
SLOPE	PHYSIOGRAPHIC POSITION	SOIL TYPES IDENTIFIED	HECTARES	PERCENT
0-3%	level to nearly level	Bago clay loam	5,470	1.3
		Bantog clay loam	8,540	2.1
		Maligaya clay loam	4,150	1.0
		Peneranda silt loam	11,200	2.7
		Presna clay loam	4,250	1.0
		Quingua clay loam	2,690	0.6
		San Manuel clay loam	2,470	0.6
Sub-total			38,770	9.4
3-8%	nearly level to gently sloping	Bago clay loam	2,130	0.5
		Guimbaloan clay loam	395	0.1
		Nayon clay loam	600	0.1
		Rugao clay loam	5,590	1.3
Sub-total			8,715	2.12
8-15%	moderately sloping	Mayon clay loam	2,950.7	
Sub-total			2,950	0.7
15-23%	strongly sloping	Botog clay loam	3,070	0.7
		Faraon clay loam	1,120	0.3
		Luisiana clay loam	2,870	0.7
			7,060	1.7

Table 2.3. cont'd.

SLOPE	PHYSIOGRAPHIC POSITION	SOIL TYPES IDENTIFIED	HECTARES	PERCENT
25-40%	Very strongly sloping	Botog clay loam	8,110	2.0
		Faraon clay loam	3,255	0.6
		Rugao clay loam	9,290	2.2
		Guimbalaon clay loam	59,290	14.4
		Nayon clay loam	3,610	0.9
Sub-total			83,555	20.33
40%	Very steep and rugged	Annam clay loam	107,000	25.8
		Bolog clay loam	8,797	2.1
		Faraon clay loam	13,915	3.3
		Guimbalaon clay loam	25,290	6.1
		Guimbalaon-Annam complex	33,730	8.1
		Langa clay loam	15,380	3.7
		Rugao clay loam	35,810	8.6
		Sivilla clay loam	30,040	7.2
Sub-total			269,960	65.68
GRAND TOTAL			411,010	100.00

Source: Bureau of Soils, 1985.

Figure 2.2 The Replacement Cost Method Used in Estimating On-site Cost of Soil Erosion in the Magat Watershed.



The results in Box D of Figure 2.2 are presented in Tables 2.6 to 2.8 which show the estimates for nutrient losses in terms of urea, solophos, and muriate of potash To illustrate the procedure undertaken, in Table 2.6, the soil loss for LMU 2.1a is 17 tons/ha. The fourth column lists 1.26 as the weighted average percentage of organic carbon (OC) found in the first two soil

Table 2.4. Soil Analysis for Open Grasslands in Selected Magat Watershed LMUs.

LMU	Depth 1st two layers (cm.)		Organic Carbon (1)		Available (ppm)		Exchangeable (meq/100 gm)	
2.1a	0-10	10-45	1.28	1.23	5.08	4.73	0.08	0.03
2.1b	0-3	3-21	2.95	1.49	53.55	79.28	-	-
2.2b	0-10	10-55	3.3	1.16	3.68	18.03	-	-
2.2c	0-6	6-16	1.39	0.88	2.28	1.93	-	-
2.4a	0-15	15-55	3.59	1.14	5.91	3.53	0.19	1.11
2.6a	0-7	7-19	-	-	1.93	1.58	-	-
2.6b	0-8	8-41	3.03	1.46	14.88	2.98	-	-
2.7	0-40	10-40	1.52	0.84	6.0	3.4	0.6	0.2
2.8	0-4	4-23	2.97	1.53	6.10	3.78	0.54	0.21
2.9b	0-5	5-35	2.67	1.53	0.53	0.53	0.55	0.10
2.9c	0-6	6-27	4.7	1.88	18.38	3.33	-	-
2.10	0-8	8-30	2.63	1.57	-	-	-	-
2.11b	0-13	13-36	3.31	2.41	2.98	0.88	0.67	0.49
2.11c	0-10	10-38	-	-	8.7	9.2	0.1	-
2.12a	0-10	10-28	2.68	2.49	15.93	11.38	-	-
2.12b	0-17	17-41	-	-	3.3	2.7	0.1	-
3.1b	0-10	10-26	3.26	1.51	2.63	4.03	-	-
3.2a	0-12	12-46	0.72	0.48	0	2.6	0.7	0.8
3.2b	0-10	10-62	3.57	2.03	4.27	3.68	0.13	0.03

Source: Bureau of Soils, 1983.

Table 2.5. Sheet Erosion Rate for Open Grassland in Selected Magat Watershed LMUs.

LMU	AREA	EROSION (Sheet & Rill) (l/ha/yr)	TOTAL EROSION/LMU
2.1a	6423	17	109191
2.1b	4268	12	51228
2.1c	1015	31	31465
2.2a	492	16	7872
2.2b	636	27	17172
2.2c	3169	*	*
2.3a	94	7	658
2.3b	554	99	54846
2.4a	3149	20	62980
2.4b	125	54	6750
2.5a	996	27	26892
2.5b	2595	170	441150
2.6a	4410	24	105840
2.6b	15026	23	646118
2.6c	17417	88	1532696
2.7	1281	51	65331
2.8	352	17	5984
2.9a	2256	34	76704
2.9b	11133	52	578916
2.9c	12672	45	570240
2.10	6931	58	401998
2.11a	3641	29	105589
2.11b	4496	70	314720
2.11c	7110	92	654120
2.12a	4563	91	415233
2.12b	20992	168	3526656
2.13	162	70	11340
3.1a	906	53	48018
3.1b	3677	156	580966
3.2a	1138	53	60314
3.2b	17840	180	3211200
TOTAL	156346		13,772.187
AVE.		87.76	

Source: NIA, 1982.

Table 2.6. Replacement Cost Analysis of Nitrogen Loss in Open Grassland of Selected Magat Watershed LMUs.

LMU	AREA	SOIL LOSS	OC_w *	NITROGEN		UREA	
	(ha)	(t/ha)	(%)	(%)	(kg/ha)	(kg/ha)	(kg/LMU)
2.1a	6423	17	1.26	0.063	10.71	23.8	152,867.4
2.1b	4269	12	1.70	0.085	10.20	22.66	96,735.5
2.2b	636	27	1.55	0.077	20.79	46.20	29,383.2
2.2c	3169	78	1.07	0.053	41.34	91.86	291,104.3
2.4c	3149	20	1.80	0.090	18.0	40.0	125,960.0
2.6b	15026	43	1.69	0.084	36.12	80.26	1205,985.8
2.7	1281	51	1.01	0.051	26.01	57.80	74,041.8
2.8	352	11	1.78	0.089	9.79	21.75	7,656.0
2.9b	11133	52	1.69	0.084	43.68	97.06	1080,659.0
2.9c	12672	45	2.50	0.125	56.25	125.0	1584,000.0
2.10	6931	58	1.85	0.093	53.94	119.86	830,749.6
2.11b	4496	70	2.73	0.136	95.2	211.55	951,128.8
2.12a	4563	68	2.56	0.128	215.04	477.86	2180,475.2
3.1a	3677	158	2.21	0.110	173.8	386.22	1420,130.9
3.2a	1138	53	0.54	0.027	14.31	31.20	36,168.4
3.2b	17840	80	2.28	0.114	205.2	456.0	8135,040.0

* This is the weighted average of two soil horizons.

Table 2.7. Replacement Cost Analysis of Phosphorous Loss in Open Grassland of Selected LMUs in the Magat Watershed.

LMU	AREA	SOIL LOSS	AVAILABLE	PHOSPHOROUS		P_2O_5	
	(ha)	(t/ha)	(PPM)	(%)	(kg/ha)	(kg/ha)	(kg/LMU)
2.1a	6423	17	4.96	0.03875	6.579	15.06	96,730.4
2.1b	4269	12	75.60	0.5906	70.872	162.29	629,816.0
2.2b	636	27	15.42	0.1205	32.535	74.50	47,382.0
2.2c	3169	78	2.06	0.0161	12.558	28.76	91,140.4
2.4a	3149	20	4.18	0.0326	6.52	14.93	47,014.5
2.6a	4410	24	1.71	0.0133	3.192	7.31	32,237.1
2.6b	15026	43	5.30	0.0414	17.20	40.76	612,459.7
2.7	1281	51	4.05	0.0316	16.11	36.90	47,268.9
2.8	352	11	4.20	0.0328	3.61	8.26	2,907.5
2.9b	11133	52	0.53	0.0041	2.13	4.88	54,329.0
2.9c	12672	45	6.67	0.0521	23.44	53.69	680,359.7
2.11a	3641	29	2.98	0.0233	6.75	15.47	56,326.3
2.11b	4496	70	1.64	0.0126	8.96	20.52	92,257.9
2.11c	7110	92	9.07	0.0708	65.13	149.16	1060,527.6
2.12a	4563	91	13.0	0.1015	92.36	211.51	965,120.1
2.12b	20992	168	2.92	0.0228	38.30	87.71	1841,208.3
3.1b	3677	158	3.47	0.0271	42.82	98.05	360,529.8
3.2a	1138	53	1.91	0.0149	7.89	18.08	20,575.0
3.2b	17840	180	3.77	0.0294	52.92	121.18	2161,851.2

Table 2.8. oss in Open Grassland of Selected LMUs in the Magat Watershed.

U	AREA	SOIL LOSS	EXCHANGEABLE K		K		K_2O	
	(ha)	(t/ha)	(me/100yr)	(gm/gm soil)	(gm/gm soil)	(kg/ha)	(kg/ha)	(kg/LMU)
2.1a	6423	17	0.04	0.0000156	0.0000156	2.65	3.18	20,425.1
2.4a	3149	20	0.86	0.0003354	0.003356	67.08	80.49	253,463.0
2.7	1281	51	0.30	0.000117	0.00117	59.67	71.60	91,719.6
2 [illegible]	352	11	0.27	0.000105	0.00105	11.55	13.86	4,878.7
2 [illegible]a	12672	52	0.16	0.0000624	0.00624	32.44	38.93	493,320.9
2.11a	3641	29	0.10	0.000039	0.00039	11.31	13.51	49.403.3
2.11b	4496	70	0.55	0.0002145	0.002145	150.15	180.18	810,089.3
2.11c	7710	92	0.10	0.000039	0.00039	35.88	43.05	306,085.5
3.2a	1138	53	0.77	0.0003003	0.003003	159.15	190.99	217,346.6
3.2b	17840	180	0.05	0.0000195	0.000195	35.10	42.12	751,420.8

layers of LMU 2.1a, with the weight for the average coming from the relative depths of each of the soil layers. From this average OC of 1.26%, the percentage of N in the soil is determined to be .063% (or .0126/.6 x 3 = % N, as listed in steps 1 and 2 of Appendix 2.1). Since the soil loss per hectare is 17 tons, nitrogen loss is equal to .00063 x 17 tons or 10.71 kg/ha. The equivalent amount of urea needed to provide 10.71 kg. of N is equal to 10.71/.45 or 23.8 kg. of urea per hectare. Similar procedures are employed for deriving the estimates in Tables 2.7 and 2.8 for P_2O_5 and K_2O, respectively.

The results of the replacement cost method of estimating soil erosion (in Boxes G and H of Figure 2.2) are presented in Table 2.9. The first column of the table lists the weighted average of nutrients lost as soil is eroded, in terms of their equivalent in kilograms of urea, solophos, and muriate of potash. The second column lists the value of these fertilizer equivalents using nominal fertilizer prices - - those prices actually paid by purchasers in the area. Finally the third column gives the values of fertilizer loss using shadow prices -- or those prices that account for the social cost of providing such fertilizers. (Please see Appendix 2.2 for a discussion of how such prices are derived). For the Magat watershed, therefore, the 88 t/ha/yr. of soil loss carried with each ton an average of 3.08 kg of urea, combined value of about ₱15/ton, using nominal prices. On a per hectare basis, the combined loss is about ₱1,068.00.

These values are clearly conservative estimates if we consider that the soil loss being measured is only for sheet erosion. If we assume that sheet erosion is only 40 percent of total or gross erosion, then the latter must be about 219 t/ha/yr for the grassland area. With this rate of erosion, the loss in terms of value of chemical fertilizers is about ₱3392 per hectare per year.

Since the open grassland area is about 159,517 hectares in size, losses of plant nutrients via sheet erosion losses alone per year is about ₱170 million. This may be broken down into ₱108 million worth of Urea, ₱28 million worth of P_2O_5 and ₱34 million worth of K_2O.

With respect to implications for the entire watershed, is it reasonable to use the preceding assessment of on-site cost of soil erosion to propose an erosion cost for the entire watershed? First of all, since the valuation figures have been derived from grasslands as potential production areas, they probably represent the upper bound of economic value associated with soil erosion. Indeed where no production is likely to take place, nutrient loss would carry with it no on-site economic cost.

Secondly, the great variation in erosion corresponding to the various major land uses severely limit the intuitive value that may be attached to an "average" entire watershed erosion rate as well as an "average" entire watershed on-site cost. Indeed the very low rates of erosion associated with forested lands may represent a baseline level of erosion below which we probably cannot expect erosion to decline. In this case, there will be no opportunity cost associated with the 3-12 t/ha/yr of erosion from forest lands.

Table 2.9. Fertilizer Losses Due to Soil Erosion

Fertilizer Cost	Quantity (kg)	Nominal Price (₱)	Shadow Price (₱)
1. Urea			
-price		3.60/kg.	9.86/kg.
-amount lost/ton of soil eroded	3.08	11.09	30.37
-amount lost/ha. of affected land	118.13	677.23	1854.96
2. Solophos (P_2O_5)			
-price		2.50/kg.	6.20/kg
-amount lost/ton of soil eroded	0.79	1.98	4.90
-amount lost/ha. of affected land	70.65	176.63	438.03
3. Muriate of potash (K_20)			
-price		4.20/kg.	8.28/kg.
-amount lost/ton of soil eroded	0.57	2.39	4.72
-amount lost/ha. of affected land	51.07	214.49	422.86
4. All fertilizers			
-amount lost/ton of soil eroded		15.46	39.99
-amount lost/ha. of affected land		1,068.35	2,715.85

There is, however, one basic limitation to our approach which leads to an under-estimation of the on-site loss. This has to do with considering yield loss as a function solely of erosion-induced fertility loss. This is a simplification since erosion also causes damages to soil structure which greatly affects crop growth. (For example, water-holding capacity significantly declines.) For lack of a devise that can quantify this damage, however, yield loss as a function solely of fertility loss is generally accepted, but this might lead to an underestimation of the effect of soil loss.

II. THE ON-SITE ECONOMIC EFFECTS OF SOIL EROSION IN THE PANTABANGAN WATERSHED

Background Information

The Upper Pampanga River Project

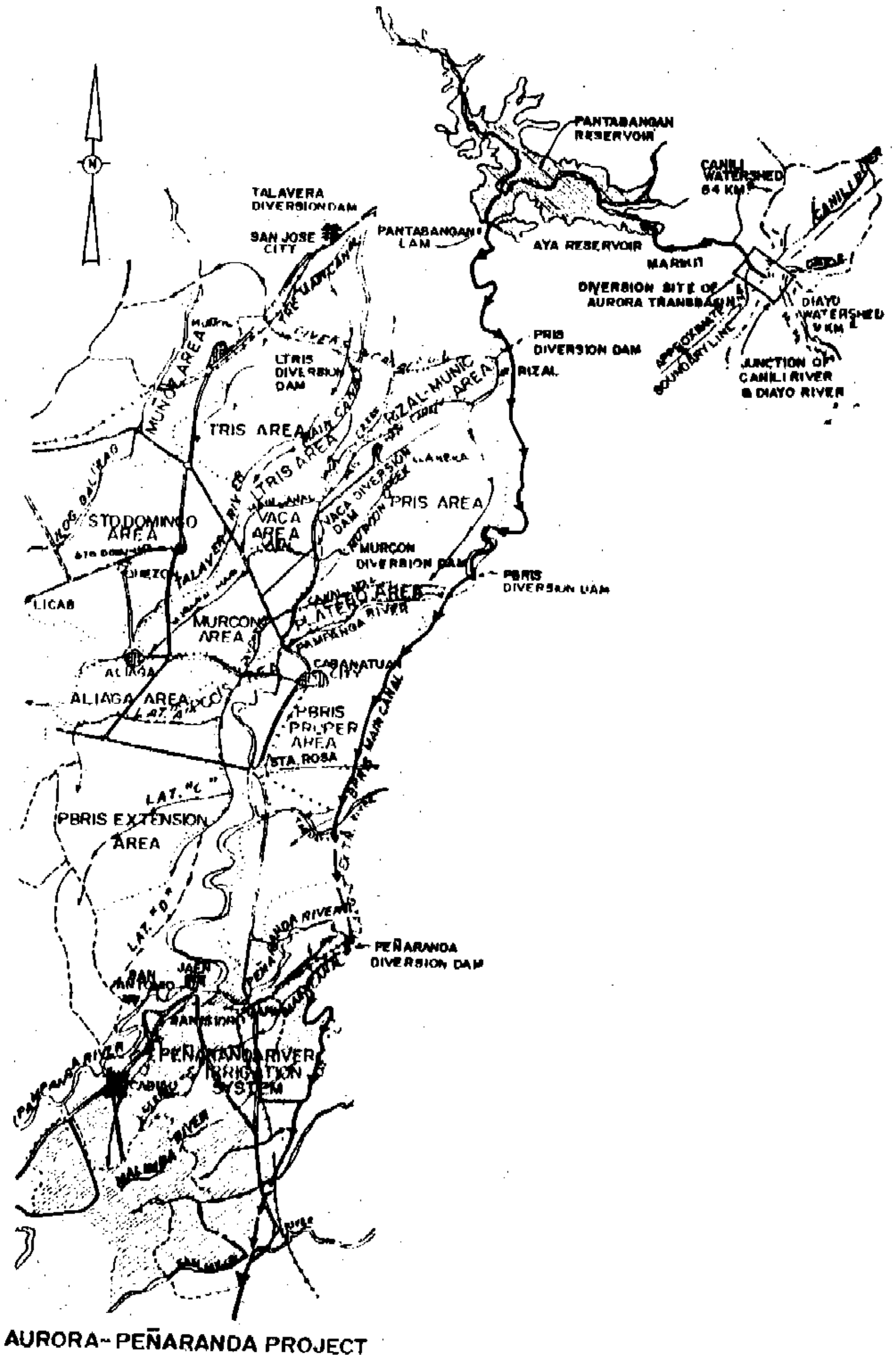
In 1969, the Upper Pampanga River Project was officially launched when Congress authorized funding for the construction of the Pantabangan dam and the associated irrigation service facilities (Map 2.3). The Pantabangan dam which accounts for one third of the total project cost, is designed to control, regulate, and harness the seasonal flows of the Pampanga river for irrigation, hydropower generation, domestic and industrial water supply, mitigation of flood damages, and provision of facilities for recreation and fish conservation (NIA, 1977). It is situated in a canyon downstream of the confluence of the Pantabangan and Carranglan rivers -- the major tributaries of the Pampanga river and the principal drainage systems contributing water to the Pantabangan reservoir.

In order to expand the irrigation service area of the Pantabangan dam and provide additional water for hydropower generation, the Aurora-Penaranda Irrigation Project was undertaken to harness the Canili and Diayo rivers that drain a smaller catchment adjacent to the Pantabangan watershed. The Canili and Diayo dams were constructed to transfer water to the Pantabangan reservoir through a diversion channel connecting the two catchments.

Thus, the Pantabangan reservoir is in effect being fed by an aggregate watershed area of about 916.5 km^2 with the Pantabangan and Canili-Diayo watershed amounting to approximately 853 km^2 and 63.5 km^2, respectively. These watersheds include portions of Nueva Ecija, Nueva Viscaya and Quezon provinces in Luzon (Map 2.2)

The dam began its operations in February 1974. In May 1976, typhoon Didang devastated Central Luzon, and severe erosion was observed. These generated extreme concern over sedimentation in the reservoir and focused attention on the watershed area upstream of the dam.

A feasibility study for a comprehensive watershed management and erosion control program in Pantabangan was therefore commissioned. This was completed in 1978 by a team from the National Irrigation Administration (NIA) and Engineering Consultants, Inc. (ECI) of Denver, Colorado (ECI-NIA, 1978).



UPPER PAMPANGA RIVER PROJECT
(SHOWING AURORA TRANSBASIN DIVERSION SCHEME
AND PENRIS AREA EXPANSION)

Map 2.3

It was superceded by another feasibility study undertaken by the Mandala Development Corporation (MADECOR) in 1979. The latter report became the basis of a $38 million World Bank loan and was finally implemented in 1980 as the Watershed Management and Erosion Control Project (WMECP) for both Pantabangan and Magat Watersheds. A government counterpart fund of $37 million was earmarked to finance the local components of the project.

As proposed, the Pantabangan WMECP would (a) rehabilitate 24,500 hectares of open grasslands with agroforestry and timber crops; (b) develop a fire control system for the watershed, (c) develop 342 kilometers of road network; (d) set up fruit, leafmeal, and charcoal processing plants, and (e) institute a human resources development program. Since it is basically a reforestation project, the last component is minimal and largely confined to extension, community development and support services (MADECOR-NIA, 1979). The Project was set for completion in 1986 but was recently extended to 1988.

There are other afforestation projects being undertaken in the Pantabangan and Canili-Diayo watersheds, mainly by the Bureau of Forest Development (BFD). Two Forest Districts of BFD have jurisdiction over the Pantabangan watershed areas not covered by NIA's WMECP - the Carranglan Forest District and the Pantabangan Forest District. Regular reforestation programs are being conducted by these districts which have planted around 9,000 hectares by 1984. In addition, BFD implements the RP-Japan Technical Cooperation Project which was started in 1977 with a total target reforestation area of 8,000 hectares (Coloma, 1984).

The Pantabangan and Canili-Diayo Watersheds

Land Use. The general land uses in the Pantabangan and Canili-Diayo watersheds may be grouped into land uses with three basic covers: forests, grasses, and crops. In 1977, these land uses were distributed as shown in Table 2.10.

Forest and open grassland areas, mainly cogonal, predominate in the watershed. The cultivated areas, primarily ricelands, are found mostly along river valleys in Carranglan and Marikit, Pantabangan. Lands devoted to kaingin and diversified farming are usually found in higher elevations. Upland rice is the pivotal crop in these areas followed by mixed planting of vegetables (corn, eggplant, tomato), root crops (camote, cassava), and legumes (beans, peanuts).

Climate. The climate in the watershed is tropical and monsoonal. The major portion or western part of the area is under Type I climate with distinct dry season from December through April and wet season from May through November. The eastern portion, toward the Sierra Madre mountains, falls under climatic Types III and IV. Climatic Type III has only four dry months in a year, while climatic type IV has no pronounced seasons but has rainfall distribution that is quite even throughout the year. The whole watershed falls within the typhoon belt where an average of 3 storms pass per year. Highest average monthly rainfall occurs in August, with 431.7 mm; the dryest month (with zero rainfall) is February.

Table 2.10. Land Uses in Pantabangan and Canili-Diayo Watershed (1977).

Land Use	Mapped Area* (hectares)	Percent of Total Area
Forest[1]		
Primary Forest	36,008	39.3
Secondary Forest	915	1.0
Sub-Total	36,923	40.3
Grassland[2]		
Open Grassland	33,487	36.5
Savannah	2,175	2.4
Sub-Total	35,662	38.9
Cropland		
Kaingin Area	2,325	2.5
Diversified crops	617	0.7
Rainfed Riceland	2,608	2.8
Irrigated Riceland	3,992	4.4
Sub-Total	9,542	10.4
Other Uses		
Residential	600	0.7
Reservoir	7,998	8.7
Riverwash, gravelly or stony	175	0.2
Sub-Total	8,773	9.6
Unevaluated Area	750	0.8
TOTAL	91,650	100.0

*Based on Bureau of Soils Mapping.

[1] As measured from the UPRP Multiple Use Management map of BFD, primary forest is only 23,747 hectares and secondary forest is 13,176 hectares.

[2] Effective area of forest plantings by NIA, BFD, and others from 1974 to 1977 is around 4,000 hectares. These are counted as grassland areas since the forest crops are still in seedling stage.

Source: ECI-NIA, 1978.

Topography. The watershed is generally of rugged topography with steep mountainous landscape, dissected by narrow flat-bottomed valleys. Table 2.11 shows that more than 75% of the watershed area above the Pantabangan reservoir have slopes greater than 25%. Also around 65% of the watershed is very hilly and mountainous with slopes of more than 40%.

Soils. The Bureau of Soils conducted a reconnaissance soil inventory work on the watershed area from June to October 1977 as part of the initial feasibility study of the WMECP. Four soil series were identified and mapped, and tentatively named as Guimbalaon, Annam, Mahipon and Bunga. The main characteristics of these soils are given in Appendix 2.3.

The soil survey has also classified the soils in the area according to erosion classes. As shown in Table 2.12, more than 40% of the watershed area has severe to excessive erosion. Slight erosion occurs on about 41% of the area, where the dominant soil cover is forest. No apparent erosion occurs on 7% of the area corresponding to irrigated and rainfed ricelands.

Estimation Procedures

In general, the replacement cost approach involves the following: (1) determination of soil nutrient distribution in the study area; (2) estimation of erosion rates for different sites; and (3) calculation of nutrient loss given the estimated rates of soil loss and the soil nutrient content of these sites in the study area. The methodology used in this study incorporates the above steps with some modifications arising from the kind of data available.

Figure 2.3 illustrates the estimation procedures adopted for the study. The numbers in parentheses represent the specific steps undertaken. First is the determination of soil nutrient distribution in the watershed, using soil chemical analyses data and soil profile descriptions of soil mapping units (SMUs) obtained by the Bureau of Soils during the reconnaissance soil survey of the watershed in 1977. This step gives a rough indication of the fertility status of soils in the area prior to implementation of the WMECP and provides information on potential nutrient losses from cumulative removal of soil layers.

Second is the delineation of areas of SMUs found in a particular land use and the selection of a representative sample of SMUs for each land use. Rill and sheet erosion per sample SMU was estimated using the modified Universal Soil Loss Equation (USLE) developed for this research program (David, 1987a-c). Third is the computation of an average erosion rate for a land use from the estimated erosion rates of its sample SMUs. Fourth is the determination of an average soil profile nutrient composition for the land use using the soil profile nutrient analysis of the sample SMUs. Last is the calculation of the amounts of nutrients and their inorganic chemical fertilizer equivalents that were actually lost, given the estimated erosion rate for the land use and the soil nutrient content of the profile.

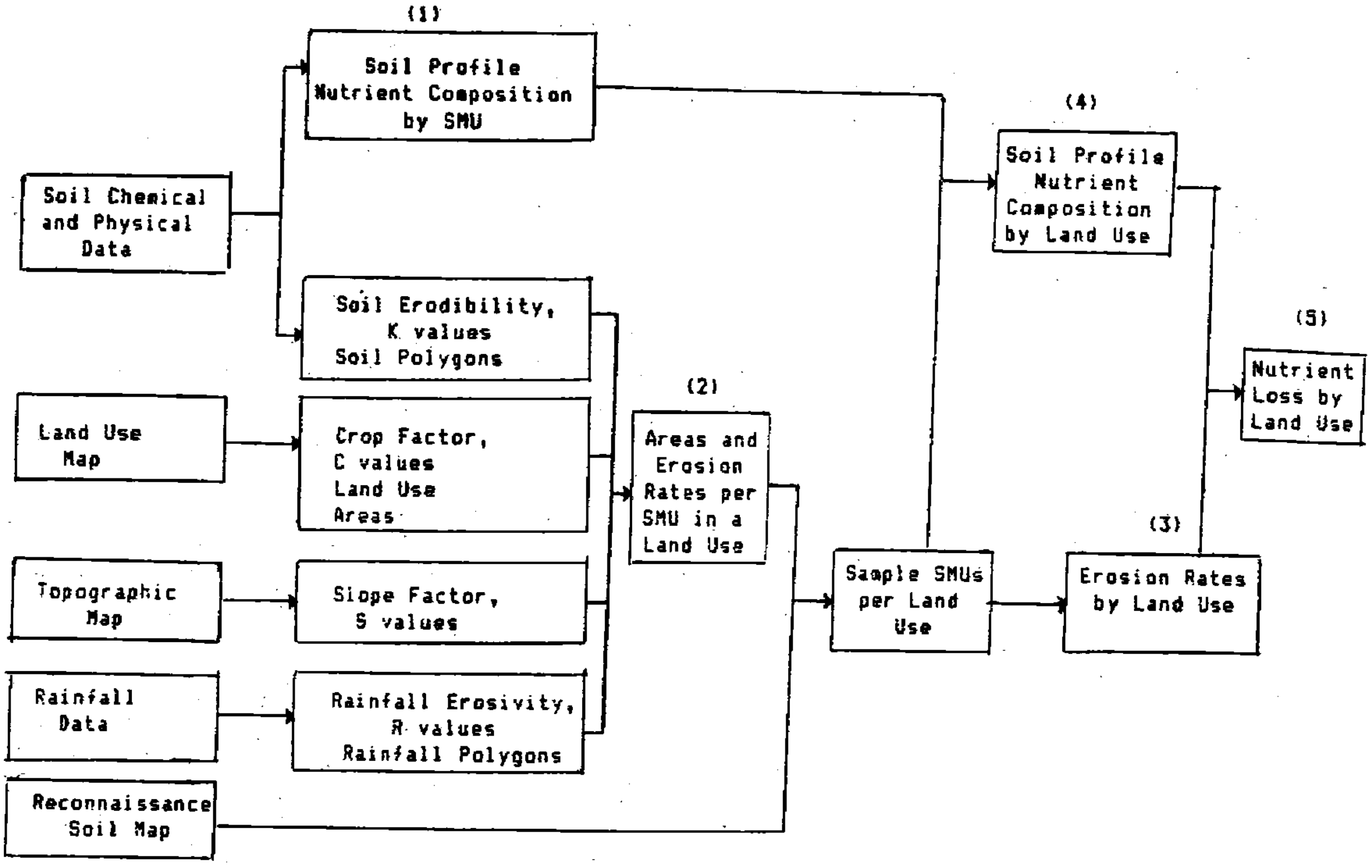


Fig. 2.3. Flowchart of Estimation Procedures

Table 2.11. Slope Grouping and Physiographic Positions of Different Soil Mapping Units, Their Proportionate Extent and Percentage.

Slope Grouping	Physiographic Position	Soil Mapping Unit	Area ha.	Percentage %
A:0 to 3% slopes	Level to nearly level	BuBA, MhHA	6,365.0	7.00
B:3 to 8% slopes	Gently sloping or gently undulating	MhHB1, MhHB3	847.5	0.93
C:8 to 15% slopes	Moderately sloping or moderately undulating	GnHC4	777.5	0.86
D:15 to 25% slopes	Strongly sloping or rolling	AmGD3, AmHD4 GnGD3	4,522.5	4.97
E:25 to 40% slopes	Steeply rolling or hilly	AmHE4,AmHE3 AmHE7,GnGE3 GnHE4,GnHE7 GnsGE7	10,662.5	11.74
F:more than 40% slopes	Very steep hilly to mountainous and rugged	AmHF1,AmHF3, AmHF4,GnGF1, GnGF2,GnGF3, GnHF4,GnHF7, GnsGF1,GnHF4 GnsHF5	59,552.5	65.51
TOTAL			82,727.5	91.01

Note: Areas covered by mapping unit Rw and W with 175.0 ha. or 0.19% and 7,997.5 or 8.80% respectively are not included in this table.

Source: ECI-NIA (1978), based on the Bureau of Soils Reconnaissance Soil Survey.

Table 2.12. Area and Percentage of Erosion Classes.

Erosion Class	Degree of Erosion	Area: in ha.	in %
0	No apparent erosion	6,365.00	7.00
1	Slight	37,525.00	41.27
2	Moderate	385.00	0.42
3	Severe	10,452.50	11.50
4	Very severe	19,520.00	21.48
5 & 7	Excession	8,480.00	9.34
TOTAL		82,727.50	91.01

Notes: Areas covered by mapping units W (Reservoir) and Rw (River wash gravelly, and stony) with approximate area of 7,997.50 hectares or 8.80% and 175.0 hectares or 0.1 respectively, are not included in this table.

Source: ECI-NIA, 1978.

The methodology developed here incorporates the assumption of declining fertility level with increasing depth of the soil profile. Moreover, erosion rates and nutrient losses were estimated for four land uses: (a) grasslands, (b) forest, (c) kaingin and diversified croplands, and (d) irrigated and rainfed ricelands. These refinements provide a more detailed assessment of the on-site economic costs of soil erosion in the Pantabangan watershed.

Step 1: Determination of soil profile nutrient composition by SMU

Using data from 155 soil auger borings, the Bureau of Soils was able to map the soils in the Pantabangan and Canili-Diayo watersheds according to soil series and phases of a series. These were further subdivided into soil mapping units based on surface texture, slope, and erosion.[3] Five soil series as cited before, and 26 soil mapping units (excluding riverwash, Rw, and reservoir, W) were identified by the Bureau. for the entire watershed (Appendix 2.4). Thirteen pit observations were taken to determine the profile description, and the physical and chemical analysis of each soil horizon for each soil series.

For purposes of this study, only information on organic matter (in %), available P (in ppm) and exchangeable K (in m.e./100 gm of soil) obtained from the auger and pit boring samples were considered. The data were consolidated according to soil mapping units. For each SMU, the soil profile was divided into 5-cm layers up to a depth of 50 cm. This depth generally represents the A and B horizons of soils in the area, although some soil mapping units, particularly of the Bunga series, have B horizons extending up to around 100 cm. depth. Average nutrient content was estimated for each 5-cm layer of soil profile for each SMU.

Step 2. Determination of areas and erosion rates per SMU in each land use type.

In order to make the estimation procedures more relevant to policy concerns, it was deemed necessary to relate erosion rates and losses with land modifications in the watershed. As shown in Appendix 2.4, several land uses may be represented in a given SMU. Alternatively, several SMU's may be represented in a given land use. The tabulated data of the Bureau of Soils do not delineate the actual hectarage of each land use in an SMU, and vice versa. These information were instead obtained from the planimeter measurements done by David (1987-c) as part of the methodology for estimating erosion rates.

David's (1987c) results had to be sorted out according to land uses (i.e. based on C values) and SMUs (i.e. based on soil erodibility or K values) so as to determine actual areas and erosion rates of different SMUs in a particular land use. Appendix 2.5 presents a listing of the SMUs found in each of the four land use types being considered - grasslands/savannah, primary/secondary forest, kaingin/diversified croplands, and irrigated/rainfed ricelands.

Sample SMU's were chosen to represent a land use type. Selection was done on the basis of area and representativeness of the SMU for a given land use. The samples covered 59 to 77% of the total area delineated for each land use type in the entire watershed (Table 2.13). Weighted average erosion rate (in tons/ha/yr) per SMU in each land use were then determined using the sample K observations for each SMU (Table 2.14).

Table 2.13. Total land use area vs. land Use Area in sample SMUs

Land Use	Total Area (has) (1)	Area of Sample SMUs (has) (2)	Percent of Total (2) ÷ (1)
Grassland/ Savannah	35,662	23,304	65
Primary/Secondary forest	36,923	27,398	74
Kaingin/Diversified cropland	2,942	2,263	77
Irrigated/Rainfed ricelands	6,600	3,916	59

Table 2.14. Areas and Erosion Rates of SMUs in each Land Use.

Land Use	Sample SMU's	Area (has.)	Erosion Rate (t/ha/yr)
Grassland/Savannah	AmGD3	1525.42	222.64
	AmHE4	1948.80	167.74
	AmHF3	1819.59	306.18
	AmHF4	1713.58	207.75
	GnGE3	1466.97	201.90
	GnHE7	4257.70	114.39
	GnHF4	4553.24	200.02
	GnHF7	1116.67	357.51
	GnsGF1	1025.07	238.94
	GnsHF4	3877.45	178.52
Primary/Secondary Forest	AmHF1	9150.18	2.74
	AmHF3	5920.57	1.67
	GnGF1	10822.78	1.88
	GnGF3	1504.32	2.33
Kaingin/Diversified Croplands	AmGD3	1222.09	290.02
	AmHE4	118.59	496.08
	AmHF3	548.50	745.65
	AmHF4	73.97	662.55
	GnsHF5	67.08	243.42
	GnsHF4	232.27	353.36
Irrigated/rainfed Ricelands	BuBA	885.82	0.14
	MhHA	2417.04	0.24
	MhHB1	406.04	0.71
	AmGD3	207.22	0.49

Step 3. Determination of average erosion rates for each land use.

The following formula was used to derive an estimate of the average erosion rate for a particular land use type:

$$\text{Erosion rate for land use } i = \frac{\sum_{j}\left[\begin{array}{l}\text{(Erosion rate)} \\ \text{(for SMUj in)} \\ \text{(land use i)}\end{array} \times \begin{array}{l}\text{(Area of SMU j)} \\ \text{(in land use i)}\end{array}\right]}{\sum_{j}\left[\begin{array}{l}\text{Area of SMU j} \\ \text{in land use i}\end{array}\right]} \qquad (1)$$

where: j = 1 to 10, for i = grassland/savannah
j = 1 to 4, for i = primary/secondary forest
j = 1 to 6, for i = kaingin/diversified croplands
j = 1 to 4, for i = irrigated/rainfed ricelands

Note that the above equation can be rewritten as follows:

$$\text{Erosion rate for land use } i = \sum_{j}\left[\begin{array}{l}\text{Erosion rate} \\ \text{for SMUj in} \\ \text{land use i}\end{array}\right] \times \frac{\text{in land use i}}{\sum_{j}\left[\begin{array}{l}\text{Area of SMUj} \\ \text{in land use i}\end{array}\right]} \qquad (2)$$

The second term in the right-hand side of equation (2) just gives the proportion of land area of each sample SMU to the total area of all samples. Thus, the estimated erosion rate for the land use is actually an area-weighted average.

Table 2.14 lists down the sample SMUs and their corresponding areas and erosion rates for the four land use types. As an example, consider grassland and savannah areas. Ten sample SMUs were selected for this land use as shown in Table 2.14 and again in Table 2.15. Using equation (1), the total soil loss for each sample SMU was obtained by multiplying its area by its erosion rate (columns 2 and 4 of Table 2.15). The total soil loss for all the 10 SMUs were summed up and divided by the total area of the samples (i.e. sum of column 6 divided by sum of column 2) to obtain the weighted average erosion rate for the land use. The same procedure was followed in deriving erosion rate estimates for primary/secondary forests as shown in Table 2.16.

Table 2.15. Computation of Average Soil Loss Rates: Grassland/ Savannah Areas, Pantabangan and Canili-Diayo Watershed, 1977.

Sample SMU's	Area (has.)	Bulk density (t/ha-cm)	Soil Loss (t/ha/yr)	Soil Loss (cm/yr)	Total Soil Loss (t/yr)	Total Soil Loss (ha-cm/yr)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
AmGD3	1525.42	130	222.64	1.71	339619.51	2612.46
AmHE4	1948.80	130	167.74	1.29	326891.71	2514.55
AmHF3	1819.59	130	306.18	2.36	557122.07	4285.55
AmHF4	1713.58	130	207.75	1.60	355996.25	2738.43
GnGE3	1466.97	120	201.90	1.68	296181.24	2468.18
GnHE7	4257.70	120	114.39	0.95	487038.30	4058.65
GnHF4	4553.24	120	200.02	1.67	910739.06	7589.49
GnHF7	1116.67	120	357.51	2.98	399220.69	3326.84
GnsGF1	1025.07	120	238.94	1.99	244930.23	2041.09
GnsHF4	3877.45	120	178.42	1.49	691814.63	5765.12
TOTAL	23304.49				4609553.69	37400.36

Weighted average erosion rate = 197.80 tons/ha/yr
or 1.60 cm/yr

Table 2.16. Computation of Average Soil Loss Rates: Primary/ Secondary Forest Areas, Pantabangan and Canili-Diayo Watershed, 1977.

Sample SMU's (1)	Area (has.) (2)	Bulk density (t/ha-cm) (3)	Soil Loss (t/ha/yr) (4)	Soil Loss (cm/yr) (5)	Total Soil Loss (t/yr) (6)	Total Soil Loss (ha-cm/yr) (7)
AmHF1	9150.18	100	2.74	0.0274	25071.49	250.71
AmHF3	5920.57	100	1.67	0.0167	9887.35	98.87
GnGF1	10822.78	100	1.88	0.0188	20346.83	203.47
GnGF3	1504.32	100	2.33	0.0233	3505.07	35.05
TOTAL	27397.85				58810.73	588.11

Weighted average erosion rate = 2.15 tons/ha/yr
or 0.02 cm/yr

Erosion rate estimates made by David (1987), using the modified USLE are given in tons/ha/yr. For this study, it was also necessary to convert these values into erosion rates in terms of soil depth lost per year to be able to later relate erosion with the removal of soil layers. This was accomplished by dividing the given erosion rates in tons/ha/yr with assumed bulk densities (in tons/ha-cm) of soils, thus producing erosion measures in terms of cm/yr.

Sabio (1981) obtained bulk density data for the four soil series (Bunga, Mahipon, Guimbalam, Annam) found in the Pantabangan and Canili-Diayo watersheds.[4] It was assumed that soil mapping units under each soil series have the same bulk densities for grassland/savannah, kaingin/diversified cropland, and riceland areas. For forest areas, a bulk density of 1 gm/cm^3 or 100 t/ha-cm was assumed for all SMUs.

As illustrated in Tables 2.15 and 2.16, soil loss rates in cm/yr (column 5) were obtained by dividing each value in column 4 by the corresponding value in column 3. The same procedures as discussed above were followed in deriving the weighted average erosion estimate (in cm/yr) for the land use.

In order to substantiate the erosion estimates, and test the hypothesis that good land cover mitigates the well-known positive relationship between slope and soil loss, the areas of the sample SMUs in each land use were delineated according to slope categories. The proportions of areas found in each slope class to the total area of the samples were determined to obtain a relative indication of the average slopes associated with the four land use types.

Step 4. Determination of soil profile nutrient composition by land use

Using the soil profile data on organic matter (%), available P (ppm) and exchangeable K (m.e/100 gm) for each sample SMU (i.e., output of step no. 1), the average nutrient content of the soil profile for each land use type was established. The formulas used by Francisco (1986) in computing for kilograms of N,P,K, Urea (45-0-0), P_2O_5 (Solophos: 0-20-0) and K_2O (Muriate of Potash: 0-0-60) were adopted and modified to estimate the nutrient stock (ar [illegible] eir fertilizer equivalent) per unit volume (i.e., hectare-cm) of soil throughout the 50-cm depth of the profile for each sample SMU, i.e.

(a) To compute kg N and equivalent kg Urea per ha-cm of soil from % OM:

$$\text{Total N }(\%) = .03\ (\%\ \text{OM})\text{[5]} \tag{3}$$

$$\text{Kg N/ha-cm} = \frac{\text{Total N }(\%)}{100} \times \text{B.D.}\text{[6]} \times (1000\ \text{kg/ton}) \tag{4}$$

$$\text{Kg Urea/ha-cm} = \frac{\text{KgN/ha-cm}\text{[7]}}{.45} \tag{5}$$

(b) To compute kg P and equivalent kg P_2O_5 (or solophos) per ha-cm. of soil from available P (ppm):

$$\text{Total P }(\%) = \frac{\text{Avail P}\text{[8]}}{(1.28)(100)} \tag{6}$$

$$\text{Kg P/ha-cm} = \frac{\text{Total P }(\%)}{100} \times \text{B.D.} \times (1000\ \text{kg/ton}) \tag{7}$$

$$\text{Kg solophos/ha-cm} = (\text{kg P/ha-cm}) \times \frac{P_2O_5}{2P} \tag{8}$$

$$= (\text{kg P/ha-cm}) \times 2.29$$

(c) To compute kg K and equivalent kg K_2O (or muriate of Potash, MP) per ha-cm of soil from exchangeable K (m.e./100 gm)

$$\text{gm K exch/gm soil} = \frac{\text{m.e. K}}{100\ \text{gm}} \times \frac{.039\ \text{gm}}{\text{m.e.}} \tag{9}$$

$$\text{gm K total/gm soil} = \frac{\text{gm K exch./gm soil}\text{[9]}}{.10} \tag{10}$$

$$\text{kg K/ha-cm} = \frac{\text{gm K total}}{\text{gm soil}} \times \frac{\text{1 kg}}{\text{1000gm}} \times \text{B.D.} \times (10^6\ \text{gm/ton}) \qquad (11)$$

$$\text{kg MP/ha-cm} = (\text{kg K/ha-cm}) \times \frac{K_2O}{2K} \qquad (12)$$

$$= (\text{kg K/ha-cm}) \times 1.20$$

Weighted average nutrient content (in kilograms) and their fertilizer equivalents were then estimated for each 5-cm layer of soil profile for each land use, using the following formulas:

(a) Weighted average kg N/ha-cm (for layer n, for land use i)

$$= \frac{\sum_j \left[(\text{Kg N/ha-cm})(\text{Area of SMUj})\right]}{\text{Total Area of Sample SMUs}}$$

$$= \frac{\sum_j \left[(\text{Kg N/cm for SMUj})\right]}{\text{Total area of Sample SMUs}} \qquad (13)$$

Weighted average Kg Urea/ (for layer n, for land use i)

$$= \frac{\text{Weighted ave. kg N/ha-cm}}{.45} \qquad (14)$$

(b) Weighted average kg P/ha-cm (for layer n, for land use i)

$$= \frac{\sum_j \left[(\text{kg P/ha-cm})(\text{Area of SMUj})\right]}{\text{Total Area of Sample SMUs}} \qquad (15)$$

$$= \frac{\sum_j \left[(\text{kg P/cm for SMUj})\right]}{\text{Total Area of Sample SMUs}}$$

Weighted average kg solophos/ ha-cm (for layer n, for land use i)

$$= (\text{weighted ave. kg P/ha-cm}) \times 2.29 \qquad (16)$$

(c) Weighted average kg K/ha-cm (for layer n, for land use i)

$$= \frac{\sum_j \left[(\text{kg K/ha-cm})(\text{Area of SMUj}) \right]}{\text{Total Area of Sample SMUs}}$$

$$= \frac{\sum_j \left[(\text{kg K/cm for SMUj}) \right]}{\text{Total Area of Sample SMUs}} \qquad (17)$$

Weighted ave. kg MP/ha-cm (for layer n, for land use i)

$$= (\text{weighted ave. kg K/ha-cm}) \times 1.20 \qquad (18)$$

Tables 1 and 2 of Appendices 2.6 to 2.8 show samples of the computations for forest areas for the three major nutrients. Using nitrogen as the example, in Appendix 2.6 columns 5 to 7 of Table 1 were calculated using equations (3) to (5). Columns 8 and 9 were obtained by multiplying columns 6 and 7 by the SMU area.

To derive Table 2, equations (13) and (14) were used. For each 5-cm soil layer, the values in column 8 of Table 1 were summed across the 4 sample SMU's and divided by the total area of all samples to obtain a weighted average value of kg N/ha-cm, i.e. column 2. Column 3 may be obtained either by using equation (13) for values in column 9 of Table 1, or by using equation (14). In the latter case, each value in column 2 was simply divided by the conversion factor, 0.45.

Step 5. Determination of nutrient loss given the estimated erosion rates by land use

The amounts of nutrients that are actually lost through erosion were determined using the results of steps 3 and 4. Weighted average erosion rates in cm/yr were multiplied by the average nutrient content of soil in kg/ha-cm to estimate the corresponding amount of nutrient lost per hectare per year for each 5-cm soil layer for each land use. The number of years it takes to lose each 5-cm layer was also determined for each land use.

Next, the amount of nutrient lost per ton of soil eroded was estimated by dividing the amount of nutrient lost per hectare per year, obtained through the computations above by the weighted average erosion rate in tons/ha/yr.

Lastly, the cumulative amounts of nutrients (kg/ha) lost through time (years) given the respective rates of soil loss (assumed to remain constant with time) for each land use were computed and graphed.

Appendices 2.6 to 2.8, Tables 3 and 4 illustrate the procedure and computations for the three nutrients (N,P,K) for forest areas. Again using nitrogen as the example, refer to Tables 3 and 4 of Appendix 2.6. Given a soil loss rate of 0.02 cm/yr, it would take 250 years to lose a 5-cm layer of soil in forested areas. Multiplying this rate by the values in column 2 of Table 2 gives the kg N/ha lost from each 5-cm soil layer, i.e. column 2 of Tables 3. The kg Urea/ha lost, i.e. column 3 of Table 3, was computed by using the same conversion factor, 0.45. In Table 4, column 2 was derived by dividing each value in column 2 of Table 3 by the soil loss rate of 2.15 tons/ha./yr. to obtain the measure of lost in kg N/ton of soil eroded. This was again converted into kg urea/ton, of soil eroded, i.e. column 3 of Table 4, using the conversion factor.

From Table 3, since it takes 250 years to lose the first 5-cm layer of soil then the cumulative loss of N or urea per hectare was obtained by simply cumulating a yearly loss per hectare of 2.91 kg N or 6.46 kg urea.[10]

Results and Discussion

Soil Loss Rate Estimates

The results presented in Table 2.17 and 2.18 highlight the significant relationship between soil cover slope and erosion rate. On the average, rill and sheet erosion is highest in kaingin and diversified cropland areas where erosion rate is estimated at around 428.59 tons/ha/yr. Open grasslands and savannah areas show the next highest erosion rate of 197.80 tons/ha/yr. The lower rate of soil loss for grassland and savannahs was obtained despite the fact that more than 90% of their area is in S5 and S6 (i.e., slopes greater than 25%), compared to only 50% of kaingin/diversified croplands in the same slope range. This is primarily because the former areas are relatively undisturbed, whereas the latter are open and cultivated (disturbed).

Table 2.17. Weighted Average Sheet and Rill Erosion Rates and Number of Years to Lose Each Layer of Soil, by Land Use, Pantabangan and Canili-Diayo Watersheds, 1977.

Land Use[1]	Average Erosion Rates[2] tons/ha/yr	cm/yr	Years to lose each 5-cm soil layer
Kaingin/Diversified cropland	428.59	3.32	1.5
Grassland/Savannah	197.80	1.60	3.0
Primary/Secondary forest	2.15	0.02	250.0
Irrigated/Rainfed Riceland	0.28	0.002	2500.0

[1] Exclusive of riverwash (Rw), reservoir (W) and residentia areas.

[2] Inclusive of natural erosion which can be assumed a around 2.15 tons/ha/yr or 0.02 cm/yr corresponding to the erosio rate from the forest areas.

The importance of forest cover in preventing accelerate erosion is indicated by the very low rate of soil loss at 2.1 tons/ha/yr even at relatively steep slopes associated with this land use (i.e., 87% of the area in S6). This rate may be considered as corresponding to natural or geologic erosion in the watershed.[11] The least erosion occurs in irrigated and rainfed riceland areas; and this is to be expected since these areas are mostly found on level to nearly level slopes along river valleys in the watersheds.

In terms of soil depth, erosion in kaingin and diversified cropland areas removes approximately 3 cm. of top soil per year. This indicates critically severe erosion effects since, at this

2.18 Distribution of Land Use Areas into Slope Classes.

lope ange (%)	Kaingin/Diversified Croplands (has.)	(%)	lands/ nahs (has.)	(%)	Primary/Secondary Forest (has.)	(%)	Irrigated/Rainfed Ricelands (has.)	(%)
3.0	-	-	-	-	74	12.66	3510.08	89.63
8.0	-	-	-	-		-	406.04	10.37
to 15.0	-		356.36	1.53	-	-	-	-
to 25.0	1119.96	19.[illegible]	1300.92	5.58	74.09	0.27	-	-
to 40.0	36.04	1.59	6732.27	28.89	-	-	-	-
0	1106.58	.91	14914.94	64.00	23854.02	87.07	-	-
	2262.58	10.0	23304.49	100.00	27397.85	100.00	3916.12	100.00

d on total areas of sample SMUs for each land use.

rate, it would take only a year and a half to lose the first 5-cm layer of top soil and only 15 years to lose the entire 50-cm depth of A and B horizons (Table 2.17). Although still pronounced, erosion in grassland and savannah areas removes half as much soil (i.e., 1.6 cm per year). For forest and riceland areas, it would take hundreds and thousands of years, respectively, to lose even the first 5-cm. of soil given their very low rates of erosion.

Nutrients and Fertilizer Equivalents Lost with Soil Depth

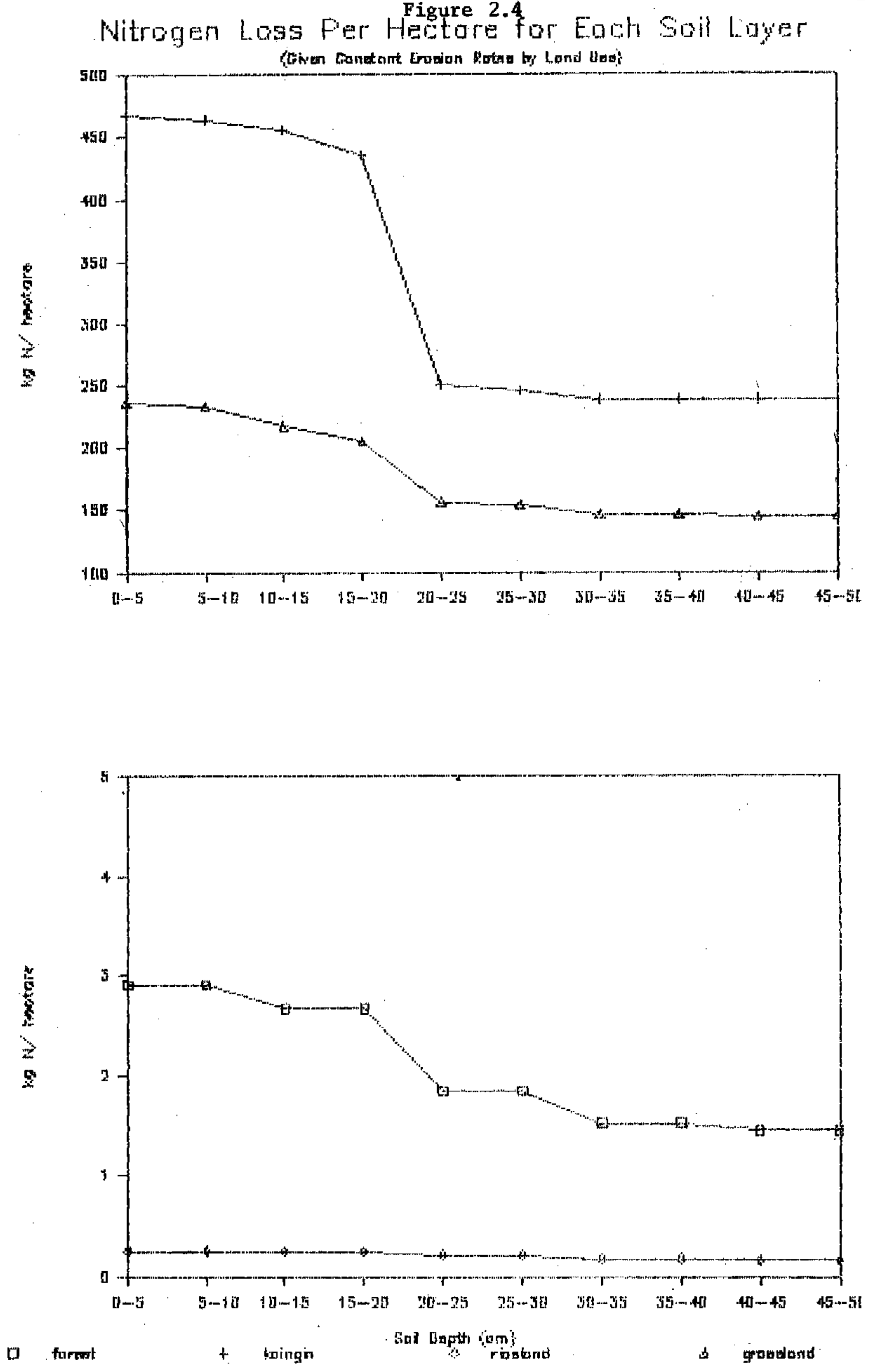
One of the basic assumptions in this study is that soil fertility declines at a decreasing rate with reduction in depth of the soil profile. This follows from the fact that soil nutrients are largely concentrated within the upper layers of the A horizon and rapidly declines thereafter. Hence, it is expected that, for any given erosion rate, the amount of nutrients lost via erosion does not remain constant over time.

Rather, with the constant rate of soil loss, the amount of nutrients being carried away declines at a decreasing rate as the more fertile upper soil layers are removed. On a cumulative basis, this further implies that the loss of nutrients increases at a declining rate. Figures 2.4 and 2.5 illustrate these relationships in the case of nitrogen for the four land uses. Figure 2.5 confirms that the rate of cumulative nutrient loss does, in fact, declines as the soil layers are eroded.

Tables 2.19-2.24 summarize the results of the replacement cost analysis in terms of the actual amounts of N,P,K, and equivalent amounts of Urea, solophos (P_2O_5) and muriate of potash (K_2O) lost per hectare and per ton of soil eroded from each 5-cm layer of soil.[12/] As with nitrogen, phosphorous and potassium content of soils in the area also decreases with depth of the profile. Thus, in valuing the cost of erosion via the amounts of lost nutrients, it is necessary to determine at what particular layer erosion is taking place to be able to know what amount of nutrients to use. For example, if erosion is removing the first 5-cm layer of soil in a grassland area, the loss is around 237 kg N, 11 kg P, and 175 kg K per hectare per year or 1.20 kg N, 0.06 kg P and 0.88 kg K per ton of soil eroded. Once erosion has reached the 10-15 cm layer, however, the loss declines to 217 kg N, 9 kg P, and 138 kg K per hectare per year or 1.10 kg N, 0.05 kg P and 0.70 kg K per ton of soil lost.

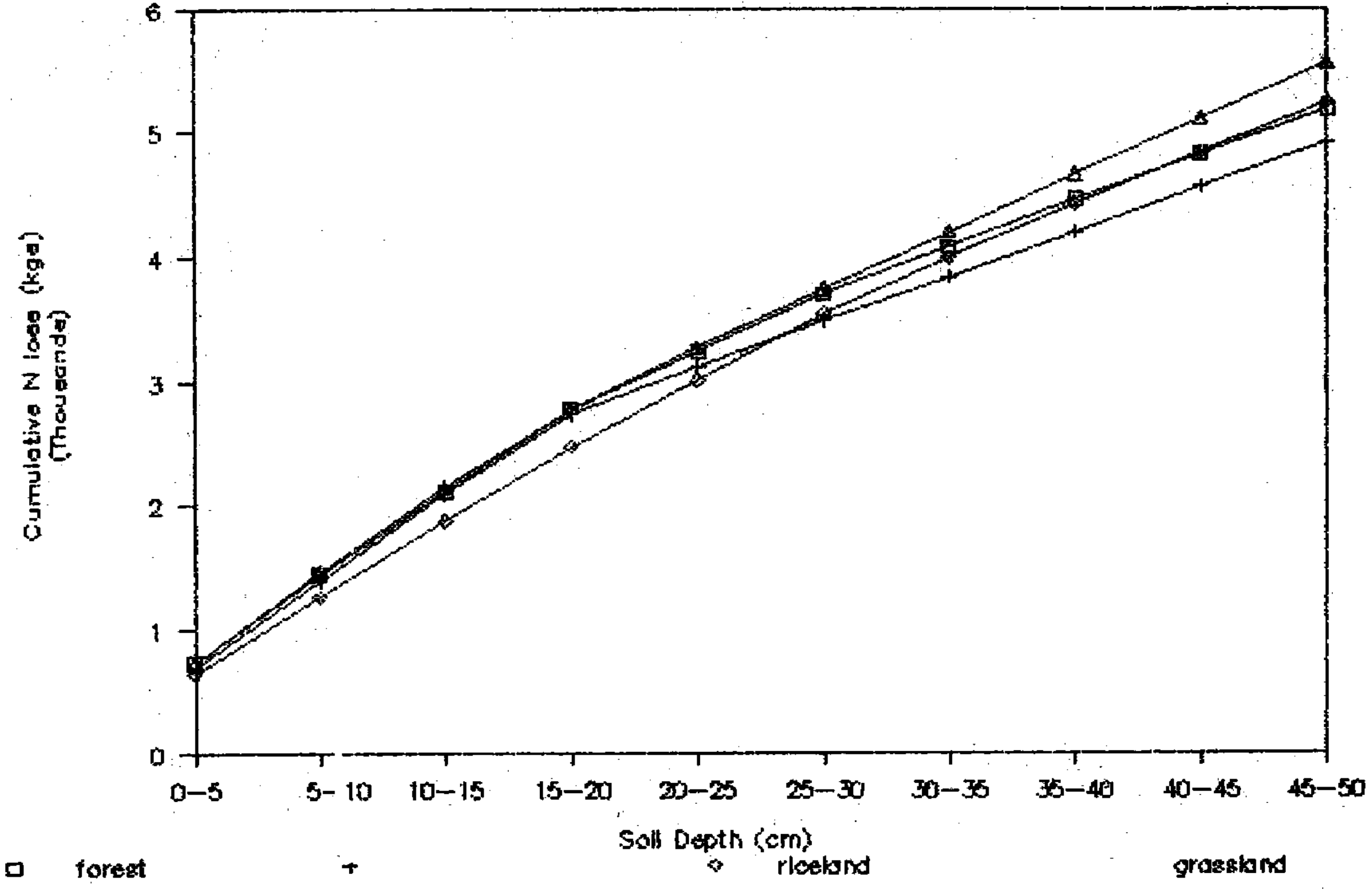
It should be noted that the time it takes to remove the soil layers varies greatly among the four land uses (as indicated in Table 2.17). This means that at any given time in the future, erosion will be taking place at varying depths of the profile of each land use. Correspondingly, the values used in computing the cumulative loss of nutrients over a given time period or planning horizon would depend on the nutrient content of the particular layers involved. In Figure 2.6, the cumulative loss of nitrogen for forest and riceland areas is linear over a period of 30 years, indicating constant rate of nutrient loss per unit time.

Figure 2.4


Nitrogen Loss Per Hectare for Each Soil Layer
(Given Constant Erosion Rates by Land Use)
kg N/ hectare
500
450
400
350
300
250
200
150
100
0--5
5--10
10--15
15--20
20--25
25--30
30--35
35--40
40--45
45--50
kg N/ hectare
5
4
3
2
1
0
0--5
5--10
10--15
15--20
20--25
25--30
30--35
35--40
40--45
45--50
Soil Depth (cm)
□ forest
+ kaingin
◇ riceland
△ grassland

Cumulative Nitrogen Lost With Eroded Soil Layers

By Land Use, Pantabangan and Canili-Diayo Watershed, 1977



1 re 2.5

Table 2.19. Nitrogen and Urea, equivalent lost <u>(kg/ha/yr)</u> from each soil layer, given constant erosion rate by land use, Pantabangan and Canili-Diayo Watershed, 1977.

Soil Depth cm.	Kaingin/Diversified Cropland N	Kaingin/Diversified Cropland Urea	Grassland/Savannah N	Grassland/Savannah Urea	Primary/Secondary Forest N	Primary/Secondary Forest Urea	Irrigated/Rainfed Riceland N	Irrigated/Rainfed Riceland Urea
0 - 5	467.88	1,039.72	236.66	525.89	2.91	6.46	0.25	0.56
5 - 10	463.74	1,032.52	233.47	518.82	2.91	6.46	0.25	0.56
10- 15	455.89	1,013.08	217.10	482.45	2.67	5.93	0.25	0.55
15- 20	435.03	966.72	205.09	455.76	2.67	5.93	0.24	0.54
20- 25	249.95	555.44	156.06	346.82	1.84	4.09	0.22	0.48
25- 30	245.97	546.60	153.41	340.91	1.84	4.09	0.22	0.48
30- 35	238.51	530.01	145.89	324.21	1.52	3.37	0.18	0.39
35- 40	238.51	530.01	145.89	324.21	1.52	3.37	0.18	0.39
40- 45	238.51	530.01	144.27	320.61	1.44	3.20	0.16	0.36
45- 50	238.51	530.01	144.27	320.61	1.44	3.20	0.16	0.36

Phosphorous and Solophos (P205) Equivalent Lost (kg/ha/yr) From Each Soil Layer, Given Constant Erosion Rate by Land Use, Pantabangan and Canili-Diayo Watershed, 1977.

Kaingin/Diversified Cropland		Grassland/Savannah		Primary/Secondary Forest		Irrigated/Rainfed Riceland	
P	P_2O_5	P	P_2O_5	P	P_2O_5	P	P_2O_5
45.38	103.91	11.13	25.50	0.62	1.41	.017	.038
44.14	101.08	10.18	23.31	0.62	1.41	.017	.038
38.91	[illegible].10	8.97	20.54	0.54	1.25	.017	.038
38.91	89.10	8.83	20.22	0.54	1.25	.017	.038
13.85	31.73	5.04	11.53	0.45	1.03	.018	.041
17.85	.73	5.04	11.53	0.45	1.03	.018	.041
13.85	31.73	5.04	11.53	0.37	0.86	.017	.040
13.85	31.73	5.04	11.53	0.36	0.83	.017	.040
13.85	.73	5.54	12.68	0.36	0.83	.017	.040
13.85	31.73	5.54	12.68	0.36	0.83	.017	.040

Table 2.21. Potassium and Muriate of Potash (K20) Equivalent Lost (kg/ha/yr) From Each Soil Layer, Given Constant Erosion Rate by Land Use, Pantabangan and Canili-Diayo Watershed, 1977.

Soil Depth (cm)	Kaingin/Diversified Cropland		Grassland/Savannah		Primary/Secondary Forest		Irrigated/Rainfed Riceland	
	K	K_2O	K	K_2O	K	K_2O	K	K_2O
0-5	431.60	517.91	174.65	209.57	3.72	4.47	.152	.183
5-10	431.60	517.91	174.65	209.57	3.55	4.26	.152	.183
10-15	431.60	517.91	138.04	165.65	3.15	3.78	.152	.183
15-20	357.36	428.83	119.75	143.70	2.88	3.45	.150	.179
20-25	251.71	302.05	96.20	115.44	2.15	2.58	.118	.141
25-30	231.76	278.11	93.78	112.54	2.15	2.58	.117	.140
30-35	231.76	278.11	93.78	112.54	2.15	2.58	.117	.140
35-40	231.76	278.11	93.78	112.54	2.28	2.73	.084	.101
40-45	231.76	278.11	93.78	112.54	2.28	2.73	.084	.101
45-50	159.03	190.83	93.78	112.54	2.28	2.73	.037	.044

Table 2.22. Nitrogen and Urea Equivalent Lost (kg/per ton) of Eroded Soil From each Soil Layer, Given Constant Erosion Rate by Land Use, Pantabangan and Canili-Diayo Watershed, 1977.

Soil Depth (cm)	Kaingin/Diversified Cropland		Grassland/Savannah		Primary/Secondary Forest		Irrigated/Rainfed Riceland	
	N	Urea	N	Urea	N	Urea	N	Urea
0-5	1.09	2.43	1.20	2.66	1.35	3.00	0.90	2.01
5-10	1.08	2.40	1.18	2.62	1.35	3.00	0.90	2.01
10-15	1.06	2.36	1.10	2.44	1.24	2.76	0.88	1.95
15-20	1.02	2.26	1.04	2.30	1.24	2.76	0.86	1.92
20-25	0.58	1.30	0.79	1.75	0.86	1.90	0.77	1.71
25-30	0.57	1.28	0.78	1.72	0.86	1.90	0.77	1.71
30-35	0.56	1.24	0.74	1.64	0.71	1.57	0.63	1.40
35-40	0.56	1.24	0.74	1.64	0.71	1.57	0.63	1.40
40-45	0.56	1.24	0.73	1.62	0.67	1.49	0.58	1.28
45-50	0.50	1.24	0.73	1.62	0.67	1.49	0.58	1.28

Table 2.23. Phosphorus and Solophos (P205) Equivalent Lost (kg) per ton of Eroded Soil, Given Constant Erosion Rate by Land Use, Pantabangan and Canili-Diayo Watershed, 1977.

Soil Depth (cm)	Kaingin/Diversified Cropland		Grassland/Savannah		Primary/Secondary Forest		Irrigated/Rainfed Riceland	
	P	P_2O_5	P	P_2O_5	P	P_2O_5	P	P_2O_5
0-5	0.11	0.24	0.06	0.13	0.29	0.66	.060	.139
5-10	0.10	0.24	0.05	0.12	0.29	0.66	.060	.139
10-15	0.09	0.21	0.05	0.10	0.25	0.58	.060	.139
15-20	0.09	0.21	0.04	0.10	0.25	0.58	.060	.139
20-25	0.03	0.07	0.03	0.06	0.21	0.48	.064	.147
25-30	0.03	0.07	0.03	0.06	0.21	0.48	.064	.147
30-35	0.03	0.07	0.03	0.06	0.17	0.39	.063	.144
35-40	0.03	0.07	0.03	0.06	0.17	0.39	.063	.144
40-45	0.03	0.07	0.03	0.06	0.17	0.39	.063	.144
45-50	0.03	0.07	0.03	0.06	0.17	0.39	.063	.144

Table 2.24. Potassium and Muriate of Potash (K20) Equivalent Lost (kg/ per ton) of Eroded Soil, Given Constant Erosion Rate by Land Use, Pantabangan and Canili-Diayo Watershed, 1977.

Soil Depth (cm)	Kaingin/Diversified Cropland		Grassland/Savannah		Primary/Secondary Forest		Irrigated/Rainfed Riceland	
	K	K_2O	K	K_2O	K	K_2O	K	K_2O
0-5	1.01	1.21	0.88	1.05	1.73	2.08	0.545	0.654
5-10	1.01	1.21	0.88	1.05	1.65	1.98	0.545	0.654
10-15	1.01	1.21	0.70	0.84	1.46	1.76	0.545	0.654
15-20	0.83	1.00	0.61	0.73	1.34	1.61	0.534	0.641
20-25	0.59	0.70	0.49	0.59	1.00	1.20	0.421	0.505
25-30	0.54	0.65	0.47	0.56	1.00	1.20	0.417	0.501
30-35	0.54	0.65	0.47	0.56	1.00	1.20	0.417	0.501
35-40	0.54	0.65	0.47	0.56	1.06	1.27	0.301	0.361
40-45	0.54	0.65	0.47	0.56	1.06	1.27	0.301	0.361
45-50	0.37	0.45	0.47	0.56	1.06	1.27	0.131	0.157

This follows from the fact that erosion is so slow in these areas such that only the top 5-cm layer is being eroded over the time period given. Hence, nitrogen loss is constant at 2.91 tons and 0.25 tons per hectare per year for forest and ricelands, respectively.

Cumulative nitrogen losses for kaingin/diversified croplands and for grassland/savannah areas show the expected curvilinear graphs since erosion in these areas would have reached the lower 50-cm depth of the profile within 15 and 30 years, respectively. The rate of nitrogen loss declines through time as erosion removes the less fertile materials of the soil horizons.

Kaingin and diversified croplands consistently show the greatest amounts of nutrient loss per hectare primarily because the rate of soil loss is also highest in these areas. Loss of nutrients per hectare is next highest in grasslands/savannah, followed by forest areas and least in riceland areas (see Tables 2.19 to 2.24).

The amounts of nutrients lost per ton of soil eroded depend more on the nutrient content of the soil rather than on the actual rates of erosion. It was expected that the inherent fertility status of soils would vary significantly across land uses. However, the soils data used failed to reflect this. The values shown in Tables 2.22 to 2.24 indicate small differences in nutrient content of lost soils among the four land uses.

Valuation of Lost Nutrients

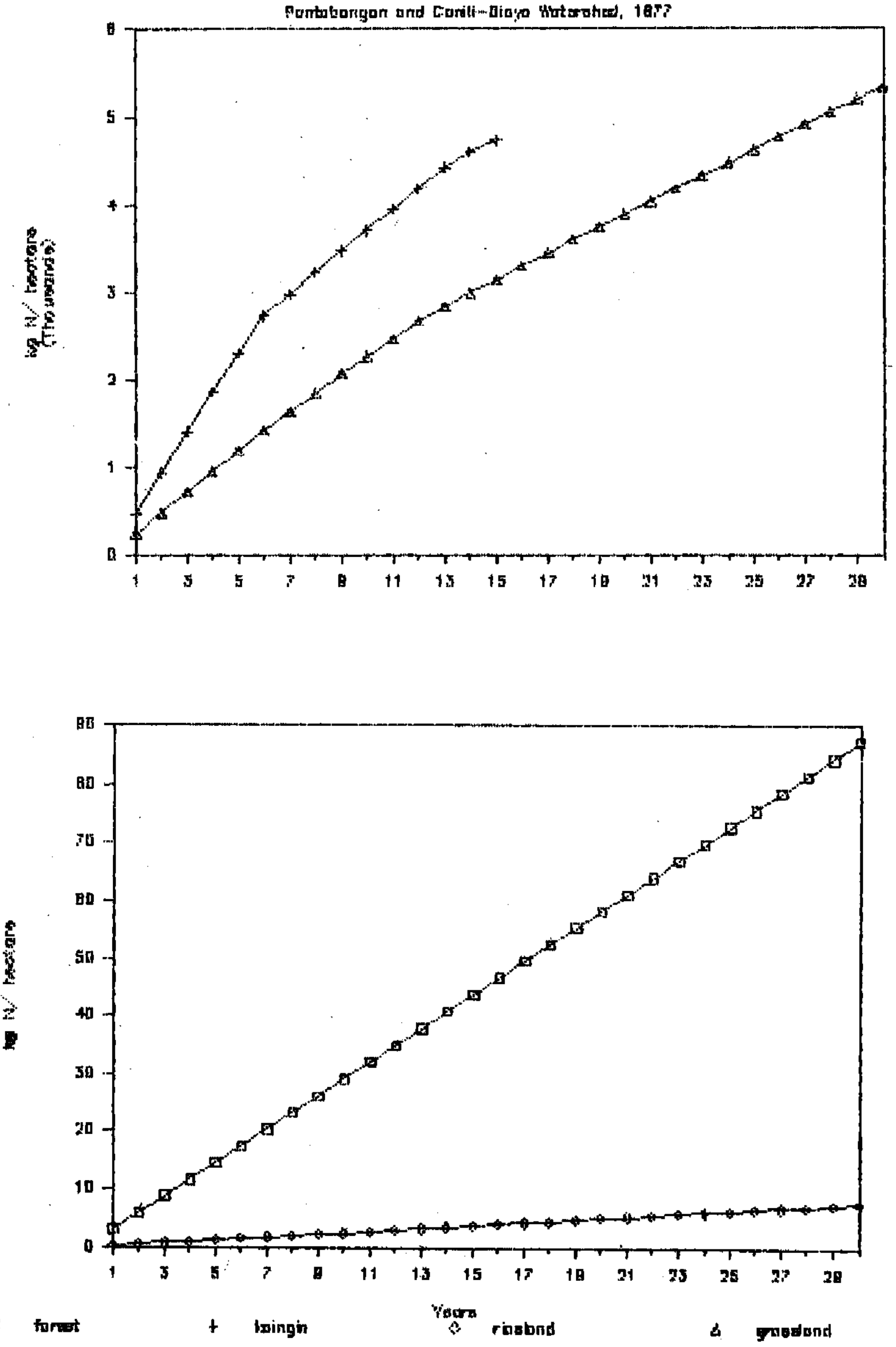
The methodology developed has, so far, only quantified the on-site physical losses (i.e., kilograms of nutrients and fertilizer equivalents) due to erosion. Valuation of these losses using appropriate prices is the next step. The most straightforward approach would be to just use the market prices of fertilizers to value the fertilizer equivalents of the lost nutrients. Or, shadow prices of these fertilizers may be used. These are obtained by correcting the market prices of fertilizer for price distortions, subsidies or direct transfers, transportation costs, etc., in order to reflect the true costs of these fertilizers to society.

Since the primary concern in this study is the on-site economic impacts of accelerated erosion, then it is reasonable to value only the nutrients lost from areas in the watershed where such type of erosion is critical. These are mainly in the kaingin, diversified cropland, grassland, and savannah areas. Tables 2.25 and 2.26 show the computed replacement values of lost nutrients in terms of urea, solophos (P_2O_5), and muriate of potash (K_2O) equivalents. These replacement costs were obtained by multiplying the amounts of fertilizers reflected in Tables 2.19 to 2.24 by their respective shadow prices. The economic (shadow) prices used were ₱2.05, ₱0.98, and ₱1.47 per kilogram of Urea, P_2O_5 and K_2O, respectively. (See Appendix 2.10 for the derivation of these prices.)

Figure 2.6

Cumulative Nitrogen Lost Through Time (by Land Use)

Pantabangan and Canili-Diayo Watershed, 1977



For each land use, the total value of nutrients lost per hectare and per ton of eroded soil is computed by summing across the three nutrients. As expected, the total replacement cost decreases from the top to the bottom layer of the soil profile. There is only a slight difference in the replacement cost per ton of soil lost between kaingin and grassland areas, again because the original soils data used did not reflect significant differences in inherent fertility status among land uses. Replacement cost per hectare, on the other hand, is significantly higher in kaingin than in grassland areas because of higher rates of erosion in the former.

The values reflected in Table 2.26 could be used to make an indicative assessment of the on-site cost of erosion from the entire Pantabangan and Canili-Diayo watersheds. Considering the first 5-cm layer of soil, a total of ₱2,541 and ₱1,411 per hectare have been computed as the replacement costs of nutrients from kaingin and grassland areas, respectively. Given that the total areas under these two land uses are 2,942 and 35,662 hectares as per the Bureau of Soils Reconnaissance Survey, then the total value of nutrients lost (if erosion is taking place from the first 5-cm layer of the top soil) amounts to approximately ₱57.8 million per year (2942 has. x ₱2,541/ha + 35,662 has x ₱1,411/ha). This is still a conservative estimate since only sheet erosion has been included. Note, however, that the total replacement cost per hectare (and for the entire watershed) would be diminishing over time as erosion reaches the lower soil horizons.

Table 2.25 Replacement Cost of Lost Nutrients per ton of Eroded Soil.

Soil Depth	Kaingin/diversified Cropland				Grassland/Savannah			
	Urea	P_2O_5	K_2O_5	Total	Urea	P_2O_5	K_2O_5	Total
0-5	4.98	0.24	1.78	7.00	5.45	0.13	1.54	7.12
5-10	4.92	0.24	1.78	6.94	5.37	0.12	1.54	7.03
10-15	4.84	0.21	1.78	6.83	5.00	0.10	1.23	6.33
15-20	4.63	0.21	1.47	6.31	4.72	0.06	1.07	5.85
20.25	2.66	0.07	1.03	3.76	3.59	0.06	0.87	4.52
25-30	2.62	0.07	0.96	3.65	3.53	0.06	0.82	4.41
30-35	2.54	0.07	0.96	3.57	3.36	0.06	0.82	4.24
35-40	2.54	0.07	0.96	3.57	3.36	0.06	0.82	4.24
40-45	2.54	0.07	0.96	3.57	3.32	0.06	0.82	4.24
45-50	2.54	0.07	0.66	3.57	3.32	0.06	0.82	4.24

Table 2.26. Replacement Cost(₱) of Lost Nutrients per hectare of Land Use.

Soil Depth	Kaingin/diversified Cropland				Grassland/Savannah			
	Urea	P_2O_5	K_2O	Total	Urea	P_2O_5	K_2O	Total
0-5	2131.43	101.83	308.07	2541.33	1078.07	24.99	308.07	1411.13
5-10	2116.67	99.06	308.07	2523.79	1063.58	22.84	308.07	1394.49
10-15	2076.81	87.32	243.51	2407.64	989.02	20.13	243.51	1252.66
15-20	1981.78	87.32	211.24	2280.33	934.31	19.82	211.24	1165.36
20-25	1138.65	31.10	169.70	1339.44	710.98	11.30	169.70	891.98
25-30	1120.53	31.10	165.43	1317.06	698.87	11.30	165.43	875.60
30-35	1086-52	31.10	165.43	1283.05	664.63	11.30	165.43	841.36
35-40	1086.52	31.10	165.43	1283.05	664.63	11.30	165.43	841.36
40-45	1086.52	31.10	165.43	1283.05	657.25	12.43	165.43	835.11
45-50	1086.52	31.10	165.43	1283.05	657.25	12.43	165.43	835.11

Assumptions and Limitations of Procedure

The values presented in the preceeding sections are only as good as the soils data used. Thus, one major limitation of the methodology is the insufficiency of the data base necessary to conduct the analyses. The results of the soil chemical analyses undertaken by the Bureau of Soils during their reconnaissance soil survey of the watershed in 1977 were questionable in some instances. Inconsistent and discontinuous sampling layers were taken from the soil auger borings such that there were portions of the profile where no data for OM, P, and K were available. In these cases data from the lower layer of soil auger sample and from pit borings were used to represent the missing data for the profile.

Other limitations and assumptions of the methodology are summarized below:

(1) Each soil mapping unit (SMU) is homogeneous with respect to soil characteristics. This allowed the use of the same soil chemical analyses data for different land use types within the same SMU.

(2) Nutrient content (i.e., fertility level) of soils decreases over the soil horizons. This means that a non-linear relationship exists between soil loss and nutrient loss. In the absence of a continuous function relating soil depth with nutrient content, the soil profile was divided into 5-cm layers

of 5-cm was chosen because it was the smallest sampling depth taken by the Bureau in their soil auger borings.

(3) No chemical fertilizers are being applied and therefore the nutrient content of the profile represents the inherent fertility of soils in the area. This assumption holds true particularly for grassland and forest areas and for kaingin areas where virtually no fertilization is practiced. For riceland areas, however, the computed nutrient losses may have included loss of artificially applied fertilizers.

(4) Only the major nutrients (N, P, K) are considered even though other nutrients (e.g., micronutrients) contribute to soil fertility/productivity. Moreover, the decrease in water-holding capacity of the soil as erosion removes each soil layer was not included as an on-site cost. It is recognized that erosion effects on this particular soil property is an important avenue for on-site productivity decline. However, insufficient data base did not permit inclusion of this cost in the estimation procedure.

(5) The total N, P, and K in the soil were used as bases for computing the fertilizer equivalents of lost nutrients, although only a small fraction of these totals (e.g., around 10% in the case of N) are potentially mineralizable (i.e., has fertilizing value) for a given cropping season. This was done in order to capture the total loss in nutrients associated with the loss of soil layers. The rationale is that had thes

been retained, then they could have provided nutrients as much as the total N, P, K available in the soil through time.

(6) Constant erosion rates in tons/ha/yr is assumed to occur over time. Natural regeneration rate of the soil is considered to be zero. Hence, the estimated losses of soil (and therefore of nutrients and fertilizers) are gross amounts. If there is a positive rate of soil formation, then the net loss of soil is actually lesser than what has been computed in this study.

(7) Computation of erosion rate in terms of soil depth lost is highly influenced by assumptions on bulk density. The data from the Bureau of Soils survey in 1977 did not include bulk density information throughout the soil profile. Instead, data taken by Sabio in 1981 for the four soil series were adopted for the SMU's in each soil series. Bulk density is higher for cultivated areas compared to undisturbed areas, but assumed to remain constant over the soil profile. It is more realistic to consider that bulk density increases with soil depth, i.e. soil becomes more compact from the top to the bottom of the soil profile. Since this was not assumed in this case, then there is an overestimation of the actual depth of soil removed especially as erosion reaches the lower soil horizons. A constant depth of soil removal (cm/yr) was assumed through time and throughout the profile, though in reality, it is expected to decrease further on in the future when erosion reaches the lower horizons. At that time, there would not be as much

erodible materials compared to the upper soil layers, since the soil is more compacted and less erosive.

In computing for the soil profile nutrient content, however, the assumption of constant bulk density in the profile results to a slight underestimation. If a higher bulk density is assumed for the lower soil layers, then this would mean a higher amount of nutrient content per unit volume of soil.

(8) The rate of natural or geologic erosion, corresponding to the erosion rate computed for forest areas, is not deducted from the estimated erosion rates for grasslands/savannahs and kaingin/diversified croplands. Thus, the losses of soil, nutrients, and fertilizers from these areas that are actually due to accelerated erosion should be smaller than the losses reported here.

Concluding Remarks

The primary objective of this paper is to present a methodology for estimating on-site economic losses due to erosion in the Pantabangan and Canili-Diayo watersheds. The replacement cost approach used has been tailored according to the quality and quantity of available information. As a first approximation, the method was able to show declining marginal losses of nutrients due to erosion over time and over the soil profile. These losses were also found to vary significantly across land uses, mainly due to significant differences in estimates of erosion rates.

Kaingin and diversified cropland areas showed the highest rate of soil loss and consequently, the highest amounts of nutrients lost. Grassland and savannah areas rank second in terms of soil loss and nutrient loss. Estimated erosion rate is much lower for forest areas indicating that forest cover is still the most effective means of controlling erosion in steep slopes. Practically zero erosion occurs in the low-lying areas devoted to irrigated and rainfed rice.

Valuation of the nutrient losses could be undertaken by using either market or shadow prices of their inorganic or chemical fertilizer equivalents. This step was not undertaken anymore since it is just a matter of multiplying the amounts of fertilizers lost by their respective unit (shadow) prices in order to derive the total value of on-site economic loss due to erosion from a given land use and from the entire watershed area.

Provided that a sufficient data base could be generated, the approach developed here could give reliable indication of the economic costs of soil loss. The approach is simple and does not require elaborate computations, and is very feasible under Philippine situation.

NOTES

1. A soil series is a group of soils having similar horizon characteristics and arrangement in the soil profile.

2. Example of a soil mapping unit is AmGD3. Am stands for the soil series,, G for texture, D for slope and 3 for erosion class.

3. Some discrepancies were observed between the delineated SMU areas according to the soil polygon method used by W. David and the SMU areas delineated by the Bureau of Soils. To reconcile these results, only those SMUs identified by both maps as belonging to a given land use were included in the sample for that land use.

4. The original data were given in g/cm^3 of soil. To convert this into t/ha-cm, the following formula was used:

$$t/ha\text{-}cm = g/cm^3 \times 10^8\ cm^3/ha\text{-}cm \times ton/10^6\ g$$

5. Based on Caramancion (1971).

6. Bulk density in ton/ha-cm.

7. Urea is 45% N.

8. Available P = 1.28% Total P (Oagmat), 1980).

9. Exchangeable K = 10% Total K (Bonoan, 1984).

10. In case of other land uses (e.g. kaingin and grasslands with much higher rates of erosion the annual loss of nutrients (fertilizer equivalents) are determined by first computing the number of years it takes to lose each 5-cm soil layer and then using the corresponding values of nutrients (fertilizer equivalents) lost per hectare, depending on the soil layer being eroded at the particular year under consideration.

11. Ideally this rate of natural erosion should be deducted from the computed erosion rates for the kaingin and grassland areas in order to arrive at the erosion rates actually due to land modifications. This was not undertaken since the computed natural rate is very minimal compared to the total erosion rate estimated for these land uses.

12. The succeeding discussions focus on nutrient losses. Basically the same discussions could be said about their fertilizer equivalents since these values only differ by some conversion factors.

CHAPTER III
THE DOWNSTREAM COST OF SOIL EROSION

The off-site economic impact of erosion centers on its role in the sedimentation of the Pantabangan and Magat reservoirs. Through sedimentation of the reservoir, erosion reduces the potential irrigation, hydroelectricity, and flood control benefits of the project. This reduction in potential benefit is in terms of (a) shorter reservoir and dam service life, (b) the opportunity cost of providing for excessive sediment storage capacity, and (c) reduction in useful storage capacity of the reservoir. Strictly, in the case of the two reservoir systems we are discussing, which are on-going projects, the environmental costs associated with (b) are sunk costs while those associated with (a) and (c) are amenable to policy, being linked to incremental erosion. It is nevertheless instructive to assess the cost of (b) since these are quite large and should be of relevance for new construction projects. We present estimates for (a) and (b) for the case of Magat and estimates for (a) to (c) for the case of Pantabangan.

I. OFF-SITE ECONOMIC EFFECTS OF EROSION IN THE MAGAT WATERSHED

Reduction in Project Life

At any given rate of sedimentation, the yearly sediment input in the reservoir may be computed by multiplying sediment yield in tons per hectare per year by the reservoir's trap efficiency (assumed to be 93%) and by the size of the watershed area. The value obtained is then divided by 1.3 tons which measures the specific weight of a cubic meter of sediment. This gives the annual volume of sediment input that must be absorbed by the reservoir.

The sediment pool capacity for Magat was designed for an annual rate of 20 t/ha/yr of sedimentation. However, a follow up study (Madecor, 1982) determined that a higher sedimentation rate of 34.5 t/ha/yr was occurring. At the design sedimentation rate of 20 t/ha/yr, the reservoir was expected to remain operational for 95 years (after which time, the sediments will block the outlet works of the dam). The new erosion rate means, however, that the operational life of the reservoir will only be 55 years.

Table 3.1 presents the data for the computation of foregone benefits associated with the loss of 40 years of reservoir operation. While the real social discount rate might certainly be lower, we use a discount rate of 15%, since this is the rate with which most current projects are assessed. (This is also in line with our strategy of choosing to be conservative with respect to the valuation of environmental costs. Using a discount rate of 15%, the present value of the net irrigation and hydro-power benefits that are lost due to the reduced service

Table 3.1. Present Value of Foregone Benefits Associated with a Reduction in the Reservoir's Service Life (in P1,000)

Year	Total Cost	Total Benefit	Net Benefit
64-65	10,256	275,903	265,647
66	26,042	275,903	249,861
67-85	10,256	275,903	265,647
86	29,356	275,903	246,647
87-103	10,256	275,903	256,647

Net Present Value (at 15% interest) = 262,623

Notes:

1. The undiscounted irrigation and power benefits remain the same for the years before Year 64.
2. There is no change in the operating and maintenance expenses.
3. The second replacement for pumps, transformers, and electrical equipment will take place in Year 66, and that of turbines and generators will take place in Year 86.

life of the reservoir is ₱262,623, with an annualized value (for 50 years) of about ₱39,430. This foregone value is directly caused by the additional 14.5 t/ha/yr contributed by the 406,960 hectares watershed area. On a per hectare basis, the cost of this added sedimentation is about ₱0.10 per year, or P0.01 per year per ton of new sediment input.

Losses due to Opportunity Cost of Sediment Pool

In the Magat River Project Feasibility Report (1973), the reservoir is expected to provide full water supply to 95,100 hectares of irrigable land amounting to an average annual volume of 2060 million cubic meters of water. With some allowance for conveyance losses, this means that the amount of water needed for a hectare of farmland is about 21,661 cubic meters per year. The average irrigation requirement of the different land classes in the Magat service area by cropping season, for rice lands, was estimated at 16,299 cubic meters per hectare per year (with 6,933 cubic meters per hectare for the wet season and 9,366 cubic meters per hectare for the dry season).

This average irrigation requirement of 16,299 cubic meters per hectare per year is approximately 75% of the annual per hectare irrigation releases of 21,661 cubic meters. This means that, in general, the conveyance efficiency of the irrigation canals is set at about 75% or that a conveyance loss of 25% is allowed for in the system. Note that we are assuming here that the design irrigable hectarage is based on the sum of irrigation needed per hectare for an entire year. In fact, the design command area will probably be based on a reasonable area that can be irrigated during the dry season.

The sediment storage capacity of the Magat reservoir is about 500 million cubic meters (MCM). Since the annual per hectare water releases from the reservoir is 21,661 cubic meters, the number of potential irrigated hectares that has been supplanted by the sediment pool is about 23,086 (or 500 MCM /21,661 cubic meters per hectare). The loss of this potentially irrigable hectarage due to the requirement of setting aside 500 million cubic meters of storage capacity for the sediment pool has social cost implications since additional hectarage can, in fact, be added to the command area.

The crop yield differences between irrigated and non-irrigated rice lands are about ₱1,740 per hectare during the wet season and about ₱4,691 per hectare for the dry season. The total difference is therefore about ₱6,431 (or ₱1,740 + ₱4,691) per hectare per year. Since the irrigated hectarage lost is about 23,086, the loss in yield due to the sediment pool is therefore about ₱148,787,000 (or ₱6,431 X 23,086) per year.

Since the estimated sediment input rate was 20 t/ha/yr, for the 406,960 hectares in the watershed, the total sediment input per year is 8,139,200 tons. The loss associated with sedimentation is therefore about ₱365.61 per hectare or ₱18 per ton per year [₱148,787,000 / (20 X 406,960)]. Note that not all of this represents true opportunity cost since some amount of the 20 t/ha/yr of sedimentation will be due to upstream erosion that will represent the minimal natural erosion rate.

To summarize the off-site cost in Magat on a per ton basis, the reduction in project life due to additional sedimentation from 20 to 34.5 t/ha/yr is only about ₱0.01/t/yr. However the irrigation losses due to the need for a sediment pool to absorb 20 t/ha/yr is about ₱18/t/yr. Estimates for losses due to opportunity cost of sediment storage in terms of reduced power generation capacity in the Magat system are not presented since these were limited by data problems.

II. OFF-SITE ECONOMIC EFFECTS OF EROSION IN THE PANTABANGAN WATERSHED

Background Information

The Upper Pampanga River Project may be divided into three major phases namely: (1) the construction of the Pantabangan dam and appurtenant structures, (2) the irrigation phase and (3) the power phase. Construction of the Pantabangan dam complex, which is the heart of the project, began in March 1971 and was completed in August 1974. Tables 3.2 and 3.3 show the main features of the Pantabangan dam and reservoir.

The irrigation phase of the UPRP involved the development of new irrigation facilities and rehabilitation of existing ones. The service area of the UPRP was originally about 82,469 hectares, excluding built-up areas, waterways, roads, etc. Of this total, new irrigation systems covered 35,152 hectares, while rehabilitated systems covered 47,317 hectares.

Table 3.2. Statistical Data on Pantabangan Dam.

Type	Zoned-earthfill
Height Above Streamed	107.0 meters
Volume of Embankment	12.3 MCM
Crest Length	1610.0 meters
Crest Elevation	232.0 meters
Maximum Water Surface Elevation	230.0 meters
Top of Flood Control Pool	221.0 meters
Top of Conservation storage	216.0 meters
Top of Dead Storage (Intake inlet sill elevation)	171.5 meters
Base Width at Maximum Section	480.0 meters
Crest Width	12.0 meters
Mean Annual Inflow	1375.0 MCM

As an extension of the UPRP, the Aurora-Penaranda Transbasin Diversion Project (APIP) was undertaken to augment the water supply to the Pantabangan reservoir. Dams were constructed across the Canili and Diayo rivers that drain the Aurora Basin, to enable a transbasin transfer of water to the Pampanga River basin through a diversion channel. The APIP also included the rehabilitation of existing and construction of new irrigation systems. This subsequently increased the service area of the Upper Pampanga River Integrated Irrigation System (UPRIIS) to more than 100,000 hectares when the diversion complex was completed in July 1976. As indicated in Table 3.4 and illustrated in Figure 3.1, the current area coverage of the four irrigation districts under the UPRIIS and served by the Pantabangan dam is about 103,000 hectares. Another related related project that is now being proposed is the Casecnan Transbasin Diversion Project. This project plans to divert the excess water in the Cagayan Basin to the Pantabangan reservoir through the construction of two 27-kilometer long tunnels. A power plant that would utilize the available head is also proposed at the end of these tunnels. Once completed, this project will increase the UPRIIS service area to around 150,000 hectares and generate additional electric power.

Table 3.3. Statistical Data on Pantabangan Reservoir.

	Elevation (m.)	Surface Area (has.) [1]	Volume of Storage (MCM)
Maximum water surface	230	8420	2996
Surcharge pool	221-230	8420	688
Flood Control Pool	216-221	6962	330
Conservation Pool (irrigation and power)	171.5-216	6309	1753
Inactive Storage and Sediment Storage	140-171.5	1764	225
Dam Bottom	140		

[1] At top elevation of each storage pool.

Source: NIA, 1977 (UPRP Completion Report).

Table 3.4. UPRIIS Service Area by District.

District	Service Area (hectares)	Places covered	Systems Operated
I	24,803.24	Nueva Ecija: San Jose, Talavera, Sto. Domingo, Quezon Licab, Munoz, Llanera	TRIS, LTRIS, SAE, SDA
II	24,782.68	Nueva Ecija: Talavera, Rizal, Gen. Natividad, Aliaga, Llanera, Cabanatuan	PRIS, RMA, LTRIS, VCIS, MCCIS
III	28,400.01	Nueva Ecija: Cabanatuan, Sta. Rosa, San Leonardo, Penaranda Aliaga, General Natividad	PBRIS (proper & extension,) Platero, PCCIS & Aliaga
IV	25,300.00	Nueva Ecija: Penaranda, Gapan San Isidro, Cabiao Pampanga: Arayat and Candaba Bulacan: San Miguel & San Ildefonso	PENRIS (proper & extension)
TOTAL	103,285.93 hectares		

Source: UPRIIS, Cabanatuan City.

Part of the original World Bank (IBRD) loan for the UPRP was the incorporation, in the initial construction, of provisions for the addition of power generating facilities at the Pantabangan dam. A detailed engineering study was completed in August 1970 and authorization for the power phase was granted in December 1973. Construction started in 1974 and was completed in early 1977.

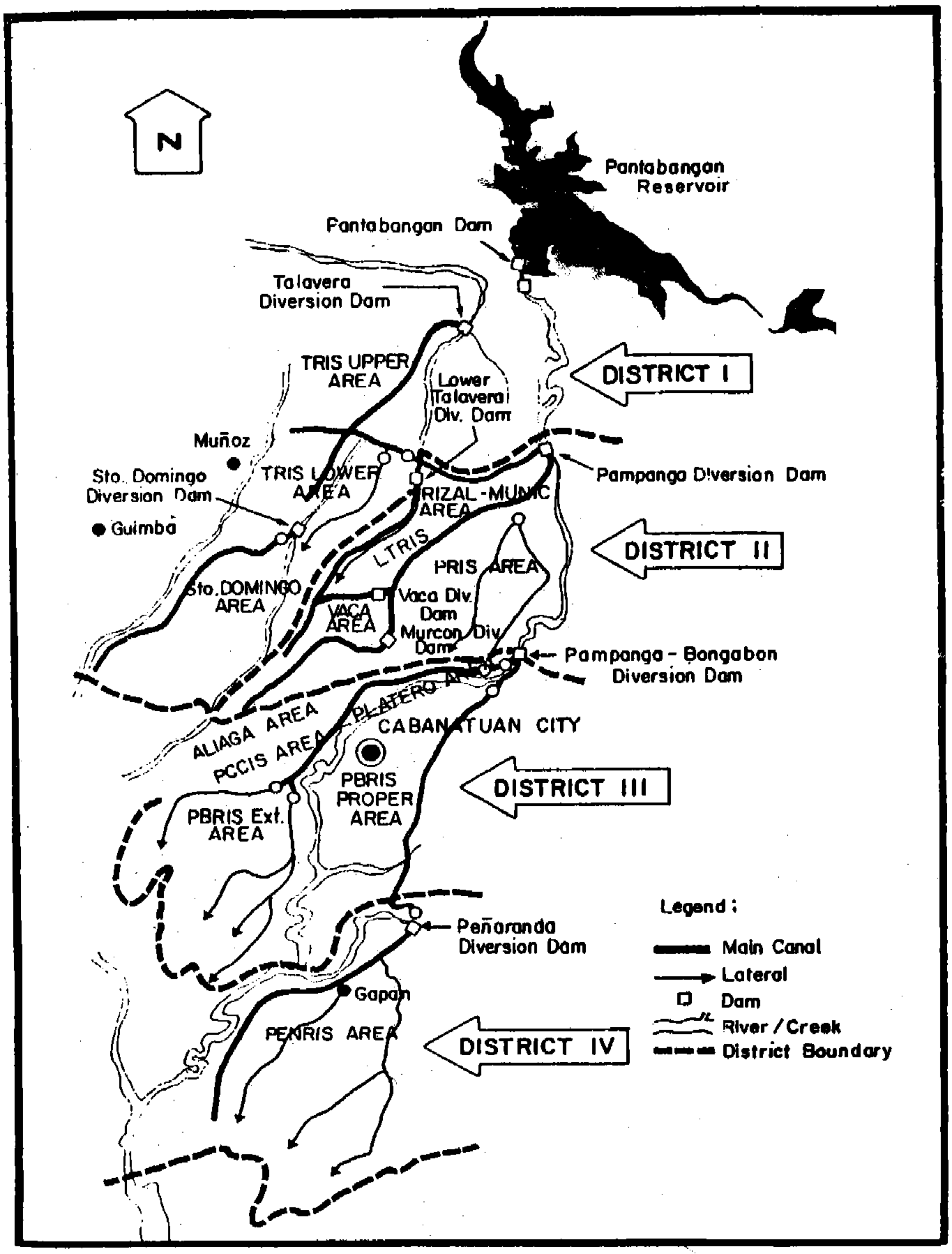


Fig. 3.1 The Upper Pampanga River Integrated Irrigation Systems and Pantabangan Reservoir, Nueva Ecija.

The main components of the Power Phase are (1) the Pantabangan hydroelectric power plant equipped with two 50-MW power generating units, located at the downstream toe of Pantabangan dam and at the outlet of Diversion Tunnel No. 2; (2) the 230 (kilowatt) outdoor package type switchyard; (3) the 230 KV transmission line to the existing (National Power Corporation) grid at Muñoz, Nueva Ecija; and (4) the Masiway re-regulation dam. The latter is located 5 kilometers downstream from the Pantabangan dam and power plant and intended to re-regulate the daily fluctuations in power releases for uniform release into the irrigation system.

Reduction in Service Life of the Pantabangan Dam and Reservoir

In the initial feasibility report of the UPRP, the U.S. Bureau of Reclamation estimated the sediment inflow into the Pantabangan reservoir based on periodic sampling of suspended sediment loads from July 1960 through 1963 at the Pantabangan, Carranglan, and Pampanga River gages. A composite rating curve was constructed for the Pampanga river at the damsite which enabled them to estimate a 100-year sediment volume of 130 MCM (USBR, 1966). Figure 3.2 shows a schematic of the Pantabangan reservoir and the allocations of its storage capacity. In the final design of the dam, an inactive storage of 95 MCM was incorporated together with a sediment pool of 130 MCM. Thus, the total volume of storage which falls below the level of the intake sill (of the power and irrigation diversion tunnels) at elevation

171.5 m, is around 225 MCM. This volume of storage, in effect, represents the total dead storage of the reservoir.

The 100-year sediment input of 130 MCM corresponds with an annual sediment inflow of 1.3 million cubic meters into the Pantabangan reservoir. Assuming a specific weight of 1.3 tons/per cubic meter for the deposited sediments and a total watershed area of 82,894 hectares above the reservoir, gives a sediment yield of around 20 tons/ha/year from the watershed (see Table 3.5). Thus like the Magat dam, the Pantabangan dam was originally designed to accommodate 20 t/ha/yr of much sediment. With a sediment storage of 130 MCM, the service life is projected at 100 years. However, since an allowance was made for a 95 MCM inactive storage (which could also be filled with sediments), then the service life is prolonged to around 173 years (225 MCM 1.3 MCM/yr).

An updated estimate of sediment inflow and deposition into the Pantabangan reservoir for 1977 was given in David (1987). Based on the computed average sheet and rill erosion rate of 108 tons/ha/yr from the entire Pantabangan and Canili-Diayo watershed area a gross erosion rate of 270 tons/ha/yr was estimated (with the assumption that land slip, gully and channel erosion represents around 60% of total erosion). With a sediment delivery ratio of 30%, a sediment yield of 81 tons/ha/yr was estimated. Given a trap efficiency of 95%, the annual sediment deposition in the Pantabangan reservoir was computed to be about 77 tons/ha/yr or a total of 4.9 MCM/year from the entire

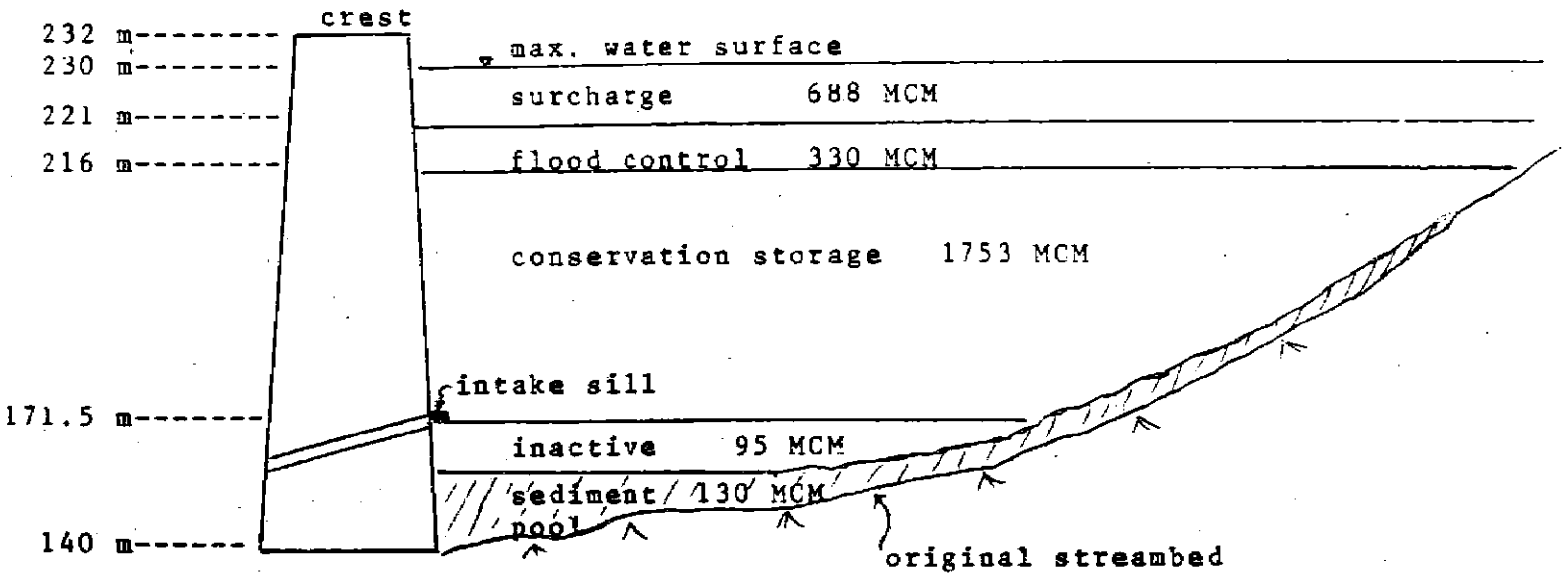


Figure 3.2 Pantabangan Reservoir Storage Allocations

watershed area of 82,894 hectares. At this rate of sedimentation, the service life of the dam and reservoir is reduced to 46 years (i.e., 225 MCM divided by 4.9 MCM/yr).

Table 3.5. Computation of Service Life of Pantabangan Dam and Reservoir.

Item	Based on USBR 1966 Feasibility Report on UPRP	Based on W. David Erosion Estimates for 1977
Rill and sheet erosion rate	-	108 tons/ha/yr[c]
Gross erosion rate	-	270 tons/ha/yr[d]
Sediment delivery ratio	-	30%[e]
Sediment yield	20 tons/ha/yr[a]	81 tons/ha/yr[f]
Area of watershed above Pantabangan reservoir[b]	82894 has.	82894 has.
Specific weight of sediment	1.3 tons/m^3	1.3 tons/m^3
Reservoir sedimentation rate	1.3×10^6 m^3/yr[a] (1.7×10^6 tons/yr)	4.9×10^6 m^3/yr[g] (6.4×10^6 tons/yr)
Volume of dead storage (inactive and sediment pool)	225 MCM	225 MCM
No. of years to fill dead storage	173 years	46 years

Notes:

a. Computed based on reported 100-year sediment volume inflow into the Pantabangan reservoir of 130 MCM or 1.3×10^6 m^3/year sedimentation rate, assuming all these sediments are trapped in the reservoir.

b. This is watershed area excluding unevaluated areas if 750 hectares and reservoir area of 8006 hectares as per planimeter measurement of David, et.al. (1987). The drainage area used in the original USBR feasibility report is 845 km^5 or 84500 hectares.

c. Estimated average for the entire watershed area of 82894 hectares using the modified USLE.

d. Sheet and rill erosion is assumed to be 40% of gross erosion.

e. See David (1987) p. 27.

f. This is about the same as the maximum estimate of sediment yield by the ECI for 1977.

g. Based on 95% trap efficiency of the reservoir and assumption that all sediments are deposited into dead storage.

Thus assuming an original service life of 100 years, the foregone benefits associated with the 61 tons/ha/yr increase in sediment yield (i.e., 81 t/ha/yr minus 20 t/ha/yr), may be computed by taking the present value of the net benefits associated with the 54 years of project life that were lost.

Table 3.6 summarizes the computation of the cost associated with reduced service life of the dam and reservoir. Using the nominal values of total project cost and benefit for years 47 to 100 as those indicated in the economic analysis of the UPRP (given in Appendix 3.1, Table 1), the annual net benefit of the project is ₱406.82 million. With 15% discount rate, the present value of this stream of net benefits is ₱4.375 million. The annualized value of foregone benefit is ₱0.656 million, which is directly caused by the additional 4.7×10^6 tons of sediment input into the reservoir (i.e., 6.4×10^6 t/yr less 1.7×10^6 t/yr, as shown in Table 3.5. The cost of this added sedimentation is therefore around ₱7.91 per hectare (i.e., ₱0.656 $\times 10^6$ divided by 82,894 hectares) and ₱0.14 per ton of new sediment (i.e., ₱0.656 $\times 10^6$ divided by 4.7×10^6 tons).

Note that the projected service life of 46 years would apply on the assumption that all the sediment input into the reservoir are deposited in the dead storage pool. However, as shown by data from Ambuklao and Binga dams, a large percentage -- sometimes as high as 69% -- of the deposited sediments settle in the live storage or conservation pool. (Please refer to Appendix 3.2.) Thus, conservatively assuming that at least 25% of the sediments encroach in the live storage of the Pantabangan reservoir, and only 75% settle in the dead storage, then the service life of the reservoir is prolonged to around 61 years (i.e., 225 MCM divided by .75 x 4.9 MCM/yr). This is shown in the second column of Table 3.6). While this set of assumptions will affect yearly irrigable area due to the incremental reduction in active storage, it will greatly decrease the present value of the decline in reservoir service life. The life of the reservoir will be reduced by only 39 years, and this will occur much farther into the future. In this case, the cost of the additional sedimentation substantially declines to ₱1.11 per hectare or ₱0.02 per ton of sediment.

Reduction in Active Storage Capacity

A given volume of water is required to fully irrigate a hectare of land year round and to generate a kilowatt-hour of electricity. Therefore one of the major impacts of reservoir sedimentation is the reduction in its irrigation and hydropower generating capacity as the water in the active storage (conservation plus flood control pool) is displaced by sediments.

Table 3.6. Foregone Benefits Associated with Reduction in Reservoir's Service Life.

	100% of sediments into dead storage	75% of sediments into dead storage
Assumed service life of Pantabangan dam with 20 t/ha/yr sediment yield	100 years	100 years
Computed service life of the dam with 81 t/ha/yr sediment yield	46 years	61 years
Nominal values of annual project net benefit for year 47 to 100	₱406.82 million	₱406.82 million
Present worth of an annuity factor with r = 15%	.010754 (for yrs 46 to 100)	0.001144 (for yrs 61 to 100)
Present value of net benefits	₱4.375 million (54 years)	₱0.616 million (39 years)
Annualized value of foregone benefit	₱0.656 million	₱0.092 million
Annual value of foregone benefit per hectare	₱7.91	₱1.11
per ton of sediment	₱0.14	₱0.02

Source: W. Cruz et al., 1987

Reduction in Irrigated Hectarage

In the original feasibility report of the UPRP, the USBR estimated the average annual diversion requirement from the Pantabangan reservoir to be about 17,400 cubic meters per hectare of irrigated land, which already includes allowance for farm and distribution losses (Table 3.7). As actually operated, the average annual irrigation release from the Pantabangan dam is 17,595 cubic meters per hectare, 13,029 cubic meters per hectare for dry season plus 4,566 cubic meters per hectare for wet season (Table 3.8). This implies that if sediments displaced 17,595 cubic meters of water in the active storage, then a hectare of land will not be irrigated in one year. Assuming that a cubic meter of sediment will displace a cubic meter of water, then with a yearly sediment input of 4.9 MCM (see Table 3.5) the number of hectares that will be put out of irrigation is 278 per year (i.e., 49 MCM divided by 17,595 cubic meters per hectare). However, as pointed out earlier, not all of these sediments will be deposited in the active storage. Again, assuming that only 25% of the sediment input will encroach into the active storage then the foregone irrigated hectarage is around 70 hectares per year.

Table 3.9 summarizes the computations of the net irrigation benefit based on "with-" and "without-project" analysis. The figures were obtained from the Completion Report of the UPRP (NIA, 1977) and were based solely on the costs and returns of rice production in the UPRIIS. The computed net irrigation benefit for the dry season, in particular, is probably overestimated considering that other cash crops may be grown in the rainfed areas during the dry months. The other estimate of net irrigation benefit compares the net returns of irrigated farms with the project and the irrigated farms without the project (i.e., in the existing irrigation systems prior to rehabilitation). To make our subsequent computations conservative, the lower estimate of irrigation benefit of ₱3,558 per hectare is adopted.

Thus given a yearly loss of 278 hectares, if all the sediments are deposited in the active storage, then the value of foregone irrigation benefit amounts to ₱989,124. Under the more practical assumption of 25% sediment deposition in the active storage, the annual loss of irrigation benefit is only ₱249,060 (i.e., 70 hectares x ₱3,558/hectare). This annual loss accumulates over time because each year an additional 70 hectares is affected, while all lands already affected continue to be less productive. Thus, cumulating this loss over a period of 61 years (which is the computed service life when only 75% of sediments are inputed into the dead storage, see Table 3.6), and taking the present value at 15% discount rate, gives an annualized value of foregone irrigation benefit of ₱1,906,690. On a per hectare and per ton basis this amounts to ₱12.99 and ₱1.19, respectively.

Table 3.7 Average Annual Diversion Requirements.

Item	Meters	Inches
Consumptive use	2.03	80.00
Effective precipitation	1.07	42.26
Irrigation requirement	0.96	37.74
Farm Losses (15%)	0.17	6.66
Farm delivery requirement	1.13	44.40
Distribution losses (35%)	0.61	23.91
Diversion requirement	1.74	68.31

Source: USBR (1966), p. 35.

Table 3.8 Actual Irrigation Releases from Pantabangan Reservoir and Cropped Hectarage, Wet and Dry Seasons, UPRIIS 1978-1986.

Year	DRY SEASON Irrigation Release (MCM)	Cropped Area (has.)	Irrigation Release (m) per hectare	WET SEASON Irrigation Release (MCM)	Cropped Area (has.)	Irrigation Release (m) per hectare
1978	735.90	72069	10211	925.83	83272	11118
1979	1200.99	82906	14486	541.13	84243	6423
1980	1059.40	79891	13261	430.55	84145	5117
1981	1070.21	81112	13194	381.75	86568	4410
1982	1101.74	82211	13401	376.48	87869	4285
1983	691.54	66560	10390	100.32	73272	1369
1984	(191.94)*	(32043)*	(5990)*	252.68	85048	2971
1985	973.53	60745	16027	166.40	85311	1951
1986	1064.39	80236	13266	294.21	85214	3453
Total	7897.7	605730	104235	3469.35	754942	41096
Average	987.21	75716	13029	385.48	83882	4566

[1] Source: Dam and Reservoir Operations Division, NIA, Pantabangan Campsite.

[2] Cropped area was smaller than irrigated area in 1979 and 1980 by a margin of 1 to 7 %. In other years, cropped and irrigated hectarage are equal.
Source: UPRIIS Annual Reports, 1978 to 1986.

[3] Computed by dividing irrigation release by cropped area.

[4] Source: UPRIIS Annual Reports, 1985 to 1986.

* Dry season 1984 experienced the highest degree of water shortage at the Pantabangan reservoir. The crop was stressed hence this year was not included in computing for the total and average irrigation release, cropped area, and per hectare irrigation release for dry season.

Table 3.9 Estimates of Irrigation Benefit per Hectare, UPRIIS Service Area.

	DRY SEASON	WET SEASON	TOTAL BOTH SEASONS
Net Return per hectare (₱):			
With Project			
Irrigated	3792 (1952)	3443 (1721)	7235 (3673)
Without Project			
Irrigated	1916 (706)	1761 (567)	3677 (1273)
Rainfed	0 (0)	1216 (275)	1216 (275)
Net Irrigation Benefit per hectare (₱):			
Lower estimate[b]	1876 (1246)	1682 (1154)	3558 (2400)
Higher estimate[c]	3792 (1952)	2227 (1446)	6019 (3398)

[a] See Appendix 3.3

[b] Difference in net return between with project irrigated, and without project irrigated.

[c] Difference in net return between with project irrigated and without project rainfed.

Note: Figures in parenthesis represent financial prices.

Reduction in Power Generation

The Pantabangan hydroelectric plant is expected to contribute about 263 million KWH annually to the NPC Luzon grid. Records of its operation, however, show that, except in 1979, the power plant has been generating electricity below its target. On the average, only 186 million KWH is being generated per year. In Table 3.10, a rough estimate of the volume of water needed to generate a kilowatt-hour of electricity is obtained by dividing the total power releases from the reservoir by the corresponding amount of generated power per year. It is quite apparent that the water releases per KWH have increased since the start of hydropower generation in 1977, indicating a possible decline in the system's power generating efficiency. An average power release of 6.6 cubic meters per KWH was computed for the nine years that the power plant has been in operation.

Encroachment of sediments in the active storage pool of the reservoir would result in a potential decline in power generating capacity of the hydroelectric plant. Displacement of 6.6 cubic meters of water by sediment would mean one kilowatt-hour lost in electricity produced. With a sediment input of 4.9 MCM assuming that all these sediments displace water in the active storage, the potential loss in power production is 742,424 KWH per year. With only 25% sediment deposition in the active storage, the potential loss in power benefit is 185,606 KWH annually. Assuming a 1977 price of electricity of ₱0.17/kwh, then the total value of foregone power benefit is ₱31,553 per year. As in the case of irrigation losses, we need to cumulate this yearly effect for the 61 years of the life of the project. We then compute the present value of this stream of losses at 15% interest and annualize the amount to arrived at ₱241,477 per year. The annualized loss amounts to ₱2.91 per hectare and ₱0.15 per ton of sediment.

Opportunity Cost of Sediment Pool

The allowance for a sediment pool in any reservoir project represents a social cost that must be incorporated in its analysis. Even at the original rate of sedimentation assumed (e.g., 20 t/ha/yr in the case of the Pantabangan and Magat reservoirs), the provision of substantial storage space for sediments withholds water that could otherwise be utilized for irrigation and power generation. Viewed another way, the allocation of a sediment pool to capture sediments over and above those produced by natural or geologic erosion necessarily entails additional construction cost, since a dam larger than what is probably needed without accelerated erosion has to be erected. This latter cost, while difficult to segregate, has already been incorporated in the total construction cost of the project, and has therefore been included in its economic analysis.

The less obvious but substantial cost stems from the opportunity cost of the water stored in the reservoir's dead storage space. In the Pantabangan reservoir, the dead storage amounts to 225 MCM. By putting the intake sill of the irrigation

Table 3.10. Pantabangan Hydroelectric Plant Power Generation vs. Power Releases, 1977-1985.

Year	Total Discharge[a] (MCM)	Generated Power[a] (million kwh)	Water release (m^3)[b] per kwh
1977	1172	226.138	5.18
1978	1369	252.453	5.42
1979	1660	304.545	5.45
1980	1410	207.057	6.81
1981	1429	226.915	6.28
1982	1412	216.595	6.52
1983	689	75.319	9.15
1984	364	43.225	8.42
1985	760	124.024	6.13
TOTAL	10,265	1,676.271	59.36
Average	1141	186.252	6.60

[a] Source: National Power Corporation (NPC), Pantabangan Hydroelectric Plant.

[b] Computed by dividing total discharge by generated power.

Source: W. Cruz et al., 1987.

and power tunnels at elevation 171.5 meters, 225 MCM of water have been rendered unavailable for irrigation and power generation.

Foregone Irrigation Benefits

Based on record of actual performance of the UPRIIS as shown in Table 3.8, it may be concluded that the designed service area of 103,286 hectares is an overestimation: The UPRIIS has not attained its target irrigated hectarage in its nine years of operation. The largest cropped (irrigated) hectarage has so far been 83,000 hectares (for the dry season in 1979), and 88,000 hectares (during the wet season in 1982). On the average, the system could only irrigate 75,716 hectares during the dry season and 83,882 hectares during the wet season. It is therefore more reasonable to assume that, given the problems in design and management, the maximum possible irrigable area by the UPRIIS could not be more than 100,000 hectares.

Referring back to Table 3.8, an average diversion requirement 13,029 m^3 per hectare was computed for the dry season. With a sediment pool of 225 MCM, then the stored water could have irrigated 17,269 hectares in the dry season (i.e., 225×10^6 divided by 13029 m^3/ha). Since the system already irrigated 75,716 hectares, on the average, then with the extra water from dead storage, the maximum potential irrigable area of the system must be around 92,985 hectares exclusive of built-up areas, canals, roads, etc. (i.e., 75716 + 17269 hectares). Thus, the opportunity cost of the sediment pool in the dry season is the value of foregone irrigation benefit associated with the potential irrigated hectarage of 17,269 that is foregone. Given that the irrigation benefit per hectare is ₱1,876 during the dry season (see Table 3.9), then the total value of benefit lost is ₱32.40 million.

In the wet season, it is estimated that an average irrigation release of 4566 cubic meters is needed to fully irrigate a hectare of land. With 225 MCM of water in dead storage, a potential of 49,277 hectares could have been irrigated in the wet season (i.e., 225×10^6 divided by 4566 m^3/ha). However, not all the stored water in dead storage would have an opportunity cost. Since on the average, only 83,882 hectares are irrigated by water from the conservation pool, then around 9,103 hectares need to be irrigated by the extra water coming from the dead storage to cover the potential area of 92,985 hectares computed for the system. This means that only 42 MCM of dead storage would have a true opportunity cost during the wet season. Given an irrigation benefit of ₱1,682 per hectare in the wet season (see Table 3.9), then the 9,103 hectares represent a value of foregone irrigation benefits of ₱15.31 million for the season.

On a yearly basis, the total value of irrigation benefits lost due to the provision of a sediment pool is ₱47.71 million. Since the sediment pool was originally designed to accommodate a sediment yield of 20 tons/ha/yr from the 82,894 hectares of watershed, then the annual loss amounts to around ₱575.55 per hectare or ₱28.78 per ton of sediment.

Foregone Power Benefit

The 225 MCM of water in the dead storage could have also been utilized to generate additional hydroelectric power. This assumes that the power generating units at the plant are specifically designed to function under low head condition since the elevation at the top of the dead storage is only at 171.5 meters. In fact, with the existing turbines and generators at the Pantabangan hydroelectric plant, with rated net head of 70 meters, the minimum water level for power generation is already at 177 meters (NPC brochure). This means that the stored water in the dead storage which falls below the existing intake sill is technically not useful for power generation and therefore does not have opportunity cost under the existing conditions of the power plant.

There is currently a 15-meter difference in elevation from the bottom of the dead storage pool at 140 meters to the tail water of the power plant at 125 meters. Assuming that it is possible to install low- head turbines which could operate at a net head of 15 meters and that the intake sill would be located at 140 meters, then a position of dead storage would have potential use. A minimum water surface level above the sill would be necessary in order to maintain a net head of 15 meters after deduction of losses. Assuming that this minimum level is at 150 meters, then from the top of the dead storage pool at 171.5 meters to this elevation, the volume of storage is approximately 175 MCM (as indicated in the area-capacity curve of the reservoir shown in Appendix 3.4). Therefore, only this much water stored in the dead storage would have opportunity cost in terms of power generation.

It is further expected that a much greater volume of water would be required to generate a kilowatt-hour of electricity when the head is only 15 meters than when it is 70 meters. For the sake of discussion, the volume of water needed to generate a KWH of electric power may be computed using the same equation adopted by Francisco (1986), assuming an efficiency of 80%, i.e.:

$$KWH = \frac{QH}{439} \qquad (1)$$

where Q = discharge in cubic meters per second
H = head in meters; water surface elevation less tail water elevation less losses

For every kilowatt-hour of electricity, equation (1) gives a Q of 30.6 m^3 when the head (H) is 15 meters.

Given these assumptions, the 175 MCM of water in dead storage corresponds to around 5.72 million KWH of energy annually. At a 1977 price of ₱0.17 per KWH, then the yearly loss in power benefit is ₱0.97 million. Since the dead storage is designed to accommodate a 20 tons/ha/yr sedimentation rate from the 82,894 hectares of watershed, then the annual loss in benefits amounts to ₱11.70 per hectare and ₱0.58 per ton of sediment.

Table 3.11 presents the estimates of sedimentation cost as derived in the preceding section. It should be emphasized that these figures still underestimate the true value of foregone benefits arising from sedimentation in the Pantabangan reservoir. Only lost irrigation and power benefits were considered, though the dam and reservoir serve other functions such as flood control, fisheries, domestic water supply, and recreation. Measurement and valuation of the impacts of watershed erosion on these other services require much more information than is currently available.

Nevertheless, one significant result of the analysis is the substantial cost associated with the provision of a sediment pool. More than 90% of the total cost computed per hectare of watershed area and per ton of deposited sediments is due to the opportunity cost of the impounded water in the dead storage. This is reasonable considering that the dead storage of 255 MCM represents around 10% of the total reservoir volume of 2,308 MCM (excluding surcharge pool, and serves no other purpose except for sediment deposition. While the added construction cost due to the incorporation of a dead storage is a cost that occurs up front (at the time of dam construction) the foregone irrigation and power benefits due to the stored water are costs that are incurred annually, throughout the life of the project.

Table 3.11. Summary of Estimated Costs of Sedimentation in Pantabangan Reservoir, 1977 Prices.

Source	Annual Sedimentation Cost (₱) per hectare	Annual Sedimentation Cost (₱) per ton of sediment
Reduction in service life	1.11*	0.02*
Reduction in active storage		
(a) for irrigation	12.99*	1.19*
(b) for hydropower	2.91	0.15*
Opportunity cost of dead storage		
(a) for irrigation	575.55	28.78
(b) for hydropower	11.70	0.58
TOTAL	604.26	30.72

* Based on the assumption that 75% of sediments settle in dead storage and 25% in active storage.

Furthermore, the enroachment of sediments in the reservoir's conservation pool results in a cumulative loss in the reservoir's capacity for irrigation and hydropower generation. The computed cost, however, is not as substantial as the opportunity cost of the dead storage. The cost arising from the reduction in the dam and reservoir service life turned out to be a rather insignificant portion of the total cost. This is because such cost occurs very far in the future and must be discounted by realistic interest rates.

Given that the cost of sedimentation in the Pantabangan reservoir is ₱604.26 per hectare of watershed area and ₱30.72 per ton of deposited sediment, the total annual value of foregone benefits amounts to approximately ₱55 million assuming a sediment inflow of only 20 tons/ha/yr into the reservoir. This foregone stream of social benefits provides an indicator of the hidden social losses in the economic analysis of UPRP due to sedimentation.

CHAPTER IV
EROSION ABATEMENT AND THE COST OF CONSERVATION

I. A POLICY FRAMEWORK FOR EROSION ABATEMENT

Investment in Conservation

Is investment in conservation-oriented projects justifiable on purely economic grounds? It is quite possible that the lack of systematic studies on the costs associated with the adoption of various conservation measures for erosion abatement is due to the perception that conservation activities are not economically justifiable. This has led some advocates of environmental protection to emphasize the alternative motivation for conservation as desirable in its own right, independently of economic feasibility.

Three observations have been made in Young (1986) that are of relevance to this position. First, it is correct that there are severe capital constraints in many developing countries, and conservation projects therefore may have problems in competing for the use of limited funds. However, the recourse to promoting conservation activities on purely environmentalist grounds will rarely be fruitful since such arguments unfortunately do not carry much weight when policy-makers allocate limited budgets.

The second observation is that there may have been misplaced concern on the uneconomic prospects for conservation. The conventional view is that the returns to conservation occur too far in the future so that current abatement expenses cannot be justified (unless unrealistically low interest rates are adopted). This view has been contradicted by recent findings.

In fact, there is growing evidence from work in other countries (e.g., Dumsday and Flinn, 1977) that the correct specification of the benefits to soil conservation should include the valuation of production benefits that accrue in subsequent cropping periods. In our own Pantabangan case study, when erosion is pronounced (in cultivated lands) production effects will be substantial within a short economic time-frame of one or two years. The implication of all this is that the adoption of conservation technology that can address this problem may be justifiable on purely economic grounds so that the sooner the costs of conservation are specified the faster we can assess their potential contribution in relation to the damages inflicted by excesssive erosion.

Finally, Young (1986) has pointed out the asymmetry of costs associated with erosion control, depending on whether the land is already disturbed and abatement is required or whether the land is still protected and prevention of erosion is the objective. This is of relevance because of our observation on the protective nature of forest cover and the acceleration of erosion associated with the conversion of forest to agricultural use. This indicates that policy-makers do not have the luxury of having much time to implement conservation-oriented polices: the longer we wait the larger will be the cost of conservation.

A Pricing Policy Approach to Abatement

Addressing the need for economic assessment of the cost of conservation techniques in relation to potential benefits is only part of the policy-making challenge. This must still be evaluated within a public decision-making and pricing policy framework. In economics the policy framework is dominated by the Pigouvian taxes and subsidy approach to externality-producing or -modifying activities (of which conservation projects are a small sub-set).

One of the most difficult requirements of optimal abatement policy in the Pigouvian tradition is that the optimal subsidy to an externality-reducing program such as erosion abatement must be set equal to the marginal net benefit of abatement (Baumol and Oates,1976). This means that we do not only require point estimates of average benefits and costs; we need to quantify incremental changes in net benefit as erosion is reduced by our conservation or abatement efforts. In addition, we need these estimates not for the existing levels of erosion but for the levels that would still remain once erosion has already been reduced to the optimal situation.

The data and quantification problem is therefore doubly difficult for if we are faced with so many constraints in just arriving at point estimates of average erosion damages (and their mirror-image, potential benefits) in the current, non-optimal situation, how much more difficult will it be to arrive at estimates of marginal damages in the context of a socially optimal situation?

To arrive at implementable environmental policy, Baumol and Oates (1976) propose an approach that is not subject to the formidable data requirements associated with the classic Pigouvian framework. This alternative requires that policy-makers be able to determine an environmental goal or standard which may then be approximated by the use of appropriate pricing policy. For example, if the objective in a river management project were to attain a level of biochemical oxygen demand (BOD) that is only half of the currently observed level of, say, X, the direct regulation approach may propose that all paper factories contributing to the total BOD level should cut their effluent BOD discharge to one-half.

It may be shown that this direct regulation approach will not minimize the social cost of meeting the environmental standard of X/2. We only need to consider a simple case where there are only two paper factories, A and B, contributing to the total BOD level, with their own BOD discharges, BODa and BODb, respectively. If, for any reason, it would cost more to attain a unit reduction of BODa relative to a unit reduction in BODb, then a policy target of BODa/2 and BODb/2 will have a higher social cost than an alternative target where there will be relatively more reduction in BODb.

But how do we determine how much more BODb reduction to require relative to the reduction in BODa? This difficulty will only arise if policy makers insist on direct regulation. The useful alternative is a pricing policy that will charge a penalty on factories A and B for each unit of their BOD discharge. On their own, factories A and B will then attempt to reduce their discharges down to the level where the additional increase in cost associated with one unit of reduction will just equal the additional penalty per unit of discharge. This process will ensure that the marginal cost of the abatement program will be equal throughout the economy and will also equal the marginal penalty or "pollution price" that the government will set.

Of course, there is no assurance that the inital penalty level will be sufficient to reduce right away the BOD level to the standard of X/2. Such a policy approach will require some monitoring and periodic adjustment of the penalty so that the levels of BOD reduction after some iteration will approximate the needed reduction to the standard.

This approach, with some modifications, may be applied in designing pricing policy for erosion abatement. Consider Figure 4.1, Part A. The curve TB represents the total benefit from erosion abatement or the reduction of erosion (in terms of tons per hectare) while TC represents the total cost of erosion abatement efforts. The optimal rate of abatement may be defined as the maximum difference between these two curves where their slopes are equal (at abatement level E*). In Part B of Figure 4.1, we illustrate the optimal abatement level based on the intersection of the marginal benefit curve (associated with TB) and the marginal cost curve (associated with TC).

Our problem is that even with the detailed valuation assessment that we have carried out in Chapters II and III, we still have limited information on the functions TB and TC. The reason is that the benefit-cost analysis valuation framework that we have used essentially provides only point estimates of total and average benefit and cost. Additional work that may be carried out following this effort may be able to identify other points along the erosion/abatement axis and thereby piece together a relevant total benefit and total cost curve.

Nevertheless, we are still able to determine the relative location of our estimates on Figure 4.1. Since minimal erosion control is being undertaken in much of the watershed at the time for which the estimates apply, the on-and off-site benefit of erosion reduction should be located fairly close to the origin of the graph, in the neighborhood of A. In the case of Pantabangan, for example, our conservative estimate of the on- and off-site damage due to erosion may be viewed as the potential benefit of abatement. The off-site benefit is about ₱31 per ton/yr (from Table 3.11). We have more data on on-site benefit from Table

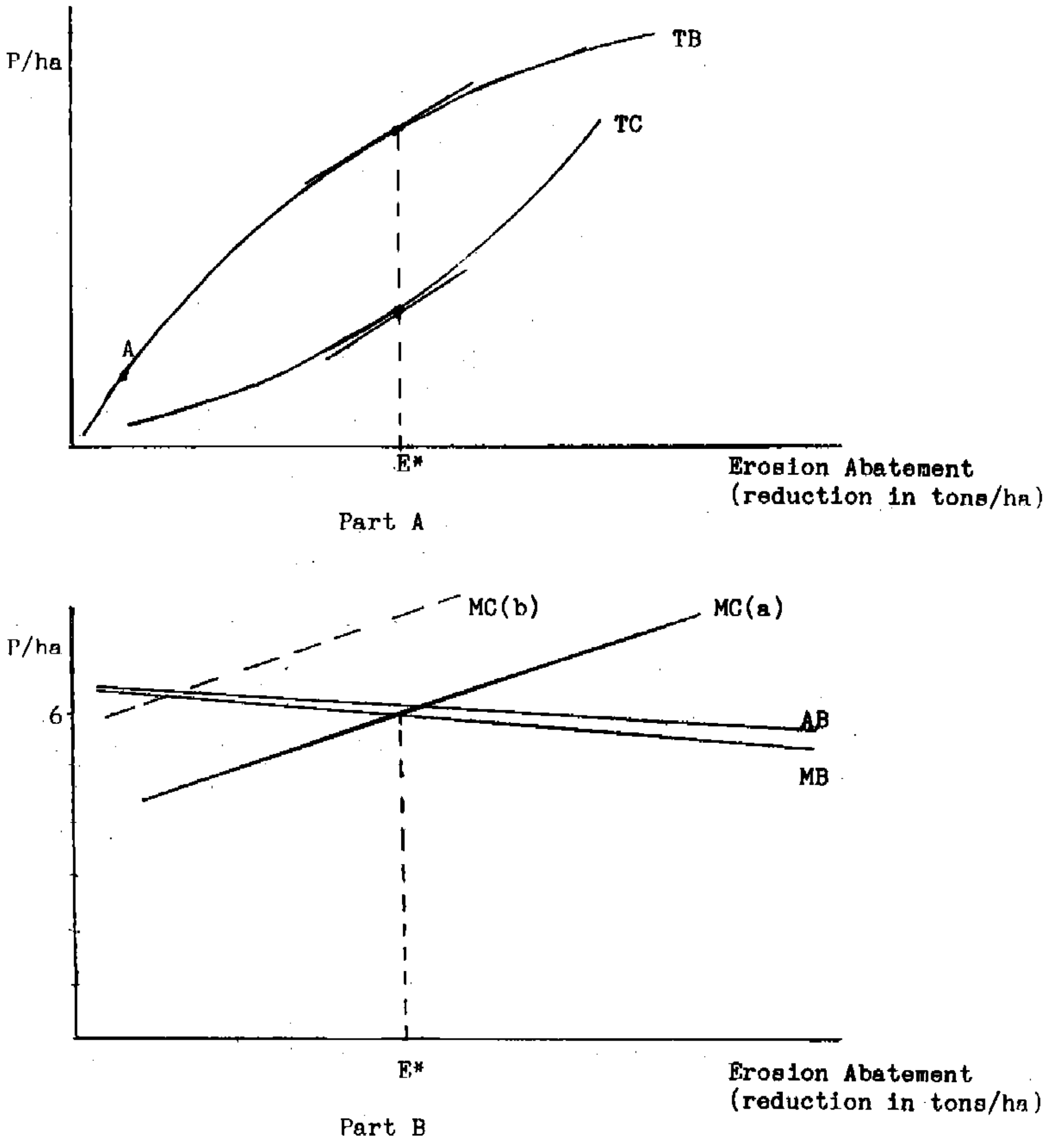


FIGURE 4.1

Benefit and Costs of Erosion Abatement

2.25, indicating that there is a range of benefits from ₱7.12 to ₱4.24 as erosion progresses from the first 5 cm soil layer to the 50 cm layer.

Since the off-site benefit is an average value, we have no a priori basis for assessing what the relevant marginal benefit will be in the range of erosion abatement associated with this average (as argued in Chapter I). It is the on-site benefit that may be used to assess the slope of TB. Table 4.1 (computed from Table 2.25) shows average benefit for 10 soil layers that are each 5 cm thick. Each of these layers corresponds to about 650 tons of soil per hectare so that we may interpret the abatement benefit in terms of benefit per ton, depending on how much erosion has already occurred.

For example, if we are in a situation where not more than 650 tons of soil have been lost (since the soil survey on which our study is based) then the average benefit to abatement will be about ₱7 per ton. However, if the abatement program is delayed, we may observe erosion already in the 30-35 cm layer, in which case the abatement benefit may only be about ₱4 per ton. Since these figures are averages for sections of the total damage function and since it is clear that these "section" averages are not greatly different from one another they approximate marginal erosion damages and therefore marginal abatement benefits. This indicates that the average abatement curve in Figure 4.1 should be fairly flat within the bounds of each 5 cm layer of soil (or in the range of about 650 tons of erosion abatement). This is illustrated by the curve AB in Part B of Figure 4.1.

From Table 2.17, we observe that if erosion in grassland areas has not been controlled in the decade or so that the survey was made, then these areas may have lost about 10-15 cm of soil and abatement benefits will be about ₱6 per ton (or a little less than the ₱6.33 average abatement benefit). The reason is that the curve AB (for average benefit) must lie above the marginal benefit curve because the latter is downward sloping.

From these considerations -- (a) that abatement of erosion is very close to the origin and (b) that the marginal benefit to abatement is about ₱6 per ton -- we may propose a pricing approach to erosion abatement that runs parallel to the Baumol and Oates (1976) standards approach. In this case, we have no basis for setting erosion standards so that the erosion level goal is best viewed as a moving target. Therefore our approach may emphasize the efficiency of the process of approaching this target. We may set an annual subsidy of ₱6 per ton of erosion controlled (or alternatively a penalty of ₱6 per ton for any watershed activity that generates new erosion, such as additional forestland reduction) for any conservation-oriented activity.

This level of subsidy may also be established as an initial standard for the cost of erosion abatement. Since such costs are not known in any great detail (as presented below), having a target cost may be a good first step in forcing proponents of

Table 4.1. Benefits from Erosion Abatement for Various Soil Layers, Pantabangan Study

Soil Loss		Benefit from Abatement (P/t)
in CM	in t/ha	for each 5 cm layer
0-5	1-650	7.12
5-10	651-1300	7.03
10-15	1301-1950	6.33
15-20	1951-2600	5.35
20-25	2601-3250	4.52
25-30	3251-3900	4.41
30-35	3901-4550	4.24
35-40	4551-5200	4.24
40-45	5201-5850	4.24
45-50	5051-6500	4.24

Note: Column 2 is derived from Column 1 using the following formula:

Soil Loss (in cm) * Bulk Density (130 t/ha-cm) = Soil Loss (in tons/ha).

various conservation practices to start quantifying the cost per ton of erosion prevented for the techniques that they are introducing. At any rate, the flatness of the marginal abatement benefit curve should dominate the determination of the socially acceptable cost of conservation; the level of erosion that will eventually prevail will then depend on how efficiently or inexpensively conservation techniques can accomplish abatement. Again in Figure 4.1 this proposition may be illustrated by drawing two marginal abatement cost curves, MC(a) and MC(b). If MC(a) were the applicable curve and it lies far above MC(b), the level of the subsidy will not be greatly affected. However, the optimal rate of abatement will probably decline significantly.

This analysis should provide policy makers with a useful first step in undertaking a system of periodic price-setting, evaluation, and recalculation of new prices. Two additional issues should not be missed in closing this model for abatement policy.

The first has to do with the prices that we are using as the basis for determining the replacement cost of erosion and therefore the potential abatement benefits per ton of erosion that is prevented. These prices are about ₱2, ₱1, and ₱1.50 per kilogram of urea, solophos, and muriate of potash, and these are clearly outdated prices, having been estimated for the period when the Pantabangan erosion control project was being studied. To update the values involved so that they would be more easily compared with current price levels, the shadow prices used for the Magat assessment, which are mid-1980s prices, may be more useful. These are about ₱10, ₱6, and ₱8 per kilogram of urea, solophos, and muriate of potash, respectively.

With these prices the equivalent initial subsidy that we may offer for each ton of erosion abatement will be about ₱29. If we consider that this amount is a very conservative estimate of potential on-site incremental benefit to conservation and that current sheet and rill erosion rates are close to 200 t/ha/yr in grassland areas (from Table 2.17), if these lands are to be brought under sustainable cultivation a substantial budget for the inclusion of abatement practices will be required per hectare.

The second issue has to do with the role of the off-site estimate of erosion damage. The price updating discussed above will be required here also. However, the major problem with this estimate is that we have no basis from our data for assessing if this average damage value is similar or very different from the marginal damage. If we continue our conservative approach and assume that the marginal damage is only about one half of the average this would still justify additional abatement efforts of about ₱15 per ton of erosion controlled. This basis for abatement subsidy will have to be fairly site-specific since this is based on the erosion effects on the large-scale irrigation and hydro-power projects in this particular watershed.

II. THE COST OF CONSERVATION

In this section our concern is to survey the conservation techniques that are available for erosion abatement. As indicated above, from the perspective of policy-making for promoting conservation, the most important consideration of any technology is its cost-efficiency in reducing erosion. To organize our presentation of various conservation practices, we focus on three aspects of potential technologies: (a) the basic type of land or soil cover modification associated with the techniques, (b) the environmental conditions in which these techniques are applicable, and (c) the economic costs required for their establishment and maintenance.

As indicated by Young (1986), conservation techniques should also include not only erosion abatement methods but also erosion prevention methods. In this discussion, however, our emphasis is on the abatement methods since most of the problem areas that we are concerned with will exhibit existing vs. potential degradation.

Table 4.2 presents our listing of abatement techniques, classified according to whether these require biological or vegetative modifications or whether mechanical or structural changes will have to be involved. (Please refer to Appendix 4.1 for detailed descriptions of these techniques.) In Column 2 of Table 4.2, we list the range of slopes for which these techniques have been found to be practical. (The letters in parentheses refer to sources which are listed below the table.) Column 3 presents the potential effectivity of these techniques in terms of the percentage of erosion that they can control.

We may conclude from Table 4.2 that the two basic types of abatement practices -- biological vs. mechanical -- make up distinct classes of conservation technology. This is true both in terms of the slopes for which they are practicable and in terms of the potential erosion reduction that may be attained. In the case of slope applicability, we observe that biological techniques are more useful for moderate slopes of up to 25% while mechanical modifications are applicable for slopes that are steeper than 50%. With respect to abatement effectivity, the biological methods (except for mulching which is very effective in protecting soils) are not as protective as the mechanical methods even considering that the latter are usually applied in steeper slopes.

Table 4.3 again lists the abatement practices to show the cost of establishment and maintenance associated with these. To summarize the costs that are reported in terms of man-days or man-animal days by different sources, we use wage rates of ₱33 per man-day and ₱66 per man-day which are based on rates used for the Magat feasibility studies. These are early 1980s wages and are for planting season months to ensure that the costs are not underestimated. For both the cost of establishment and maintenance, we list the option for undertaking the conservation practice with only labor as well as the option for using labor

Table 4.2 Conservation Practices, Slope Applicability, and Abatement Capacity.

Conservation Techniques	Slope Applicability	Erosion Abatement Capacity (%)
A. Biological or Vegetative		
1. Contour Strip cropping	2-18 (a)	32 (g)
2. Buffer strip cropping	≤ 18 (b,c,d,)	70 (h)
3. Mulching	≤ 25 (e)	70-90 (g)
B. Mechanical or Structural		
1. Conservation tillage	≤ 12 (f)	78-83 (f)
a. minimum tillage & mulch		
b. precision/strip zone		
c. zero tillage		
d. contour plowing		50 (f, i)
2. Terraces		
a. bench (also broad-based)	≤ 47 (b)	87-48 (i)
b. orchard	≤ 65 (c)	95 (i)
c. individual basin	< 58 (b)	
3. Ditches		
a. contour	< 47 (e)	71-80 (i)
b. hillside	< 47 (b)	

Sources:
- a) Cosico (n.d.)
- b) Sheng (1981)
- c) FAO (1977)
- d) Vergara and Briones (1987)
- e) Paringbatan (1986)
- f) Greenland and Lal (1977)
- g) David (1987a)
- h) Lasco (1986)
- i) Lal and Russell (1981)
- g) Hoanh, Nguyen Hoang (1987, personal interview)

Table 4.3. Costs of Various Conservation Practices.

Conservation Techniques	Cost of Establishment (Per Hectare)			Cost of Maintenance (Per Hectare)		
	MD	MD,MAD	₱	MD	MD,MAD	₱
A. Biological or Vegetative						
1. Contour Strip cropping	34(j)	6,7(j)	1122 or 660	42(j)	14,7(j)	1386
2. Buffer strip cropping	14(k)	7,2(j)	462 or 363	20(j)		660
3. Mulching	38 per year(j)		1254	42(j)		1386
B. Mechanical or Structural						
1. Conservation tillage						
a. Minimum tillage & mulch	42 per year(j)	1,5(j)	693 or 363	40(j)	0,5(j)	660 or 330
b. precision tillage & strip zone	21 (j)		693	20(j)		660
c. zero tillage	10 (j)		330	10(j)		330
d. contour	60 per year(j)	2,7(j)	990 or 528	56(j)		924 or 462
2. Terraces						
a. bench	500(b)		16500	25(j)		825
b. orchard	112(b)		3696	6(j)		198
c. individual basin	12(b)		396	0, 6(j)		158
3. Ditches						
a. contour	31(j)		1023	14(j)		462
b. hillside	100(b)		3300	5(j)		165

Sources: See list in Table 4.2.

and work animals. The costs listed therefore may have two entries and these are for the cases where input requirement for such options are available.

The establishment requirements of the various techniques are not clearly different except in the sub-classification of terracing where costs per hectare may be 4 to 16 times greater than in all the other techniques. In addition, only bench terracing seems to be in a class by itself where both establishment and maintenance costs are quite high. Ideally, we should determine the stream of establishment and maintenance costs for about a 50-year period for each technique. We can then get the present value of this stream and annualize the cost using a rate similar to one we used for assessing erosion damages (15%). However, given the very rough nature of the data that are available it is prudent to leave that detailed assessment to future work.

Working within this constraint, we may propose that with an annual cost in the order of ₱1000 per hectare then these practices will be justifiable in watersheds similar to the Pantabangan and Magat areas that we evaluated if the practice can reduce the observed erosion by about a half. This would mean that the cost of abatement will be about ₱10 per ton. We should emphasize, however, the need for extreme caution in using these numbers because of the very limited data on costs.

CHAPTER V

IMPLICATIONS FOR CONSERVATION POLICY AND CONTRIBUTIONS TO WATERSHED ASSESSMENT AND LAND CLASSIFICATION

In this concluding Chapter, we focus on two general implications of the valuation results in Chapters II and III and the policy discussion in Chapter IV: (a) on policy recommendations for commercial and social forestry and (b) on contributions to the economic assessment of watershed projects and to land classification approaches.

I. CONTRIBUTIONS TO FOREST CONSERVATION POLICY

One of the most important results of the economic studies of the URP was the quantification, with the use of the modified universal soil loss equation, of the proposition that forest cover is a major protective factor in soil conservation. In Chapter II, for example, we present details on soil erosion for the 4 major land uses in Pantabangan. The case study clearly indicates that erosion is minimized with forest cover, fairly independently of slope. With such minimum soil erosion rates, actual soil regeneration through the decomposition of tree litter and related processes effectively makes soil nutrient levels sustainable indefinitely.

Implications for Commercial Forestry

Since forest drain is occurring at substantial rates, the conservation-oriented components of current forest policy is clearly inadequate. Indeed traditional conservation approaches in Philippine forestry is highly dependent on the viability of the selective logging system (SLS) -- a management system designed to lead to sustained yield use of forests. The system essentially requires the logger to leave behind a residual stand in the logging operation to allow a second cut to be done after a period of time. If the system fails the standard government response is limited to undertaking planting, replanting, and more replanting (which does not necessarily lead to effective reforestation).

To be effective, the policy or management system geared toward the exploitation of forest resource should be able to incorporate realistic conservation components. With respect to this need for a general forest use and conservation framework, the absence of broad assessments of the true social cost of the effects of the exploitation of forest resources has meant that one of the most critical inputs into the policy choice process -- the economic benefits that may accrue to conservation-oriented policy -- could not have been realistically taken into consideration. Having no estimated value, conservation programs (given their significant and monetized costs) would have paled in comparison with logging and other resource exploitation activities whose substantial net present values and robust rates-of-return will always impress the bottom-line requirements of policy-makers constrained by increasingly tight budgets.

The valuation approaches we have illustrated, however, may now show that because soil erosion leads to environmental damage, its abatement generates true economic benefit. Measures of this environmental cost and its mirror image -- conservation benefit -- can be critical inputs into policy reform for the key forestry sectors. For commercial forestry, for example, the most important policy issue is the pricing of timber for logging. Part of the inability of government to take a passionate position to increase the price of timer (and probably a source of moral certitude among loggers that this price should be low) is that the forest has always been there and the government did not pay to produce the resource. The degradation or the removal of this resource, however, has been shown to generate substantial environmental cost. While the net social benefit to logging will probably still be positive for the Philippines, the environmental cost -- being a true economic cost and not a mere transfer payment such as the BFD forest charge -- cannot be waived.

Somebody ends up paying for this, and if the logger is not made to pay then <u>society ends up with the bill</u>. This is the reason why some foresters have been arguing that the minimum charge for cutting trees should be the cost of <u>replanting and maintaining</u> a healthy stand to replace them. (This cost would be a surrogate price for the cost of environmental degradation engendered by the loss of the old growth forest).

With respect to the pricing of environmental services of forest conservation, we have already indicated that in the SLS, the returns to conservation (through the TSI phase) are uneconomical. This is due primarily to the long gestation period that is required before the residual stand reaches marketable size (Cruz and Tolentino, 1987). Since the protection of forests provide the benefit of controlling soil erosion and its unwanted downstream effects, there is economic basis for the conservation effort to be directly subsidized by government.

One might argue that the underpricing of the timber in SLS essentially makes up for the lack of support to the concessionaire for the conservation phase. However, this is precisely the problem since the incentive structure will be biased for the logging versus the conservation activity. Because there are two distinct economic functions (or services) required in forest management, policy reform calls for adjustments in both the pricing of standing timber (toward substantially higher prices) and the conservation services of sustaining a forest cover (toward subsidizing reforestation or penalizing excessive cutting). Indeed there is no compelling reason why these two activities and pricing systems should be integrated or expected of the same firm. Each activity may be contracted out to separate bidders -- the first according to the highest offer for the wood value in a site, the second according to the expected cost of replanting and maintaining trees in the area.

Implications for Social Forestry

For social forestry, the most critical policy issues concern the problem of land tenure for forest dwellers and the need for government support for adoption of conservation practices. The prospects for enhancing conservation efforts in the social forestry framework are constrained by the extremely limited approach to land allocation for individual upland cultivators. The results of our discussions of on-site effects of erosion bring out two questions of relevance to the need to review the land disposition strategy prospects for soil conservation:

(a) If the nominal cost of nutrient losses due to erosion is about ₱1,000 per hectare (the value from the Magat case), should this not be enough incentive for upland cultivators to practice soil conservation methods?

(b) If the social cost of nutrient loss is about 2.5 times its nominal or private cost, should government directly subsidize conservation activities by upland cultivators?

On the private incentives to conservation, it is important to recognize that soil erosion does not necessarily impose current costs on the private land user as long as the topsoil layers are not completely depleted. Only when the topsoil is removed will the nutrient loss have a direct impact on current productivity of the land. Since the upland farmer has no right to the land and therefore no stake in ensuring its long-term productivity, the potential gain by reducing the ₱1068/ha/yr of lost soil nutrients cannot be captured by the farmers. It is therefore not surprising that upland farmers exploit the land until its productivity declines and then move on to a new plot.

A necessary condition therefore for the adoption of conservation practices in upland farming is the allocation of secure claims over the land. The sufficient condition is that the private cost of conservation should not be so large as to eliminate the potential gains from reducing soil loss.

This is where the social on-site cost of erosion comes into the picture. The difference between the nominal and social cost of soil erosion indicates the level of subsidy that society should be willing to provide to help reduce soil erosion. Of course, it would be unrealistic to attempt the complete elimination of erosion. If the target is to reduce erosion to one-half, from about 88 t/ha to 44 t/ha, in sites similar to Magat, the potential private gain is about ₱534 (presuming only a one-year planning period).

Contour plowing techniques as well as the construction of hillside ditches could probably accomplish this 50% reduction in erosion, but the associated cost of 30-35 man-days plus 7 man-animal days for these techniques may greatly reduce the potential saving. In this case, it should be beneficial for society to subsidize the conservation effort by up to ₱824/ha (for the 50% erosion reduction) since the potential social gain is up to ₱1,358/ha less ₱534/ha which is the private user's gain. These values are clearly conservative estimates if we consider that the soil environmental being measured is only for sheet erosion, and we have not included the downstream losses.

To emphasize this important point, the above discussion shows that substantial on-site benefit in terms of sustainable soil productivity will, in fact, result from adoption of conservation-oriented farming and forestry practices. Upland cultivators, however, will adopt these practices (which are not costless) only if they can capture the long-term benefits that will accrue -- indicating that they need (as a necessary condition to conservation) a long-term stake in the land. At the same time, social on-site benefits as well as downstream benefits imply that it will pay government to actively subsidize the technological support as a sufficient condition for abatement. In this light, the current social forestry program can only be a beginning and government must seriously look beyond this toward a massive land reform program in the uplands supported by conservation-oriented subsidies.

II. CONTRIBUTIONS TO WATERSHED ASSESSMENT AND LAND CLASSIFICATION

Implications for Benefit-Cost Analysis

The potential contribution of the quantification of environmental costs to benefit-cost analysis is substantial. This potential contribution includes not only the determination of proper shadow prices for project outputs that have significant environmental effects. More importantly, the effort of identifying the effects of soil erosion and defining the boundaries of the required management effort will help in evolving a more realistic project assessment stance for uplands and water resources development investments.

On Expanding the Project Assessment Stance

The valuation perspective assesses particular activities or processes as they occur within the watershed as a physical system. While there are various activities occurring in different bio-physical components of the watershed, the environmental effects register in a common soil erosion and sedimentation process. Through erosion and sedimentation, these upstream activities generate downstream externalities, for example in terms of reductions in irrigable hectarage and siltation of water conveyance structures. The adoption of a watershed management/irrigation development assessment stance represents an integration of the standard watershed erosion control project and the irrigation project approaches. This expanded approach is broad enough to properly assess key upstream and downstream inter-relations while still manageable enough to allow systematic evaluation. For example, it has been pointed out in this paper that there are substantial downstream irrigation losses due to accelerated erosion upstream so that soil conservation projects that are in themselves unprofitable may be socially justifiable if viewed in a broader water management and irrigation development context.

On the Opportunity Cost of Sedimentation

The need for the explicit incorporation of environmental effects of erosion in the economic assessment of reservoir projects does not mean that standard economic appraisal approaches to such projects completely fail to include environmental effects. In fact, some of these effects are implicitly incorporated in the cost and benefit streams that are regularly estimated. Consider, for example, the added reservoir or dam construction cost associated with the need for a sediment pool beyond the capacity required for "natural" or "baseline" sedimentation such as that associated with the 3-12 t/ha/yr from forest lands. This effect is implicitly incorporated in the standard appraisal because the additional construction cost associated with the sediment pool is automatically included in total construction cost and is therefore also included in the evaluation of the social profitability of the project.

It is when the assumed erosion rate at the time of project design is exceeded by actual erosion that the environmental effects lead to incremental reductions in benefits from the system, which the appraisal, of course, fails to incorporate. This failure stems not from the methodology of appraisal itself but from the lack of accuracy of erosion data.

However, there is another major effect that is not at all encompassed in the standard assessment procedure: the loss of potential irrigation and hydro-power capacity due to the requirements of allocating for a substantial sediment storage. There are, in fact, social costs from losing potential active storage capacity because options for reducing the rate of erosion (and therefore the required sediment pool or inactive storage) are available if watershed management and erosion control components are explicitly included from the inception of the reservoir project.

While the preceding measure of cost in terms of reduction in project life is an incremental one (due to additional erosion), the opportunity cost of the reservoir's sediment pool is a fundamental cost and must be incorporated even without any additional erosion and sedimentation. Sediment input reduces the reservoir's storage capacity which in turn decreases the quantity of hydro-power, irrigation water, and flood damage protection that the reservoir can provide. Because of this, an allowance for siltation is always included as a component of reservoir design, especially if this will be meant to store water from run-off over many years (as in the case of the Magat and Pantabangan reservoir).

Contributions to Assessment Methodology

On Land Suitability Classification

In conjunction with the modified Universal Soil Loss model (David, 1987a-c), the methodology for assessing the susceptibility of various land uses to productivity decline can be packaged as a practical land classification approach. The persistence of the old criterion of classifying lands as alienable and disposable (A&D) vs. forestland (non A&D) according to the simple rule of whether or not they are less than or greater than 18 percent in slope does not necessarily imply that policy-makers are satisfied with the system. Indeed our impression is that there is a fair amount of dissatisfaction concerning the extremely restrictive effect that this criterion (and the classification system that it is associated with) has imposed on the disposition of public lands.

The problem is that no serious substitute has been previously suggested that is as practical as the 18 percent rule. Our recommendation that a new system be adopted represents a feasible alternative. In fact, it may be viewed as a complementary system to be used in areas already designated as forestlands but are still within the practical limits of sedentary agriculture -- i.e., they are moderate in slope (18 -35 percent). Once land classification in an area is done, not only the slope but the true potential for erosion will be the basis for disposition. In addition, zoning restrictions on what may be cultivated (e.g., annual crops vs. trees) plus the technology and the subsidy package may all be generated by the same comprehensive assessment methodology.

On Identifying Critical Watersheds

The economic assessment methodology developed here will also have a contribution to the operational definition of what constitutes a "critical" watershed. The identification of such watersheds is useful for basic governmental planning for resource management. To be practical, such a listing of watersheds -- with all their bio-physical and socio-economic dissimilarities -- cannot be based on a one-dimensional classification system. At least three criteria are important: (a) the economic value associated with the presence of massive capital investments (usually in terms of irrigation infrastructure) downstream in addition to the presence of upstream environmental costs (b) the presence of accelerated soil erosion and (c) the conditions of demographic pressure on resources. The economic assessment methodology presented in this paper can provide the data for the set of economic criteria. The other methodologies -- on a generally applicable soil erosion estimation model and on the assessment of upland population and migration patterns -- have likewise been developed by researchers associated with the Upland Resource Policy program. Please refer to David (1987a-c) for the erosion estimation model and to C.J. Cruz et al. (1986) for the demographic assessment approach.

Suggestions for Training and Action Programs

Two potential action programs may also immediately benefit from the combined methodologies mentioned above. The first may involve the organization and training of regional level teams from the Department of Environment and Natural Resources and associated agencies to do a quick environmental, economic, and community assessment of selected watersheds, with a specialized team to make inter-watershed analyses and identify potential conservation projects. The second program may respond to the immediate need for land use suitability classification to quickly identify public lands that may be included in the national land reform effort.

The latter can be a crucial contribution. Although the classification approach to identifying areas for land reform will not be inexpensive, most of the basic information are already available. Also, in practice the cost of detailed survey and land re-classification may be well below the monetary and political cost of transferring lands in Programs A, B, and C of the land reform plan (Cruz and Cruz, 1987).

The extent of lands potentially suitable for agriculture in the public domain, which dwarfs the land reform targets in the other programs of the agrarian reform plan, requires that very serious study of the potential for government, as enlightened landowner, to allocate these lands be undertaken. Indeed, a large proportion of the population (numbering more than 14 million) already resides in these uplands, and population growth as well as the pattern of upland migration suggest that the demand for these lands will continue to increase.

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APPENDIX 2.1

Analysis of the Nutrient Content of Soil Carried by Erosion

1. To estimate the amount of N and the equivalent Urea carrie by soil loss on a per ton basis:

   a) convert Organic Carbon (OC) to % Total Organic Matter (OM), using the relationship

   $$\%\ \text{total OM} = \frac{\%\text{O.C.}}{0.6}$$

   b) compute % total N as a proportion of % total OM
   % total N = 3.0 of % total OM
   [Based on Caramancion (1971).]

   c) estimate kg of N/ha = % total N x Soil loss (in kg/ha)

   d) convert kg of N/ha to kg of Urea/ha by the formula:

   $$\frac{\text{kgN/ha}}{0.45} = \frac{\text{kg of urea}}{\text{ha}}$$

   e) calculate the weighted average kg of Urea/ha:

   $$= \frac{\text{(Urea/ha) (nos. of has./LMU)}}{\text{Total No. of hectares for all sample LMU's}}$$

   f) compute the weighted kg Urea/ton of soil:

   $$= \frac{\text{(kg Urea/LMU)}}{\text{[(Soil Loss/LMU)(No. of ha/LMU)]}}$$

2. To estimate kg of P and kg P_2O_5

   a) Determine % total P in the soil using the relationship: Available P (%) = (1.28) (% total P)*

   b) Compute kg P/ha = % total P x Soil Loss (kg/ha)

   c) Compute Kg P_2O_5 loss/ha* = kgP/ha X $\frac{P_2O_5}{2P}$

d) Estimate the weighted average kg $P_2 0_5$/ha =

$$\frac{(\text{kg } P_2 0_5/\text{ha})\ (\text{No. of has/LMU})}{\text{Total Number of Has. of all sample LMU}}$$

e) Calculate the weighted average kg $P_2 0_5$/ton =

$$\frac{\text{kg } P_2 0_5/\text{LMU}}{[(\text{Soil Loss/LMU})(\text{No. of ha/LMU})]}$$

3. To estimate the weighted kg K and kg $K_2 0$ per ton given exchangeable K (meq/100g)

a) Convert exchangeble K in meqK/100 gm to exchangeable gm k/gm soil loss using the conversion factor of 1 meq K = 0.039 gm K [Based on Oagmat, R.D. (1980)]

b) compute gm K total/gmm soil = $\dfrac{\text{gm K exch/100 gm soil}}{0.10}$

[Exchangeable K = 10% total K; Available K (%) = 1% total K (Bonoan, 1984).]

c) calculate kg K/ha = gm K total/Kg/ha x Total soil loss in gm soil

d) estimate Kg $K_2 0$ lost/ha = (Kg K/ha) x $K_2 0$/2K

e) compute for the weighted average Kg $K_2 0$ lost/ha

f) compute for the weighted average Kg $K_2 0$/ton of soi loss =

$$\frac{\text{Kg } K_2 0/\text{LMU}}{\text{'Soil Loss/LMU)(No. of ha/LMU)}}$$

Source: Francisco, 1986

Appendix 2.2

Estimation of the economic import parity price of urea, solophos, and muriate of potash, Magat Watershed area, 1985.

ITEM	UREA	TSP	MP
World market price[a] ($/MT)	260	191	108
add: bagging costs	-	30	30
add: ocean freight and insurance to Manila ($/MT)	30	30	40
	290	257	178
CIF Manila			
add: port charges, Handling and storage ($/MT)	12	12	12
add: transport cost dock market ($/MT)	1	1	1
($/MT)	303	270	19
add: dealer's margin(20%)($/MT)	61	54	38
Market Price	364	324	229
add: transport cost-market to project area Magat ($/MT)	4	4	4
Farm Gate Price ($/MT)	368	328	233
at OER of $1=₱20 (P/MT)	7,360	6,560	4,660
at SER of $1=₱26.80 (P/MT)	9,962	8,790	6,244
or (₱/kg)	986	879	624

[a] World Bank Commodity Forecasts, January 1984. Projections were expressed in 1981 constant dollar and adjusted by the World Bank's Manufacturing Unit Value (MUV) Index to reflect 1984 constant prices.

Source: Francisco, 1986, with data from Madecor, 1985.

Appendix 2.3

Land Mapping Units (LMUs) for the Magat Watershed, Showing Land Use Distribution.

LMU	TOTAL	LAND USE	AREA (HA)	%
1.1	4,570	River wash	4,570	1.11
1.2	2,825	Paddy rice irrigated	1,232	0.32
		Diversified crops	1,482	0.36
		Built-up areas (residential)	20	0.01
1.3a	29,580	Paddy rice irrigated	27,330	6.62
		irrigated paddy rice (terrace)	372	0.10
		Residential	1,822	0.44
		Orchard	56	0.01
1.3b	2,070	Paddy rice irrigated	2,054	0.50
		Residential	16	0.00
1.4	477	Paddy rice irrigated	365	0.09
		irrigated paddy (terrace)	112	0.03
1.5	4,650	Paddy rice irrigated	2,890	0.70
		irrigated paddy rice (terrace)	974	0.24
		diversified crops	126	0.03
		residential	660	.16
2.1a	7,597	open grassland	6,423	1.55
		primary forest	524	0.13
		secondary forest	407	0.10
		irrigated paddy rice (terrace)	215	0.05
		residential	28	0.01
2.1b	5,385	open grassland	4,259	1.04
		primary forest	1,106	0.27
		secondary forest	10	0.00
2.1c	1,625	open grassland	492	0.12
		primary forest	37	0.00
		secondary forest	764	0.19
		irrrigated paddy rice (terrace)	332	0.08
2.2b	5,145	open grassland	636	0.16
		primary forest	841	0.20
		secondary forest	3,053	0.74
		irrigated paddy rice (terrace)	615	0.15

Appendix 2.3. (cont'd).

LMU	TOTAL	LAND USE	AREA (HA)	%
2.2c	3,550	open grassland	3,169	0.77
		primary forest	352	0.08
		irrigated paddy rice (terrace)	29	0.01
2.3a	265	open grassland	94	0.02
		primary forest	45	0.01
		irrigated paddy rice (terrace)	126	0.03
2.2.30	5,680	open grassland	554	0.14
		primary forest	244	0.06
		secondary forest	1,539	0.37
		irrigated paddy rice (terrace)	3,343	0.81
2.3c	810	primary forest	464	0.11
		irrigated paddy rice (terrace)	346	0.08
2.4a	3,970	open grassland	3,149	0.76
		primary forest	821	0.20
2.4b	301	open grassland	125	0.03
		primary forest	31	0.01
		secondary forest	138	0.03
		irrigated paddy rice (terrace)	7	0.00
2.5a	7,090	open grassland	996	0.24
		primary forest	4,417	1.07
		secondary forest	1,677	0.41
2.5b	10,590	open grassland	2,595	0.63
		primary forest	1,572	0.38
		secondary forest	6,387	1.55
		irrigated paddy rice (terrace)	30	0.01
		residential	6	0.0
2.6a	4,420	open grassland	4,410	1.07
		secondary forest	10	.00
2.6b	15,391	open grassland	15,026	3.64
		secondary forest	200	0.05
		irrigated paddy rice (terrace)	161	0.04
2.6c	17,528	residential	4	0.00
		open grassland	17,414	4.22
		secondary forest	62	40.02
		irrigated paddy rice (terrace)	48	0.01

Appendix 2.3. (cont'd)

LMU	TOTAL	LAND USE	AREA (HA)	%
2.7	2,785	open grassland	1,281	0.31
		primary forest	56	0.01
		secondary forest	1,000	
		irrigated paddy rice (terrace)	436	0.11
		residential	12	0.01
2.8		open grassland	352	0.09
		primary forest	213	0.05
2.9a	2,407	open grassland	2,256	0.55
		non-irrigated paddy rice (terrace)	143	0.03
2.9b	11,225	open grassland	11,133	2.70
		secondary forest	54	0.01
		residential	38	0.01
2.9c	12,860	open grassland	12,672	3.07
		primary forest	86	0.02
		secondary forest	102	0.03
2.10	7,065	open grassland	6,931	1.68
		primary forest	18	0.00
		secondary	116	0.03
2.11a	5,390	open grassland	3,641	0.88
		primary forest	314	0.08
		secondary forest	1,425	0.35
		residential	10	0.00
2.11b	11,305	open grassland	4,496	1.09
		primary forest	109	0.03
		secondary forest	5,812	1.41
		paddy rice non-irrigated	672	0.16
		orchard	216	0.05
2.11c	7,325	open grassland	7,110	1.73
		primary forest	32	0.01
		irrigated paddy rice	183	0.04

LMU	TOTAL	LAND USE	AREA (HA)	%
2.12a	8,320	open grassland	4,563	1.10
		primary forest	354	0.09
		secondary forest	2,828	0.69
		irrigated paddy rice (terrace)	571	0.14
		residential	4	0.00
2.12b	49,252	open grassland	20,992	5.10
		primary forest	6,435	1.56
		secondary forest	19,085	4.63
		irrigated paddy rice (terrace)	2,739	0.66
2.13	735	open grassland	162	0.09
		secondary forest	573	0.09
3.1a	5,811	open grassland	906	0.22
		primary forest	3,598	0.87
		secondary	845	0.21
		paddy rice non-irrigated	302	0.07
		irrigated paddy	160	0.04
3.1b	50,508	open grassland	3,677	0.89
		primary forest	37,723	9.15
		secondary forest	8,060	1.95
		paddy rice non-irrigated	12	0.00
		irrigated paddy rice (terrace)	460	0.11
		residential	126	0.03
3.2a	2,065	open grassland	1,138	0.28
		secondary forest	927	0.22
3.2b	100,602	open grassland	17,840	4.32
		primary forest	42,820	10.39
		secondary forest	36,028	8.74
		irrigated paddy rice (terrace)	3,868	0.94
		residential	46	0.01
			------	-----
			412,303	100.00

Source: Francisco, 1986

Appendix 2.4

There were four soil series identified and mapped in the project area and were tentatively named Annam, Bunga, Guimbalaon and Mahipon. The main characteristics and recommended use of these soils are as follows:

Annam series. The Annam soil series is primarily a mountain soil derived from weathered igneous rocks such as diorite, basalt, dacite and metavolcanic materials. During the survey most of this soil was covered with grass, some with secondary growth forest, logged-over areas and residential places. This type of soil occurs on the slopes greater than 15 percent. It is moderately deep, usually from 50 to 130 cm, but boulders are exposed on the steep slopes. The dominant color is brown to reddish brown. The dominant texture is clay loam and is well-drained internally.

It is strongly acidic with an average pH of 5.5. Its organic matter on the surface soil is moderately high, 3.5%; but its phosphorus and potassium contents are low, 7.04 ppm and 0.17 m.e./100 g, respectively. It has manganese concretions on the surface soil and a cation exchange capacity of 28.2 m.e./100 g.

Based on its land capability classification, this soil is recommended for tree and forest crops. This soil will not need liming at the start but may develop higher acidity with nitrogen fertilizer applications. It needs nitrogen, phosphorous and potassium fertilization.

Bunga series. The Bunga series occurs in a level to nearly level collu-alluvial landscape and is derived from quarternary alluvian/talus deposits and terrace gravels. The dominant color is dark gray to gray brown with strong brown and light gray mottles. It has a clayey texture, deep (147-155 cm), moderately well-drained externally but poorly drained internally.

The Bunga series is strongly acidic with a pH of 5.4 on the surface soil and 5.6 in the subsoil. Its organic matter is moderate (2.53%), phosphorus is very low (0.18 ppm) and potassium is moderate (0.33 m.e./100 g).

This soil occupies only 990 hectares and is already devoted to paddy rice production. No change is recommended in the use of this soil. It needs phosphorus and nitrogen fertilization.

Guimbalaon series. The Guimbalaon series is a mountain soil derived primarily from igneous rocks such as diorite, basalt and metavolcanic materials. Smaller areas whose soils are derived from sedimentary rocks such as sandstone shale, mudstone and conglomerate are included in this series. This soil is predominantly clayey in texture, moderately deep (usually deeper than 50 cm) and well-drained. One distinguishing characteristic of this soil is the presence of boulder and rock outcrops. The surface soil is dark gray to dark grayish brown with soft manganese concretions.

The Guimbalaon series is strongly acidic with a pH of 5.5. The organic matter is relatively high (4.14%) but its phosphorus is very low (0.30 ppm). Its potassium content is moderate (0.24 m.e./100 g).

This soil is recommended for tree and forest crops. At the start, it will not need liming but it might develop higher acidity with nitrogen fertilization. It needs high phosphorus fertilization and moderate rates of nitrogen and potassium.

Mahipon series. The Mahipon series occurs on the level to nearly level collu-alluvial landscape derived from guarternary alluvium/talus deposits and terrace gravels. This soil is dominantly clayey in texture, moderately deep (usually 60 cm or deeper) and well-drained on the surface but with restricted drainage internally. The surface soil is gray to grayish brown with few manganese concretions mixed with gravel and stones.

This soil is moderately acidic (pH 5.8). The organic matter is moderate (3.04%) but the soil is very low in phosphorus (0.76 ppm), although moderate in potassium.

This soil occupies about 6,220 hectares in the northwestern portion of the project area and is being planted to rainfed rice and upland crops. Some areas are in grass. About 5,375 hectares of this soil are on first class land and 847 hectares are on second class land.

Because of its position in the landscape of mild slope, this soil is recommended for cultivated agriculture either for rainfed rice production or for upland crops. High fertilization with phosphorus and moderate in nitrogen and potassium are required.

Source: MADECOR-NIA, 1979 as summarized from the Bureau of Soils, Soil Survey Report, 1977.

Appendix 2.5

Table 1. Area, Percentage and Present Land Use of soil mapping unit, Pantabangan and Canili-Diayo Watershed, 1977

Soil Mapping Unit (Symbol and Description)		Area (ha)	Percentage	Present Land Use
AmGD3	Annam silty clay loam; 15.0 to 25.0 percent slopes; severely eroded	3,065.00	3.37	grass & kaingin
AmHD4	Annam clay loam; 15.0 to 25.0 percent slopes; very severely eroded	1,037.50	1.14	grass & residential site
AmHE3	Annam clay loam; 25.0 to 40.0 percent slopes; severely eroded	660.00	0.73	savannah
AmHE4	Annam clay loam; 25.0 to 40.0 percent slopes; very severely eroded	1,832.50	2.02	grass & kaingin
AmHE7	Annam clay loam; 25.0 to 40.0 percent slopes; excessively eroded with gullies more than 30 meters apart	1,012.50	1.11	grass
AmHF1	Annam clay loam; more than 40.0 percent slopes; slightly eroded	18,357.50	20.10	primary forest
AmHF3	Annam clay loam; more than 40.0 percent slopes; severely eroded	3,427.50	3.77	grass, secondary forest, kaingin
AmHF4	Annam clay loam; more than 40.0 percent slopes; very severely eroded	1,715.00	1.89	grass, savannah and kaingin
BuBA	Bunga clay; 0.0 to 3.0 percent slopes	990.00	1.09	irrigated rice

Table 1. cont'd

Soil Mapping Unit (Symbol and Description)		Area (ha)	Percentage	Present Land Use
GnHC4	Guimbalaon clay loam; 8.0 to 15.0 percent slopes; very severely eroded	777.50	0.86	grass
GnGD3	Guimbalaon silty clay loam; 15.0 percent slopes; severely eroded	420.00	0.46	grass
GnGE3	Guimbalaon silty clay loam; 25.0 to 40.0 percent slopes; severely eroded	305.00	0.34	grass and non-irrigated rice
GnHE4	Guimbalaon clay loam; 25.0 to 40.0 percent slopes, very severely eroded	937.50	1.05	primary forest & kaingin
GnHE7	Guimbalaon clay loam; 25.0 to 40.0 percent slopes; excessively eroded with gullies more than 30 meters apart	4,587.50	5.05	grass and savannah
GnGF1	Guimbalaon silty clay loam; more than 40.0 percent slopes; slightly eroded	17,502.50	19.25	primary forest
GnGF2	Guimbalaon silty clay loam; more than 40.0 percent slopes; moderately eroded	385.00	0.42	secondary forest
GnGF3	Guimbalaon silty clay loam; more than 40.0 percent slopes; severely eroded	2,400.00	2.64	secondary forest

Table 1. cont'd

Soil Mapping Unit (Symbol and Description)		Area (ha)	Percentage	Present Land Use
GnHF4	Guimbalaon clay loam; more than 40.0 percent slopes; very severely eroded	7,025.00	7.73	grass
GnHF7	Guimbalaon clay loam; more than 40.0 percent slopes; gullies more than 30 meters apart	717.50	0.80	grass
GnsGE7	Guimbalaon gravelly silty clay loam; shallow phase; 25.0 to 40.0 percent slopes excessively eroded with gullies more than 30 meters apart	1,307.50	1.44	grass & residential
GnsGF1	Guimbalaon gravelly silty clay loam; shallow phase; more than 40.0 percent slopes; slightly eroded	992.50	1.09	grass & savannah
GnsHF4	Guimbalaon gravelly clay loam; shallow phase; more than 40.0 percent slopes; very severely eroded	6,175.00	6.79	grass & savannah
GnsHF5	Guimbalaon gravelly clay clay loam shallow phase; more than 40.0 percent slopes; excessively eroded	855.00	0.94	grass & kaingin
MhHA	Mahipon clay loam; 0.0 to 3.0 percent slopes	5,375.00	5.91	irrigated and non-irrigated rice
MhHB1	Mahipon clay loam; 3.0 8.0 percent slopes; slightly eroded	672.50	0.74	non-irrigated rice

MhHB3	Mahipon clay loam; 3.0 to 8.0 percent slopes; severely eroded	175.00	0.19	grass
Rw	Riverwash gravelly and stony with loose sand	175.00	0.19	
W	Includes the flooded surface area of the reservoir	7,997.50	8.80	
TOTAL		90,900.00	100.00%	

Appendix 2.6.
List of SMU's in each Land Use Category*

SMU's	Grassland & Savannah	Primary and Secondary Forest	Kaingin & Diversified Croplands	Irrigated & Rainfed Ricelands
AmGD3	x	x	x	x
AmHD4	x			
AmHE3	x	x		
AmHE4	x	x	x	
AmHE7	x	x		
AmHF1	x	x	x	
AmHF3	x	x	x	x
AmHF4	x	x	x	x
BuBA	x			x
GnHC4	x	x	x	x
GnGD3	x	x		x
GnGE3	x	x	x	x
GnHE4	x			x
GnHE7	x	x	x	x
GnGF1	x	x	x	x
GnGF2		x		
GnGF3	x	x		x
GnHF4	x	x	x	x
GnHF7	x	x		x
GnsGE7	x	x		
GnsGF1	x	x	x	
GnsHF4	x	x		x
GnsHF5	x	x	x	x
MhHA	x	x	x	x
MhHB1	x	x		x
MhHB3	x			

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*As collated from soil polygon data of W. David.

APPENDIX 2.7

Table 1. Nitrogen content and urea equivalent per unit volume and layer of soil for each sample SMU in primary/secondary forest areas, Pantabangan and Canili-Diayo Watersheds, 1977

SMU1	Soil	Bulk	Nitrogen Content and Urea Equivalent					
Area	depth	density	per ha-cm of soil				Total	
(has.)	(cm.)	(t/ha-cm)	% OM	%N	kg N	kg Urea	kg N/cm	kg Urea/cm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
AmHF1	0-5	130	3.51	0.1053	136.89	304.20	1252568.14	2783484.76
9150.18	5-10	130	3.51	0.1053	136.89	304.20	1252568.14	2783484.76
	10-15	130	3.38	0.1014	131.82	292.93	1206176.73	2680392.73
	15-20	130	3.38	0.1014	131.82	292.93	1206176.73	2680392.73
	20-25	130	2.31	0.0693	90.09	200.20	824339.72	1831866.04
	25-30	130	2.31	0.0693	90.09	200.20	824339.72	1831866.04
	30-35	130	2.16	0.0648	84.24	187.20	770811.16	1712913.70
	35-40	130	2.16	0.0648	84.24	187.20	770811.16	1712913.70
	40-45	130	2.16	0.0648	84.24	187.20	770811.16	1712913.70
	45-50	130	2.16	0.0648	84.24	187.20	770811.16	1712913.70

SMU2	Soil	Bulk	Nitrogen Content and Urea Equivalent					
Area	depth	density	per ha-cm of soil				Total	
(has.)	(cm.)	t/ha-cm)	% OM	%N	kg N	kg Urea	kg N/cm	kg Urea/cm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
AmHF3	0-5	130	3.37	0.1011	131.43	292.07	778140.52	1729201.14
5920.57	5-10	130	3.37	0.1011	131.43	292.07	778140.52	1729201.14
	10-15	130	3.17	0.0951	123.63	274.73	731960.07	1626577.93
	15-20	130	3.17	0.0951	123.63	274.73	731960.07	1626577.93
	20-25	130	1.90	0.0570	74.10	164.67	438714.24	974920.53
	25-30	130	1.90	0.0570	74.10	164.67	438714.24	974920.53
	30-35	130	1.76	0.0528	68.64	152.53	406387.92	903084.28
	35-40	130	1.76	0.0528	68.64	152.53	406387.92	903084.28
	40-45	130	1.76	0,0528	68.64	152.53	406387.92	903084.28
	45-50	130	1.76	0.0528	68.64	152.53	406387.92	903084.28

SMU3	Soil	Bulk	Nitrogen Content and Urea Equivalent					
Area	depth	density	per ha-cm of soil				Total	
(has.)	(cm.)	(t/ha-cm)	% OM	%N	kg N	kg Urea	kg N/cm	kg Urea/cm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
GnGF1	0-5	120	4.48	0.1344	161.28	358.40	1745497.96	3878884.35
10822.78	5-10	120	4.48	0.1344	161.28	359.40	1745497.96	3878884.35
	10-15	120	3.90	0.1170	140.40	312.00	1519518.31	3376707.36
	15-20	120	3.90	0.1170	140.40	312.00	1519518.31	3376707.36
	20-25	120	2.87	0.0861	103.32	229.60	1118209.63	2484910.28
	25-30	120	2.87	0.0861	103.32	229.60	1118209.63	2484910.28
	30-35	120	1.95	0.0585	70.20	156.00	759759.16	1688353.68
	35-40	120	1.95	0.0585	70.20	156.00	759759.16	1688353.68
	40-45	120	1.69	0,0507	60.84	135.20	658457.94	1463239.95
	45-50	120	1.69	0.0507	60.84	135.20	658457.94	1463239.85

Table 1. Cont.

SMU4 Area (has.) (1)	Soil depth (cm.) (2)	Bulk density (t/ha-cm) (3)	Nitrogen Content and Urea Equivalent per ha-cm of soil				Total	
			% OM (4)	%N (5)	kg N (6)	kg Urea (7)	kg N/cm (8)	kg Urea/cm (9)
BnGF3 1504.32	0-5	120	3.78	0.1134	136.08	302.40	204707.87	454906.37
	5-10	120	3.78	0.1134	136.08	302.40	204707.87	454906.37
	10-15	120	3.65	0.1095	131.40	292.00	197667.65	439261.44
	15-20	120	3.65	0.1095	131.40	292.00	197667.65	439261.44
	20-25	120	2.58	0.0774	92.88	206.40	139721.24	310491.65
	25-30	120	2.58	0.0774	92.88	206.40	139721.24	310491.65
	30-35	120	2.58	0.0774	92.88	206.40	139721.24	310491.65
	35-40	120	2.58	0.0774	92.88	206.40	139721.24	310491.65
	40-45	120	2.58	0.0774	92.88	206.40	139721.24	310491.65
	45-50	120	2.58	0.0774	92.88	206.40	139721.24	310491.65

Table 2. Weighted average nitrogen content and urea equivalent per ha-cm of soil for each soil layer, primary/secondary forest areas, Pantabangan and Canili-Diayo Watersheds, 1977.

Soil depth (cm) (1)	kg N/ ha-cm (2)	kg Urea/ ha-cm (3)
0-5	145.30	322.89
5-10	145.30	322.89
10-15	133.42	296.48
15-20	133.42	296.48
20-25	92.01	204.48
25-30	92.01	204.48
30-35	75.80	168.44
35-40	75.80	168.44
40-45	72.10	160.22
45-50	72.10	160.22

Table 3. Nitrogen and urea equivalent lost per hectare per year given a constant erosion rate* for primary/secondary forest areas, Pantabangan and Canili-Diayo Watersheds, 1977.

Soil loss rate: 0.02 cm/year
No. of years to lose each 5-cm layer = 5/0.02 = 250

Soil depth (cm) (1)	Nitrogen and urea equivalent lost kg N/ha (2)	kg Urea/ha (3)	Cumulative years to lose soil layers (4)
0-5	2.91	6.46	250
5-10	2.91	6.46	500
10-15	2.67	5.93	750
15-20	2.67	5.93	1000
20-25	1.84	4.09	1250
25-30	1.84	4.09	1500
30-35	1.52	3.37	1750
35-40	1.52	3.37	2000
40-45	1.44	3.20	2250
45-50	1.44	3.20	2500

Table 4. Nitrogen and urea equivalent lost per ton of soil eroded given a constant erosion rate for primary/secondary forest areas, Pantabangan and Canili-Diayo Watersheds, 1977.

Soil loss rate: 2.15 tons/ha/yr

Soil depth (cm) (1)	Nitrogen and urea equivalent lost kg N/ton (2)	kg Urea/ton (3)
0-5	1.35	3.00
5-10	1.35	3.00
10-15	1.24	2.76
15-20	1.24	2.76
20-25	0.86	1.90
25-30	0.86	1.90
30-35	0.71	1.57
35-40	0.71	1.57
40-45	0.67	1.49
45-50	0.67	1.49

Table 1. Phosphorus content and solophos (P_2O_5) equivalent per unit volume and layer of soil for each sample SMU in primary/secondary forest areas, Pantabangan and Canili-Diayo Watersheds, 1977.

SMU1 Area (has.)	Soil depth (cm.)	Bulk density (t/ha-cm)	Phosphorus Content and P205 Equivalent per ha-cm of soil				Total	
			Avail P ppm	Total P %	kg P	kg P205	kg P/cm	kg P205/cm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
AmHF1	0-5	130	6.01	0.0470	61.04	139.78	558518.41	1279007.16
9150.18	5-10	130	6.01	0.0470	61.04	139.78	558518.41	1279007.16
	10-15	130	5.78	0.0452	58.70	134.43	537144.16	1230060.13
	15-20	130	5.78	0.0452	58.70	134.43	537144.16	1230060.13
	20-25	130	5.78	0.0452	58.70	134.43	537144.16	1230060.13
	25-30	130	5.78	0.0452	58.70	134.43	537144.16	1230060.13
	30-35	130	4.68	0.0366	47.53	108.85	434919.49	995965.64
	35-40	130	4.68	0.0366	47.53	108.85	434919.49	995965.64
	40-45	130	4.68	0.0366	47.53	108.85	434919.49	995965.64
	45-50	130	4.68	0.0366	47.53	108.85	434919.49	995965.64

SMU2 Area (has.)	Soil depth (cm.)	Bulk density (t/ha-cm)	Phosphorus Content and P205 Equivalent per ha-cm of soil				Total	
			Avail P ppm	Total P %	kg P	kg P205	kg P/cm	kg P205/cm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
AmHF3	0-5	130	3.42	0.0267	34.73	79.54	205647.30	470932.31
5920.57	5-10	130	3.42	0.0267	34.73	79.54	205647.30	470932.31
	10-15	130	2.78	0.0217	28.23	64.66	167163.59	382804.63
	15-20	130	2.78	0.0217	28.23	64.66	167163.59	382804.63
	20-25	130	0.62	0.0048	6.30	14.42	37281.09	85373.69
	25-30	130	0.62	0.0048	6.30	14.42	37281.09	85373.69
	30-35	130	0.62	0.0048	6.30	14.42	37281.09	85373.69
	35-40	130	0.62	0.0048	6.30	14.42	37281.09	85373.69
	40-45	130	0.62	0.0048	6.30	14.42	37281.09	85373.69
	45-50	130	0.62	0.0048	6.30	14.42	37281.09	85373.69

SMU3 Area (has.)	Soil depth (cm.)	Bulk density (t/ha-cm)	Phosphorus Content and P205 Equivalent per ha-cm of soil				Total	
			Avail P ppm	Total P %	kg P	kg P205	kg P/cm	kg P205/cm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
GnGF1	0-5	120	0.70	0.005469	6.56	15.03	71024.49	162646.09
10822.78	5-10	120	0.70	0.005469	6.56	15.03	71024.49	162646.09
	10-15	120	0.35	0.002734	3.28	7.51	35512.25	81323.05
	15-20	120	0.35	0.002734	3.28	7.51	35512.25	81323.05
	20-25	120	0.35	0.002734	3.28	7.51	35512.25	81323.05
	25-30	120	0.35	0.002734	3.28	7.51	35512.25	81323.05
	30-35	120	0.35	0.002734	3.28	7.51	35512.25	81323.05
	35-40	120	0.22	0.001719	2.06	4.72	22321.98	51117.34
	40-45	120	0.22	0.001719	2.06	4.72	22321.98	51117.34
	45-50	120	0.22	0.001719	2.06	4.72	22321.98	51117.34

Table 1. Cont.

SMU4 Area (has.)	Soil depth (cm.)	Bulk density (t/ha-cm)	Phosphorus Content and P205 Equivalent per ha-cm of soil				Total	
			Avail P ppm	Total P %	kg P	kg P205	kg P/cm	kg P205/cm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
6n6F3 1504.32	0-5	120	0.70	0.005469	6.56	15.03	9872.10	22607.11
	5-10	120	0.70	0.005469	6.56	15.03	9872.10	22607.11
	10-15	120	0.44	0.003438	4.13	9.45	6205.32	14210.18
	15-20	120	0.44	0.003438	4.13	9.45	6205.32	14210.18
	20-25	120	0.35	0.002734	3.28	7.51	4936.05	11303.55
	25-30	120	0.35	0.002734	3.28	7.51	4936.05	11303.55
	30-35	120	0.35	0.002734	3.28	7.51	4936.05	11303.55
	35-40	120	0.35	0.002734	3.28	7.51	4936.05	11303.55
	40-45	120	0.35	0.002734	3.28	7.51	4936.05	11303.55
	45-50	120	0.35	0.002734	3.28	7.51	4936.05	11303.55

Table 2. Weighted average phosphorus content and P205 equivalent per ha-cm of soil for each soil layer, primary/secondary forest areas, Pantabangan and Canili-Diavo Watersheds, 1977.

Soil depth (cm) (1)	kg P/ ha-cm (2)	kg P205/ ha-cm (3)
0-5	30.84	70.63
5-10	30.84	70.63
10-15	27.23	62.36
15-20	27.23	62.36
20-25	22.44	51.39
25-30	22.44	51.39
30-35	18.71	42.85
35-40	18.23	41.75
40-45	18.23	41.75
45-50	18.23	41.75

Table 3. Phosphorus and solophos (P_2O_5) equivalent lost per hectare per year, given a constant erosion rate for primary/secondary forest areas, Pantabangan and Canili-Diayo Watersheds, 1977.

Soil loss rate: 0.02 cm/year
No. of years to lose each 5-cm layer = 5/0.02 = 250

Soil depth (cm)	Phosphorus and P205 equivalent lost		Cumulative years to lose soil layers
	kg P205/ha	kg P205/ha	
(1)	(2)	(3)	(4)
0-5	0.62	1.41	250
5-10	0.62	1.41	500
10-15	0.54	1.25	750
15-20	0.54	1.25	1000
20-25	0.45	1.03	1250
25-30	0.45	1.03	1500
30-35	0.37	0.86	1750
35-40	0.36	0.83	2000
40-45	0.36	0.83	2250
45-50	0.36	0.83	2500

Table 4. Phosphorus and solophos (P_2O_5) equivalent lost per ton of soil eroded, given a constant erosion rate for primary/secondary forest areas, Pantabangan and Canili-Diayo Watersheds, 1977.

Soil loss rate: 2.15 tons/ha/yr

Soil depth (cm)	Phosphorus and P205 equivalent lost	
	kg P/ton	kg P205/ton
(1)	(2)	(3)
0-5	0.29	0.66
5-10	0.29	0.66
10-15	0.25	0.58
15-20	0.25	0.58
20-25	0.21	0.48
25-30	0.21	0.48
30-35	0.17	0.40
35-40	0.17	0.39
40-45	0.17	0.39
45-50	0.17	0.39