Special Papers

The Economics of Soil Erosion: Theory, Methodology and Examples

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1. Introduction

Soil is an essential input to farming. This is especially true throughout Southeast Asia (SEA), where agricultural production is crucial to development, the livelihoods of the majority of the population depend on the primary sector, and non-labour inputs for the poorest farms are negligible. And yet agricultural land use in SEA countries often results in the degradation of natural soil fertility and reduced productivity. Soil degradation under farming also inflicts external or off-site costs, through the processes of erosion, sedimentation and leaching.

The impacts of land degradation and the depletion of soil resources have profound economic implications for low income countries. Environmental damage results in loss of current income and increased risk, and particularly affects the poor. Degradation of land resources also threatens prospects for economic growth and future human welfare.

In the developing countries, empirical research on the economic costs of land degradation is confined largely to analysis at the level of individual farms or watersheds. On-site impacts are most frequently studied, typically by analysis of the effect of soil loss on crop production. Limited data suggest that the impact of soil erosion on crops may be more dramatic in the tropics than under temperate conditions, due to the relative fragility of tropical soils, or more extreme climatic conditions (Lal 1981 and 1987; Stocking 1984). The off-site impacts of land degradation are often much harder to evaluate, because the off-site benefits provided by land resources are not traded at all.

The available evidence indicates that the costs of land degradation, and thus the benefits of conservation, may be substantial in developing countries, despite relatively low average returns to agriculture. Estimates of the cost of land degradation in these countries vary from under 1% to over 15% of GNP (Barbier and Bishop 1995). However, these calculations are often more illustrative than definitive, due to the paucity of empirical data and various methodological problems. Moreover, attempts to estimate the costs and benefits of soil conservation on a regional or national level confront serious methodological problems (Stocking 1987).

The purpose of the following paper is to provide an overview of an economic analysis of soil erosion, concentrating particularly on explaining the farm-level economics of soil erosion and discussing with examples the appropriate methodology for measuring on and off-site costs.

2. The Farm-Level Economics of Soil Erosion

To understand fully why some farmers may decide to invest in soil conservation whereas others may not requires adopting an economic approach to soil erosion.

Soil is essentially a semi-renewable resource. Although one could argue that topsoil accretes, it does so at an extremely slow rate. In general, the rate at which topsoil is degraded' or 'eroded' through cultivation is generally faster than the rate at which it regenerates. Thus soil in agriculture is usually treated as a potentially depletable resource, and it is generally assumed that most farming practices will result in rates of erosion that will exceed the natural' or background' rate of soil erosion that would occur if no cultivation took place.

From an economic perspective, soil conservation implies saving' soil for future use. Alternatively, a farmer may choose to work the soil harder today, at the expense of more erosion and less soil available for the future. This suggests that, as with other natural resources, the terms conservation and depletion as applied to soil erosion have a particular economic meaning. That is, *conservation* essentially implies a redistribution of resource use rates into the *future*, whereas *depletion*, or in the case of soil *erosion*, implies a redistribution of resource use rates towards the *present*. This terminology proves to be extremely important in thinking about a farmer's incentive to invest in more soil conservation.

For instance, this economic approach to soil erosion and conservation would suggest that the optimal rate of soil conservation should not be confused with eliminating soil erosion altogether, or even with reducing soil erosion to some background' or ideal' rate[1]. Rather, the optimal level of soil conservation is the level at which the marginal benefits of additional conservation just equal its costs. Since soil conservation is not costless, then clearly it is not optimal to reduce erosion to zero - even if it is physically possible to do so.

From the farmer's perspective, there are essentially two components to the *costs* of soil erosion:

- *direct costs* - the costs to the farmer of the effort (i.e. labour), materials, equipment, physical structures, etc. that are required to undertake soil conservation measures
- *foregone output*[2] - any loss of current output that results from using less' soil today or less land.

In comparison, the benefits that a farmer receives from soil conservation derives from soil being a potential income-yielding asset. The 'stock' of soil available to a farmer is essentially an economic asset that can be exploited through cultivation to yield a stream of present and future income. Thus to the farmer, the *benefits* of soil conservation are essentially the perceived gains in having more rather than less soil available currently and in the future. There are likely to be two types of such benefits of soil conservation:

- the *gains* in current and future production and thus income accruing to the farmer from having

more soil available today and in the future.
- any additional future*resale* or *bequest* value that accrues to the farmer from having more soil and thus more potential land productivity at the time of the future bequest or sale.

Alternatively, we can turn this around and say that the economic *costs* of *soil erosion* are that the farmer must forego the above future productivity benefits. Hence the economics literature sometimes refers to these losses as the *user costs* of any soil erosion incurred today.

Consequently, from the perspective of the individual farmer, the optimal level of soil conservation (and thus soil erosion) can be determined in two ways:

- it is the level of erosion at which the additional user costs of soil erosion avoided just equal the additional costs of soil conservation, or
- it is the level at which the present value of the additional income (and resale/bequest value) derived from soil conservation just equal the additional costs of soil conservation.

In the appendix of this paper, a formal model of the farmer's decision to conserve or deplete soil is depicted.

3. Private Versus Social Rates of Erosion

If each farming household in Southeast Asia always eroded soil at an optimal rate, and if these optimal private rates of soil erosion were consistent with what all of society would wish erosion rates to be, then there would be no economic problem of soil erosion as such. Based on the marginal benefits and costs of additional conservation that it faced, each farming household would determine automatically its own private rate of soil erosion, and this rate would in turn automatically reflect the socially optimal rate of erosion.

However, it is much more likely that private rates of soil erosion diverge from social rates. Moreover, observed rates of soil erosion from cultivated land may not always even be privately optimal. There are several reasons for this.

First, at best farmers are concerned only with the *on-site* costs and benefits of soil erosion, whereas society must also be concerned with any *off-site* or external costs. Externalities are defined as costs or benefits arising in a process of production or consumption which are not reflected in market prices. A typical negative externality resulting from soil erosion on agricultural land is the sedimentation of downstream reservoirs, hydroelectric facilities or irrigation channels. The protection of watersheds provided by tree plantations, orchards and other perennial crops is an example of a positive externality. These off-site costs and benefits are not reflected in the prices of agricultural outputs, nor in farmer decision-making, but they are an integral part of the economic impacts of land degradation. Designing appropriate polices to correct such externalities is difficult. An efficient response may be to 'internalize' the off-site costs of land degradation through fiscal measures, e.g taxes on agricultural inputs or outputs, or through the development of legal mechanisms for the compensation of environmental externalities. However, the limited rural markets and weak institutions typical of many SEA countries reduce the appeal of such approaches. As a consequence, in regions where off-site costs are significant they would suggest that private rates of soil erosion diverge from social rates.

Imperfect land and capital markets may also play a significant role in affecting the farmer's decision to control soil erosion. The most reliable indicator that a farming household will have of the effects of soil erosion on future land productivity is through land prices. However, in many SEA countries, rural land markets are imperfect or distorted. Consequently, the user costs of soil erosion may not be reflected adequately or even bear any relation to land values. Similarly, the lack of effective rural credit markets may distort the farming household's decision as to whether it is worthwhile investing in protecting the soil because of its future productivity and income potential as opposed to exploiting it for immediate gain today. In other words, the opportunity cost' of conserving the soil may be extremely high. If the farmer has also to borrow in the short term to invest in conservation, then distorted or non-existent local capital markets may make the direct costs of conservation prohibitively expensive.

It is also likely that the farmer's *private rate of discount* - i.e. the value attached to future as opposed to present income - will be higher than the *social rate of discount*. A farmer's discount rate may be affected by both *pure time preference*, reflecting the farmer's attitude to risk and uncertainty as well as the level of household poverty, and the *marginal opportunity cost of capital*, which represents the scarcity value of savings and returns to alternative investments. It was noted above how distorted land and capital markets may affect the marginal opportunity cost of capital faced by the farming household. However, even without these distortions, private individuals are also presumed to have a high degree of time preference, and thus employ higher discount rates, on average, than society as a whole. The rationale is that society can more effectively minimize risk by diversifying its investments; and of course society 'lives' forever while individuals do not. This divergence between public and private rates of time preference leads individuals to discount future benefits excessively and thus to consume assets that society as a whole would have them conserve. In other words, society will ascribe a higher value to future crop yields foregone due to soil exhaustion than will farmers. Society is also likely to be more concerned about long run stability, sustainability and equity in agriculture, all of which may depend in some measure on conservation efforts (Conway and Barbier 1990). Hence a socially optimal level of soil depletion will usually be significantly below the level tolerated by farmers. The combination of widespread poverty and poorly developed land tenure institutions and rural capital markets in many SEA countries may also imply high rates of private time preference, and thus add to the significant divergence between public and private discount rates.

The farmer's decision to control soil erosion is clearly influenced by the future returns to a farming system, which in turn is affected by *technological improvements*. Technical innovation is largely devoted to devising *substitutes* for, or increasing the productivity of scarce factors. The depletion of a scarce natural resource poses a threat when it is considered *essential* to future economic opportunities, i.e. if there is no apparent substitute for the resource, if degradation is for all practical purposes irreversible and/or if its future value is uncertain but believed to be high (Pearce, Barbier and Markandya 1990). Fertile land clearly meets the definition of an essential resource, particularly in many low-income and lower middle-income economies which, despite development efforts over the past twenty-five years, still appear to be highly dependent on primary production from their resource base. In these countries subsistence agriculture accounts for a substantial proportion of national income and an overwhelming segment of the labour force. The prominent role of agriculture in national welfare in such countries justifies concern about the possible lack of substitutes for natural soil fertility, and the scarcity of alternative economic opportunities.

However, what holds for the economy as a whole may not hold for the individual farmer. From a private perspective, there are almost always substitutes for arable land, since individual farmers can often find alternative or supplementary occupations, and few people consider the value of their land in terms of national economic security. Hence farmers tend to treat soil fertility as just one income-producing asset among many, and as suggested already, there are many factors that may discourage them from maintaining soil fertility.

Finally, *other market, policy and institutional failures*, such as insecure tenure or ownership of the land, distorted market prices for inputs and outputs, imperfect competition, incomplete markets, etc., can all affect the farmer's perception of the costs and benefits of controlling soil erosion. Throughout Southeast Asia, agricultural policies in particular have the most direct impact on the incentives for farmers to engage in soil conservation. In general, there are two ways in which agricultural policies affect these incentives.

First, polices that affect the prices of agricultural products *do not automatically take into account the wider environmental costs* of agricultural land use. As discussed already, markets fail to reflect the *externalities* arising from the off-site costs of soil erosion. In addition, imperfect capital and land markets may mean that farmers ignore the *user costs* of soil erosion, and thus over-produce for agricultural markets. In the absence of deliberate policies to internalize these costs, and without well-functioning markets for agricultural land, the market will tend to 'underprice' soil resources, leading to excessive land degradation from a social point of view.

In addition, agricultural policies can affect production decisions such that sub-optimal land management practices are encouraged, resulting in unnecessary land degradation. This can occur in several ways (Barbier and Burgess 1992):

- higher aggregate crop prices and lower agricultural input costs increase the profitability of crop production, thus encouraging an *aggregate expansion* of agricultural production onto marginal or more erodible land
- the impact of agricultural pricing on the relative returns to agricultural production can influence long-run decisions to *invest* in sustainable land management and conservation
- changes in the relative prices of crops (and crop inputs) can influence the *substitution* of more environmentally benign cropping and farm production systems for systems that are more environmentally damaging
- the *variability* of crop prices and crop price inputs can affect farmers' choice of crops and cultivation practices, and decisions to invest in sustainable land management, by affecting the *risks* associated with alternative agricultural investments and production systems.

In addition to agricultural policy, other economic policies can also have profound effects on land use. Virtually any policy which distorts the market prices of agricultural inputs and outputs can alter incentives for soil conservation. The impact of specific policies on farmer decision-making and land degradation is often ambiguous, however, making generalization difficult. Impacts on households will vary to the extent that policies affect certain groups more than others.

Finally, soil conservation requires *access to inputs*: labour, capital (including land, equipment and materials, or the funds to obtain them) and information (technology). Poorer farmers - particularly female-headed households - often lack access to one or more of these inputs, preventing them from adopting conservation measures. Even when they know of appropriate technologies, farmers may lack access to sufficient labour to undertake soil conservation measures on their own, and may also suffer limited access to capital with which to hire additional manpower or purchase any tools required. For example, in many areas the best time to install or maintain soil conservation structures is at the beginning of the growing season, when soils are softened by rain and vegetation cover is light. But this is also the moment of peak labour demand for field preparation and planting. The true opportunity cost of soil conservation is thus often higher than at first appears, when considered in relation to other demands on farmers' resources.

To summarize, soil erosion is an economic problem if:

- farming households ignore all or some of the user costs of soil erosion
- any off-site, or external, costs are ignored.

Economic analysis of this problem requires:

- determining the farm-level incentives for soil conservation; i.e., to what extent is the farmer ignoring the user cost of soil erosion, and if so, why?
- measuring the on-site and off-site costs of soil erosion
- determining the appropriate policies and investments to correct the problem.

The remaining sections will focus principally on the second of these issues, employing examples from Southeast Asia.

4. Measuring On-Site Costs: Methodologies and Examples

In measuring the on-site costs of soil erosion the main objective is usually to estimate the present value of net income lost through excessive (i.e. sub-optimal) soil erosion. The methodologies for measuring these costs are generally straightforward, but they have to be used with care. As we shall see presently, a critical issue is determining what net income might be for the farming system 'without' erosion. The following section reviews briefly the various methodologies for measuring on-site costs, and illustrates them with some examples from Southeast Asia.

Methodologies

Figure 1 illustrates the basic methodology proposed in most empirical analyses for measuring the on-site cost of soil erosion on a plot of land[3]. The two curves depict for a farming household the present value of net revenues per hectare with and without erosion. The on-site cost of erosion would therefore be the difference between the two curves, or area A.

However, measuring A is not straightforward. The problem is that we observe the farm with erosion, and we do not necessarily know what land productivity and income would have been in the absence of erosion. Moreover, as discussed above, the optimal level of erosion on a farm will generally not be a 'zero level' of erosion.

Nevertheless, many studies of the on-site costs of soil erosion have attempted to estimate A in one of two different ways:

- *change in productivity approach* - the difference in crop yields with and without erosion, multiplied by the unit price of the crop, and less the costs of production
- *replacement cost approach* - as there often are nutrient and herbicide losses associated with erosion, on-site costs are sometimes measured in terms of the loss in marginal productivity of crop output from incremental changes in inputs, multiplied by the unit price of the crop, and less the costs of the foregone inputs.

Unfortunately, the application of both of these approaches to estimating the on-site cost of soil erosion is usually flawed and may lead to over-estimation of the on-site cost of soil erosion if not carefully applied. The problem again is that both approaches assume that the comparison is between a situation 'with' and 'without' erosion, as if it is possible to eliminate soil erosion altogether. This is simply not the case. No feasible technology exists to produce crops without some degree of erosion. In addition, as discussed in Section 2, even if it is feasible to reduce erosion to negligible levels, this can only be accomplished by the farmer investing in conservation measures, which is not a costless exercise.

The change in productivity approach is illustrated in Figure 2. Assume for simplicity that soil erosion does not affect the costs of production but only revenues, through impacts on crop yields.[4] Let R_o be the gross revenues per hectare of the farm if no soil loss occurred, which are also assumed to be the revenues at initial time T_o. However, soil erosion occurs over time so actual yields for any time $T > T_o$ will be less than R_o. The change inproductivity approach assumes that for any particular time period, T, the (undiscounted) revenueimpacts of yield losses from soil erosion in that period will be the distance AB between R_o and the gross revenues per hectare with erosion.

However, this method is likely to over-estimate the on-site costs of soil erosion. The assumption that gross revenues could be maintained indefinitely at R_o is not realistic. As argued previously, this is unlikely to be either feasible or optimal. Even if it is technically feasible to reduce soil erosion, the costs of investing in soil conservation on some plots of land may not be economically worthwhile. For other plots of land, it may be worthwhile reducing erosion and thus improving yields, but it may be too costly to restore yield and net income to the initial levels before erosion sets in. Thus measuring on-site costs in terms of all the net income losses associated with productivity changes before and after erosion on all cropland may be misleading.

The replacement cost approach is shown in Figure 3. Assume that the input (e.g. fertilizer) is used optimally, at the point where its price equals its value marginal product. Thus X_1 is the actual level of use of fertilizer. However, soil erosion and runoff will cause some of the fertilizer to be washed away, and consequently only X_o of the input is effectively applied to the crop. The loss of input is therefore $X_1 - X_o$, and the total input cost to the farmer of this loss is measured by area B in Figure 2, whereas the total loss in market value of changes in crop productivity is areas A and B. Thus the net loss to the farmer of soil erosion is really area A. However, as it is often difficult to obtain information on the value marginal product of inputs used in crop production, many analysts simply use the costs of 'replacing' the lost inputs $X_1 - X_o$, i.e. area B, as an approximation of the net losses to the farmer, i.e area A. This is why this method has been referred to as the 'replacement cost' approach.

Clearly, using the cost of replacing inputs to measure the market value of changes in crop output arising from losses in these inputs is a second-best approach. There is no reason to believe that area B will always be a good approximation of area A, and certainly such a 'replacement cost' estimate can only be an accurate reflection of on-site cost by chance. Moreover, it is doubtful in Figure 2 that area A would be an appropriate measure of on-site cost in the first instance. We simply do not know how to guarantee that all the purchased inputs applied, X_1, will reach the crop. Because it is generally infeasible - and often not optimal - to reduce soil erosion to zero, it is inevitable that some input runoff will occur. Thus to use the entire area A in Figure 2 to measure the on-site cost of soil erosion will generally overestimate this cost as well. To use the cost of 'replacing' the loss of $X_1 - X_o$ units of inputs as the 'proxy' measure of A compounds the estimation error further.

To understand the correct methodology for estimating the on-site cost of soil erosion, one must return to the basic theory outlined in Section 2. For the on-site cost of soil erosion to be an economic cost it must be an opportunity cost, which is defined as the value of a foregone alternative. In the case of soil erosion, the alternative for the farmer is to invest in soil conservation. However, soil conservation is not a costless activity, and in any case is likely to affect the net profitability of the farming system over time. Thus effectively, the on-site cost of soil erosion must be the loss in the long-run net profitability of the farming system from not investing in soil conservation, provided of course that such an investment is an economically worthwhile alternative. That is, the on-site cost of soil erosion is the difference between the (present value) net returns of the farming system with soil conservation and the (present value) net returns with erosion.

Figure 4 illustrates this approach for a typical case. The 'with erosion' curve shows the present value of net returns per hectare for a plot of cropland. Because of soil erosion, the net returns will eventually decline over time. The 'with conservation' curve shows the economic returns after the next best alternative, which is the investment in the most feasible conservation measures. As conservation usually involves upfront direct costs as well as possibly changes in cropping patterns and even loss of productive area, the present value net returns to the farming system with conservation will generally be lower than without conservation for some time initially. However, because conservation prevents topsoil from eroding so fast means that eventually at some future time *T* the present value net returns of the farming system with conservation will begin to exceed the returns without conservation, and will hopefully continue to do so indefinitely. Thus in the simple case shown in Figure 4, the on-site cost of soil erosion would be measured by the difference between the two curves, or areas *A* plus *B*[5]. Since in this example and in most typical cases area *A* is negative, then the on-site cost of soil erosion would translate into *B* - *A*.

A further point should also be emphasized here. Note that only if conservation is a viable economic alternative to continuing with current farming practices that lead to much greater erosion would there be any on-site cost to soil erosion. That is, in Figure 4 if area *A* turned out actually to be greater than area *B* than this would imply that the net present value of the farming system with conservation would be less than that with current erosive farming practices. In other words, there is no viable economic alternative to the present farming conditions that induce erosion, and so consequently the on-site cost of soil erosion is effectively zero - despite the fact that *physically* lots of erosion may be taking place. This is a very difficult point for non-economists to understand, but it is fundamental to understanding the correct economic methodology for assessing the on-site cost of soil erosion.[6]

Of course it does not follow from this that, because we may observe a farmer *not* investing in soil conservation, that it is always right to conclude that the on-site cost of soil erosion is zero. As discussed in Section 3, there are many factors that might distort the farmer's incentives to invest in soil conservation, and these distortions may mean that from the *private* perspective of an individual farmer the net present value of the farming system with conservation may appear to be much less than the present value of the existing system with severe erosion. In contrast, once the distortions to economic costs and benefits are taken fully into account, it may turn out that from a *social* (i.e. economic) perspective the on-site cost of soil erosion in the farming system is significant. It is the task of the economic analyst to determine the true economic on-site cost of soil erosion of a farming system, regardless of whether or not the farmer is observed to be actually taking this cost into account in production decisions.

Although the methodology outlined above and in Figure 4 is the more sound approach to estimating the on-site cost of soil erosion, it has often proven to be very difficult to implement empirically. Determining an economically viable alternative conservation investment to current erosive practices is not easy, nor is projecting the likely current and future profitability of farming systems with this conservation investment and comparing it with the profitability of continuing with existing erosive farming practices. The data constraints are often formidable, whereas simplifying assumptions and generalizations may be misleading. This may particularly prove to be the case in developing regions such as Southeast Asia, where there are many diverse and heterogeneous small-scale farming systems scattered over extremely varied topological, climatic and soil conditions, and where differences in social, ethnic and household characteristics in rural areas can be important determinants of long-term investment and farm profitability. It is not surprising therefore that many analysts have ended up using the change in productivity and replacement methods as an alternative. These approaches may be less reliable or even second-best from an economic perspective, but they might be the only implementable choices[7].

Example 1: On-Site Costs of Soil Erosion on Java, Indonesia

Magrath and Arens (1989) conducted an analysis of the on-site costs of soil erosion for mainly upland rainfed (*tegal*) cropping systems on Java, Indonesia. The results are also summarized in Repetto *et al.* (1989). The main method for estimating these costs was the change in productivity approach. The basic assumption was that yields and thus farm revenues would decline as erosion proceeds, and the available evidence suggested that costs that would tend to fall along with output account for a small share of production costs in Javanese rainfed agricultural systems. The result is that soil erosion was expected to lower net farm income, and might eventually lead to the adoption of less profitable crops. To account for possible adjustments in cropping systems, farm budgets for a variety of representative dryland cropping systems across Java were constructed, and then used to estimate the effects the yield losses from erosion on net farm incomes. This was done comprehensively for a single year (1985). Assuming that the one-year loss in net income recurs over each successive year, the Magrath and Arens 'capitalize' this one-year cost of erosion to obtain a total present value of current and future losses. The latter figure is their estimate of the on-site costs of soil erosion on Java.

The method and results are illustrated in Table 1. As indicated in the table, the one-percent decline in productivity and the predicted average yield declines from soil erosion for dryland farming systems in each province of Java are applied to the total area of these cropping systems. This yields the single-year cost of soil erosion for 1985. This one-year loss is then capitalized to obtain the present value of losses in farm income in current and future years. For Java as a whole, this on-site cost of soil erosion in 1985 was estimated to be approximately Rp 539.6 million (US$ 327 million), which amounted to around 4% of the total value of dryland crops on Java[8].

Despite the impressive and comprehensive effort that went into estimating of on-site erosion costs on Java, the analysis suffers from the standard limitations of the change in productivity approach to measuring these costs. Because Magrath and Arens do not take into account the costs and impacts of conservation in their measurement of the effects of yield losses from erosion on net incomes, their analysis essentially assumes that all these yield and net income losses represent the full economic costs of soil erosion. As discussed previously, this is unlikely to be the case. Thus their results probably over-estimate the on-site costs of soil erosion on Java.

Example 2: On-Site Costs of Soil Erosion, Magat Watershed, the Philippines

Due to data limitations, Cruz, Francisco and Conway (1988) employ the replacement cost method to estimate the on-site costs of soil erosion in the Magat watershed of the Philippines. The major upper watershed degradation problem was seen to be the conversion of primary and secondary forest to grasslands and other forms of land use. The average annual sheet erosion rate for grasslands was estimated to be around 88 tons per hectare compared to 28 tons for all other land uses. The nutrient losses associated with this erosion on representative land unit areas for grasslands were translated into equivalent quantities of inorganic fertilizers - nitrogen (N), phosphorous (P) and potassium (K) - lost per ton of soil erosion. The cost of replacing these equivalent fertilizer losses were then valued in terms of both nominal and shadow fertilizer prices. The resulting estimate was considered to be the on-site cost of soil erosion from land conversion in the Magat watershed[9].

The basic approach and results are shown in Table 2. The first column of the table indicates the weighted average of nutrients lost from erosion on grasslands in terms of their equivalents in kilograms of urea, solophos and muriate of potash. The second column shows the value of these fertilizer losses in terms of nominal, or actual, prices paid for these inputs by local farmers, and the third column shows the value in terms of shadow, or adjusted, prices that account for the full social cost of the fertilizer inputs. Thus the on-site cost of soil erosion is estimated to be around pesos 1,068 per ha (US$ 50.1/ha) in nominal prices and pesos 2,716 per ha (US$ 127.5/ha) in shadow prices.

This use of the replacement cost approach to estimate the on-site costs of soil erosion clearly displays all the shortcomings of this method outlined above. More fundamentally, it is unclear whether soil erosion from grassland represents a true economic 'on-site' cost in the first place. It is true that erosion of grasslands results in loss of nutrients, but whether this loss translates into real economic costs in terms of foregone net income over time depends clearly on the economic activity utilizing the grasslands. It is not evident from the analysis what economic activity takes place on the grasslands, or whether these lands are utilized at all. Moreover, erosion rates on cultivated land may actually be higher than that on grasslands; for example, in the neighboring Canili-Diayo and Pantabangan watersheds average rates of erosion on croplands are around 428.6 tons/ha annually as opposed to 197.8 tons/ha for grasslands (Cruz, Francisco and Conway 1988). Erosion rates from grasslands are therefore not really representative of erosion on cultivated lands. Thus not only does the use of the replacement cost method of measuring the on-site costs of soil erosion on grasslands yield an unreliable estimate, it is doubtful whether erosion from these lands are actually an economic 'on-site' cost as such.

5. Measuring Off-Site Costs: Methodologies and Examples

The main objective in measuring off-site costs is to estimate the present value of any external costs arising from sedimentation and other downstream impacts. The methodologies for measuring these costs are usually standard approaches of estimating environmental externalities, but again these estimation procedures have to be used with care. This section will overview briefly the methodologies for estimating off-site costs, and to illustrate them with examples relevant to Southeast Asia.

There are many possible downstream or off-site impacts of soil erosion that result from water-borne runoff and sedimentation. These impacts include: reservoir sedimentation; losses to navigation; irregular flow of irrigation; effects on agricultural, fishing and industrial production in lowlands and coastal regions; impacts on water supply and potability; and impacts on drought or flood cycles. The resulting economic costs of these impacts would normally be measured in terms of the present value of foregone net economic benefits from any loss of downstream economic activity, including loss or damage to property, or from any direct welfare effects.

However, the actual methodologies employed in estimating off-site costs are usually fairly specific to the type of downstream impacts and welfare losses encountered. In this short paper, it is impossible to outline the approaches relevant to all the many possible downstream impacts of soil erosion. Instead, one particular off-site cost - sedimentation of dam reservoirs - will be examined in detail.

Sedimentation of dam reservoirs has been recognized throughout Southeast Asia as a major consequence of land degradation and erosion in upper watersheds. The potential economic costs in terms of losses in hydroelectric power, irregular or inadequate flow of irrigation water, reduced flood control and even impacts on water supply and potability have considered to be significant.

The basic methodology for estimating these costs is outlined in Figure 5. For simplicity's sake, assume that the purpose of the dam is to deliver water for irrigation. The curve *DD* represents the demand for irrigation water from the dam. Initially, without reservoir sedimentation, the dam is able to supply Q_o amount of water at a price P_o to satisfy this demand. However, sedimentation of the reservoir reduces its storage capacity and may affect the planned lifetime of the entire dam project. All of these impacts would effectively increase the marginal costs of the dam's delivery of irrigation water, or another way of looking at it, in order to supply the same quantity of irrigation water as planned before reservoir sedimentation, additional dredging costs or investments in sedimentation ponds would have to be incurred. In Figure 5, this can be represented by an increase in the marginal costs of delivering water, from $S = MC_o$ to $S = MC_1$. This results in a net loss in both consumer and producer surplus equal to area *A*. This net welfare impact is essentially the of-site cost associated with reservoir sedimentation.

This approach can be extended to estimating the off-site costs of reservoir sedimentation in terms of all other uses as well, such as hydroelectricity generation, flood control and domestic and industrial water supply. The most common method is to measure these impacts in terms of the present value of foregone net benefits from reductions in service life and storage of the reservoir caused by sedimentation. More specifically, the type of impacts that are usually measured and included as the costs of sedimentation are:

- *Reduction in service life* - As siltation of the reservoir means that the entire lifetime of the dam may be reduced, say from 50 to 35 years, then there will consequently be loss of future economic benefits (e.g., hydroelectric power, flood control, irrigation) from this reduction in the service life of the dam.
- *Increase sedimentation of active storage* - Active or 'live' storage is the water in the reservoir that was assumed to be free of sedimentation and therefore available for use to deliver water for hydropower, irrigation, etc. Sedimentation may reduce the live storage capacity of a reservoir with a consequent loss in economic benefits. This may particularly be the case where sedimentation that is supposed to be trapped' by sediment pools may actually find its way into the 'active' storage.
- *Increase sedimentation of dead storage (unplanned)* - The dead storage of a reservoir is the portion of total reservoir storage capacity that is allocated to 'storing' sediment. Usually, engineers plan for a certain amount of dead storage in a dam's reservoir based on existing sedimentation rates, with the remaining storage capacity assumed to be active. An 'unplanned' increase in sedimentation due to greater soil erosion upstream is assumed to increase the dead storage component of a reservoir. This in turn is assumed to mean that more active storage becomes 'inactive' and thus there is a consequent loss of water available for hydropower, irrigation and other economic benefits.
- *Increase sedimentation of dead storage (planned)* - Because of the presence of severe soil erosion and thus high sedimentation rates, engineers may have to plan for a larger amount of dead storage in the reservoir than if erosion and sedimentation rates were lower. This additional water could instead have been used for more active storage, if less sedimentation meant that less planned dead storage was required. The resulting foregone economic benefits are considered the cost of this increased in planned dead storage.

However, all these approaches need to be used with caution. There is always the danger of double counting if more than one of these approaches is applied simultaneously. Considerable information is also required on sedimentation delivery and deposition rates in the reservoir, and a clear understanding of the relationship between, dead storage, active storage and the service life of the dam needs to be formulated. To illustrate some of these issues, it is useful to look at two examples from Southeast Asia.

Example One: Off-Site Costs of Reservoir Sedimentation on Java, Indonesia

Magrath and Arens (1989) examined the off-site costs of reservoir sedimentation in nine major dams on Java in terms of foregone hydroelectric and irrigation benefits. The basic assumption of the analysis was that the flow of these benefits were related to the remaining volume of storage in the reservoir. However, Magrath and Arens were unable to determine the precise relationship between active, dead and total reservoir capacity, and the effects of increased sedimentation on this relationship. Instead, they took as their upper and lower bounds the impact of sedimentation on loss of dead and total reservoir, assuming that these reductions would bracket the actual losses in active storage and thus hydroelectric and irrigation benefits.

The methods of calculation and results are shown in Table 3. Annual average sedimentation of around 24.8 million m^3 across the nine major reservoirs on Java reduce total reservoir capacity by around 0.5% and dead storage capacity by 2.3%. This results in an estimated annual loss of hydropower output of between 13.7 to 63 gigawatt hours (GWh) and 1.3 to 6.4 thousand ha respectively. Assuming an average price of electricity of around Rp 70/KWh, the annual loss in hydropower is valued at between Rp 958.4 and 4,408.8 million (US$ 0.58 to 2.67 million). The reduction in irrigated cultivated area was valued by comparing the net returns to land with and without irrigation. That is, it was assumed that the formerly irrigated area would now be cultivated without irrigation water. The resulting difference in net returns amounted to Rp 1.2 million/ha. This suggests that the annual loss of reduced water for irrigation would be around Rp 1.73 to 7.94 billion (US$ 1.05 to 4.81 million). The total capitalized value of these combined annual hydropower and irrigation losses were estimated to be between Rp 26.9 and 123.5 billion (US$ 16.2 to 74.8 million). This range represents the estimate of the off-site costs of reservoir sedimentation.

By associating losses in hydropower and irrigation benefits with reductions in total and dead reservoir storage, Magrath and Arens obtain a fairly reliable range of estimates for the off-site costs of reservoir sedimentation. By capitalizing these annual losses, they are essentially assuming that the reductions in benefits are permanent. Given that loss of total storage is occurring at 0.5% per year and dead storage at 2.3% per year, it is likely that sedimentation may affect the active service life of the reservoirs and dams. Although Magrath and Arens do indicate that the planned life of some of the major dams on Java may be affected, lack of data prevents them from calculating this additional cost of reservoir sedimentation. In any case, it is often difficult to determine how the active life of the dam is affected by such sedimentation[10].

Example Two: Off-Site Costs of Reservoir Sedimentation in Magat and Pantabangan Watersheds, the Philippines

Cruz, Francisco and Conway (1988) have also estimated the off-site costs of reservoir sedimentation of dams in the Magat and Pantabangan watersheds. Three components of these costs were measured: the reduction in service life of the dam; reduction in active storage for irrigation (Pantabangan only) and hydropower (Magat and Pantabangan); and the opportunity cost of dead storage for irrigation. Only annual and not capitalized costs were calculated. The results of the estimates are shown in Table 4.

The original service capacity of both the Magat and Pantabangan reservoirs was designed for an annual rate of sedimentation of 20 tons/ha per year. Thus their service lives were expected to be around 95 and 100 years respectively. However, actual sedimentation rates for Magat and Pantabangan are more likely to be 34.5 and 81 tons/ha/year respectively. Cruz, Francisco and Conway estimate that these changes in sedimentation rates will reduce the operational life of the Magat reservoir to 55 years and the Pantabangan reservoir to 61 years. Using a discount rate of 15%, the present value of the net irrigation and hydropower benefits that are lost due to the reduced life of the two reservoirs were calculated and annualized. For the Magat reservoir the annual losses amount to pesos 0.01 per ton of new sediment input per year, and for the Pantabangan reservoir pesos 0.02 per ton.

For Pantabangan reservoir, it was assumed that 25% of sediment deposition occurred in the active storage.[11] Cruz, Francisco and Conway suggest that the resulting displaced water could have been used for irrigation and hydropower generation. For example, an additional 70 ha could have been irrigated each year, and an 185,606 kWh of electricity generated. By employing with and without project estimates for irrigation, the yearly loss of irrigation benefits were estimated to be pesos 3,558/ha (US$ 167/ha). Assuming each year an additional 70 hectares were affected (i.e. 70 ha in year one, 140 ha in year two, 210 ha in year three, and so on for the life of the dam), the present value of the stream of losses were calculated and annualized. The annualized loss totalled pesos 1.19 per ton of sediment. Similarly, the annual loss of about pesos 31,533 (US$ 1,480) of power generation was expressed as a cumulative loss over the 61-year life of the reservoir, and the present value of this stream of losses was annualized. This amounted to pesos 0.15

per ton of sediment.

Finally, and most controversially, Cruz, Francisco and Conway argued that if the sediment, or dead storage, pools at Pantabangan and Magat had not been required to accumulate sediment, then the water stored in these pools could instead have been used for irrigation. They refer to this as the 'opportunity cost' of dead storage. The dead storage capacity of Magat reservoir is about
500 million m^3, and the sediment storage capacity of Pantabangan is around 225 million m3. Using the same methods as described above for estimating lost irrigation benefits from displaced active storage, Cruz, Francisco and Conway calculate the opportunity costs of this water in terms of generating additional irrigation benefits to be 18 (US$ 0.84) and 28.78 (US$ 1.34) per ton of sediment for Magat and Pantabangan reservoirs respectively.

As can be seen from Table 4, by far the largest off-site costs of dam sedimentation are the opportunity costs of dead storage. Unfortunately, these latter costs are clearly overestimates. To assume that all the inactive storage of these reservoirs could be used instead to supply water for irrigation is tantamount to assuming that reservoir sedimentation could be reduced to zero. This is highly unlikely. All tropical watersheds are subject to some degree of 'natural' or 'background' erosion, which means that some degree of sedimentation storage in reservoirs must be planned for[12]. For example, as noted previously, the Pantabangan reservoir was designed for an annual rate of sedimentation of 20 tons/ha per year. With a sedimentation delivery rate of 30% and a trap efficiency rate of 95%, this amounts to a gross erosion rate in the upper watershed of around
70 t/ha per year. Given that over 45% of the upper Pantabangan watershed is either grassland or cropland - which have an average gross erosion rate of 429 and 198 t/ha per year respectively - and that the average gross erosion rate across all land uses is 270 tons/ha per year, it is unrealistic to assume that the 'planned' dead storage of the reservoir could have been feasibly reduced below its present capacity. Thus there are really no 'opportunity costs' of the planed dead storage capacity of both the Magat and Pantabangan reservoirs, and these components of the off-site costs of sedimentation calculated by Cruz, Francisco and Conway should be ignored.

6. Conclusion

This paper has explored several aspects of the economics of soil erosion, with reference to examples from Southeast Asia. Both the basic theory of the farm-level decisions to control soil erosion and the methodologies for estimating on-site and off-site costs of erosion have been explored.

Unfortunately, as the examples discussed here indicate, many popular approaches to estimating on-site costs may have yielded inaccurate results because these approaches have not fully taken on board some of the important points emphasized by the basic theory of the farm-level economics of soil erosion. Thus an important principle that this theory tells us is that the on-site cost of soil erosion must be the loss in the long-run net profitability of the farming system from not investing in soil conservation, provided of course that such an investment is an economically worthwhile alternative. That is, the on-site cost of soil erosion is the difference between the (present value) net returns of the farming system with soil conservation and the (present value) net returns with erosion. In the case of accounting for off-site costs, the main objective is to estimate the present value of any external costs arising from sedimentation and other downstream impacts. Although the methodologies for measuring these costs are usually standard approaches of estimating environmental externalities, mistakes can also be made if there is confusion over whether some physical downstream effects are true economic costs.

Finally, it is worth emphasizing that estimating the costs of soil erosion is only one dimension of improving economic approaches to the problem. In designing improved policies and investments to control erosion, a critical issue that must be addressed by policy makers and analysts alike is the farm-level incentives affecting a farming household's decisions to deplete or conserve topsoil. In Section 3, a whole host of factors influencing these incentives was explored briefly. Understanding why private and social rates of soil erosion might diverge gets to the heart of the economic problem of erosion, and deserves more treatment than is possible in this short paper. Understanding how to design policies and investments to encourage farmers to 'move' towards more socially optimal rates of erosion is of course the greatest challenge of all, and certainly warrants more discussion than can be usefully covered here.

Appendix: A Farm-Level Model of Soil Erosion

Barbier (1990) takes a formal model originally developed by McConnell (1983) and adapts it to describe the soil conservation decision of farmers in the upper watersheds in Java. For simplicity, it is assumed that the land holding is fixed and only one crop is produced, or if there are multiple crops, their combined production can be explained by a single crop production function.

The behaviour of the farming household in response to soil erosion is therefore determined by the impact of soil on profits. Thus the objective of the farming household is to maximize the following functional relationship of the net present value of income stream from farm land:

$$\text{Max}_{z_1, z_2} \; PV = \int_0^{T \to \infty} e^{-rt} [pf(z_1, x) - c_1 z_1 - c_2 z_2] \, dt \tag{1}$$

subject to

$$\frac{dx}{dt} = \dot{x} = h(z_1, z_2), \; h_1 \leq 0, h_2 > 0, h_{22} \leq 0$$

$$x(0) = x_0,$$

where x = topsoil depth
z_1 = conventional crop production inputs
z_2 = conservation inputs
p = price of crops
$f(z_1, x)$ = crop production function, where $f_1 > 0, f_2 \geq 0$
r = farm household=s private rate of discount
c_1 = costs of conventional inputs, and
c_2 = costs of conservation inputs.[13]

Allowing μ to represent the 'shadow' or 'implicit' price of soil, then the first-order conditions for maximizing (1) are:

$$pf_1 - c_1 + \mu h_1 = 0 \ \_ \ \frac{pf_1 - c_1}{-h_1} = \mu \tag{2}$$

$$-c_2 + \mu h_2 = 0 \ \_ \ \frac{c_2}{h_2} = \mu \tag{3}$$

$$\dot{\mu} = r\mu - pf_2 \ \_ \ \frac{\dot{\mu}}{\mu} + \frac{pf_2}{\mu} = r. \tag{4}$$

Condition (2) indicates that at any time t, for optimal use of conventional productive inputs, the value of the marginal product, pf_1, must be equal not only to the marginal costs of using these inputs, c_1, but also their additional costs in terms of worsening soil erosion, μh_1. *Condition (3) shows that for optimal use of conservation inputs, the marginal costs of employing these inputs, c_2, must equal the additional value generated by controlling soil erosion, μh_2. Finally, condition (4) indicates that it is optimal to* >hold on= to soil up to the point where the >capital gains= in terms of improved future value of the land from conserving soil, $d\mu/dt$, plus the contribution of soil to current profits, pf_2, must equal the opportunity costs of holding on to soil, $r\mu$. That is, the household could instead deplete the soil today and invest the proceeds elsewhere, obtaining a return $r\mu$. To see this, one can combine conditions (2) and (4) to obtain:

$$\dot{\mu} + pf_2 = r\mu = r\frac{(pf_1 - c_1)}{h_1}. \tag{5}$$

That is, it is worth conserving soil up to the point where the marginal gains from holding on to the soil as an asset must equal the marginal costs. The marginal gains are represented in condition (5) by the future and current value of having additional topsoil, $d\mu/dt + pf_2$, and the marginal costs are the foregone returns that could be earned from >depleting= soil today and investing the proceeds elsewhere, $r[(pf_1 - c_1)/h_1]$. Note that in this model conservation requires the employment of inputs. Thus condition (3) must also still hold - i.e. the marginal costs of employing these inputs, c_2, must equal the additional value generated by controlling soil erosion, μh_2. *Consequently, conditions (3) and (5) together determine the overall costs and benefits to the farming household of controlling soil erosion and hence the* >optimal= level of erosion.

Note that the optimal conditions of this model assume that the farming household takes into account fully the >shadow= price of the soil. That is, the household is aware that an increase in topsoil will lead to a marginal increase in the present value stream of income from the land, as represented by equation (1). As discussed in the text, for a variety of reasons the farming household may ignore or underestimate the shadow price of soil. Assume for example that the former is the case. In the above model, this is equivalent to assuming $\mu = 0$. Thus from (4) it follows that, to the household, the value of holding onto the soil will be

$$pf_2 = 0. \tag{6}$$

Soil will therefore be over-exploited because the household behaves as if there are no gains to conserving it. The result will clearly be excessive erosion.

Footnotes

[1] In fact, as will be argued in the next seciton, it is almost pysically impossible to cultivate the soil continuously and simultaneously prevent any soil erosion from occurring.
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[2] For example, it is not uncommon for many physical conservation measures, such as bench terracing, bunds, gulley drains, etc,. to reduce the total land available for cultivation. On the other hand, on highly erodible soils, conservation can lead to improvements in productivity, particularly if the conservation measures are combined with changes in farming systems and crops that lead to better land management overall.
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[3] In what follows, Figures 1 to 3 are adapted from Dickson and Fox (1989).
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[4] This may not always be the case, as explained in Magrath and Arens (1989).
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[5] Another way of understanding this approach is to see the analogy with the standard 'with' and 'without project' method empolyed in cost-benefit analysis. That is, the farming system with soil erosion (i.e. without conservation) is the 'without project' case, whereas the system with conservation is the 'with project' case. Therefore, the 'net loss' of choosing to continue eroding the soil must be the difference between the 'with' and 'without project' case.
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[6] Again, using the 'with' and 'without project' analogy, traditional cost-benefit analysis would suggest that if the net present value of the 'without project' case exceeds that of the 'with project' case, then the latter is essentially 'uneconomical' and the 'without project' case will always be preferred. Consequently, there would be no 'net loss' in economic terms of continuting with the 'without project' case.
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[7] Nevertheless, as Bishop (1995) has shown for Mali, it is possible to use limited data on conservation investments and costs to modify the change in productivity approach so as to produce estimates of on-site costs that more closely resemble the appropriate methodology for estimating these costs as outlined here. See also the original Mali results in Bishop and Allen (1989).
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[8] Given data limitations, Magrath and Arens (1989) were able to provide an estimation of on-site erosion costs for 1985 only. However, the results for 1985 were extrapolated for other years over the 1971-85 period by indexing physical erosion rates to the dryland corpping area in each year and

indexing the costs of erosion to dryland crop prices in each year. The results are reported in Repetto et al (1989).
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[9] Essentially the same replacement cost method was also applied to estimating the on-site cost of land degradation in the Pantabangan watershed. See Cruz, Francisco and Conway (1988) for further details.
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[10] As Magrath and Arens (1989) argue, it is unclear whether complete exhaution of the planned dead storage of reservoirs is synonymous with the end of the economic life of a dam, as is often assumed.
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[11] The reservoir was designed to trap sediment in purpose-built sediment pools, but it was assumed that if excessive sedimentation occurred, some of it would find its way into the active water storage.
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[12] For example, Cruz, Francisco and Conway note that primary and secondary forest in the upper watershed has an average erosion rate of 2.15 tons/ha per year.
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[13] Where crop outputs or inputs are non-marketed, such as food produced for substitutes, in-kind inputs, labour exchange, etc., p,c_1 and c_2 could represent the relative shadow prices respectively. Note also that including x in the production function assumes that there is an immediate productivity gain from soil conservation. In many situations, it may take some time before such a gain is realized.
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Figure 1. Measuring On-Site Costs of Soil Erosion

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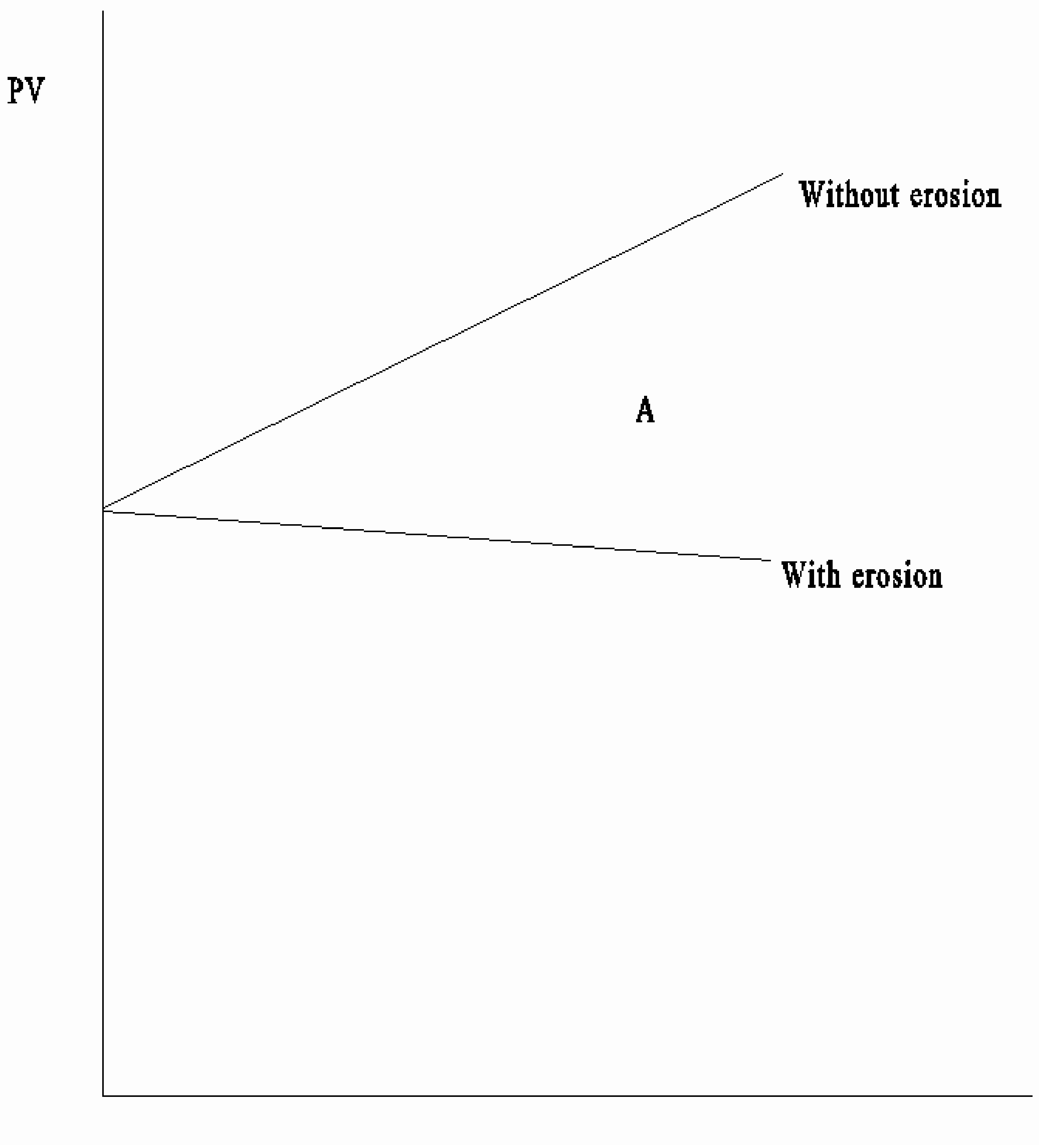

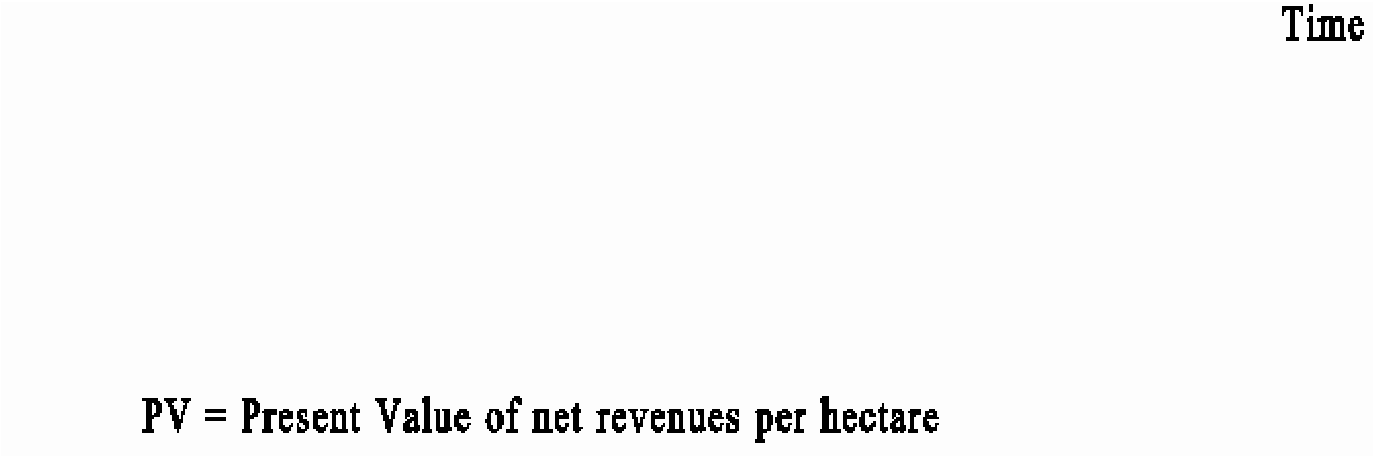

Figure 2. Change in Productivity Approach to Measuring On-Site Costs of Soil Erosion

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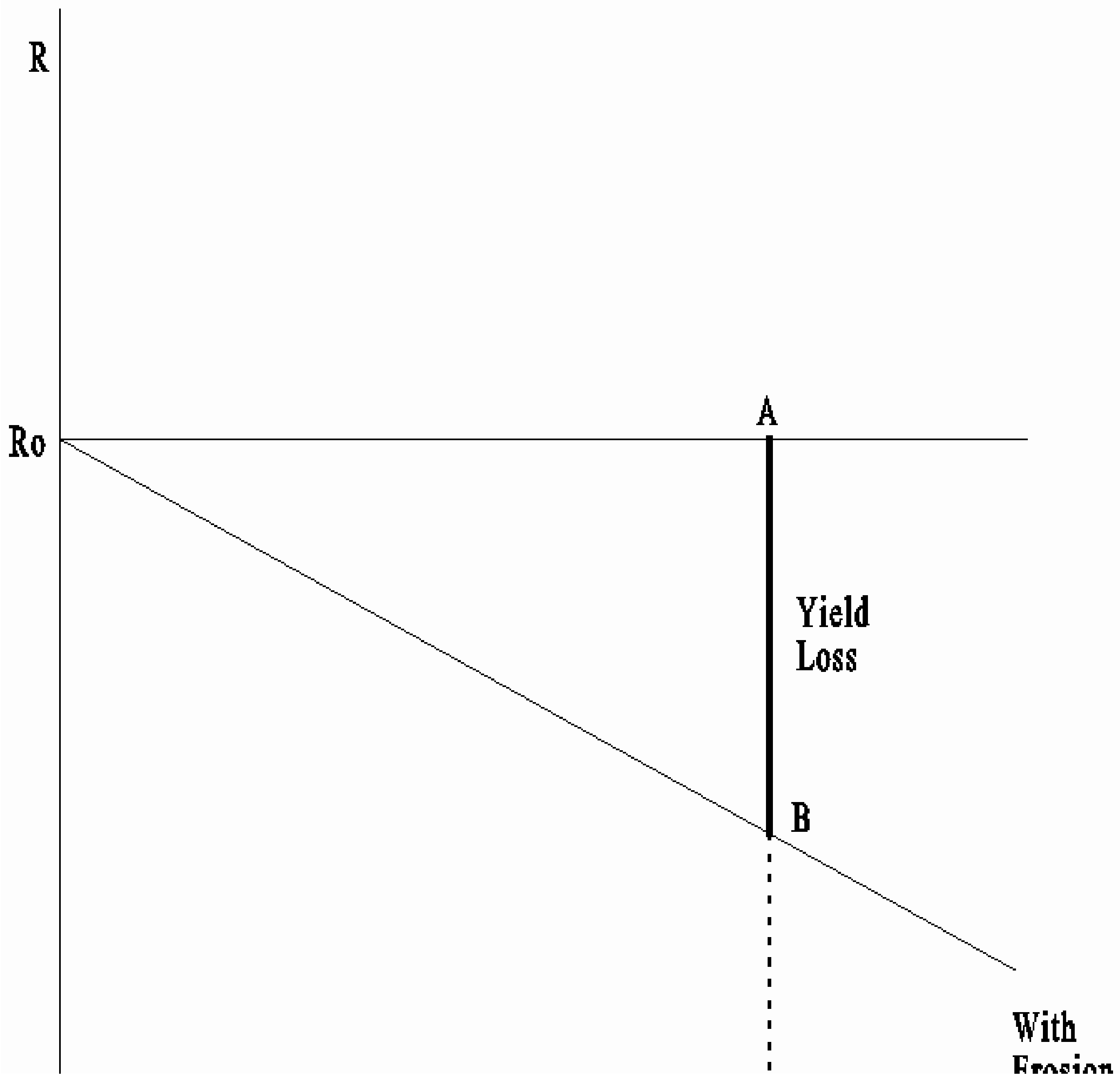


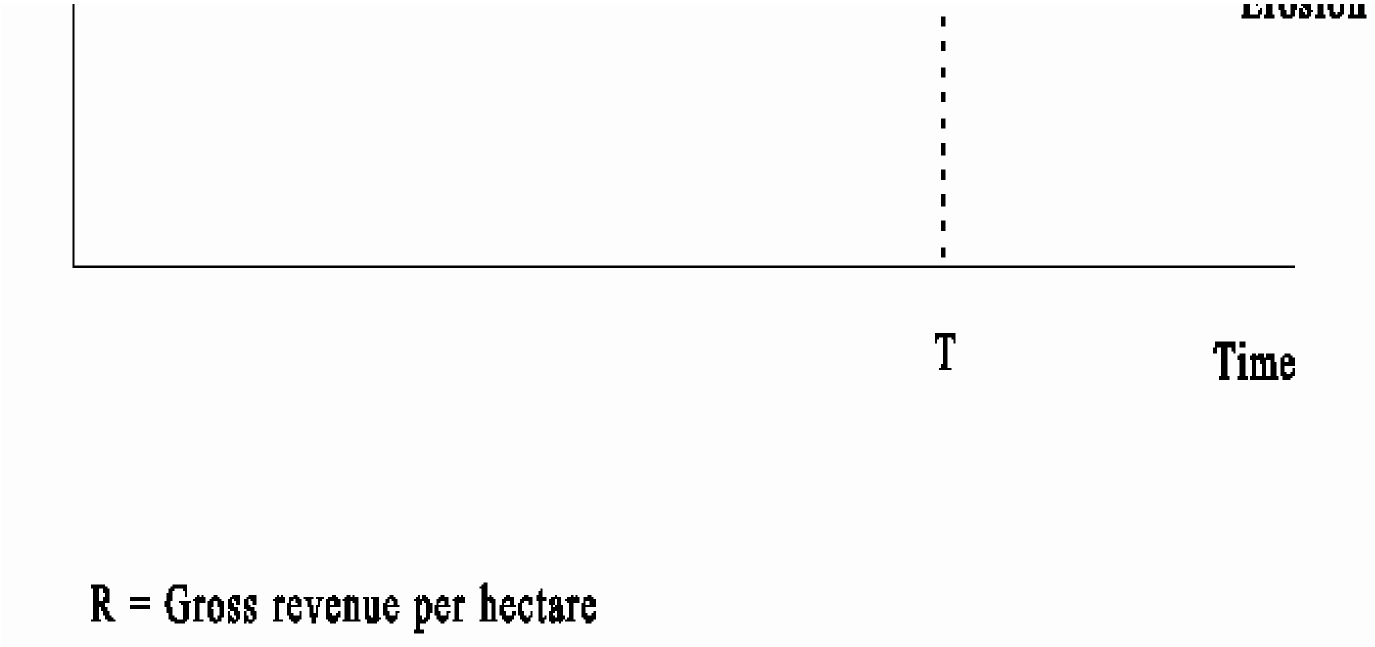
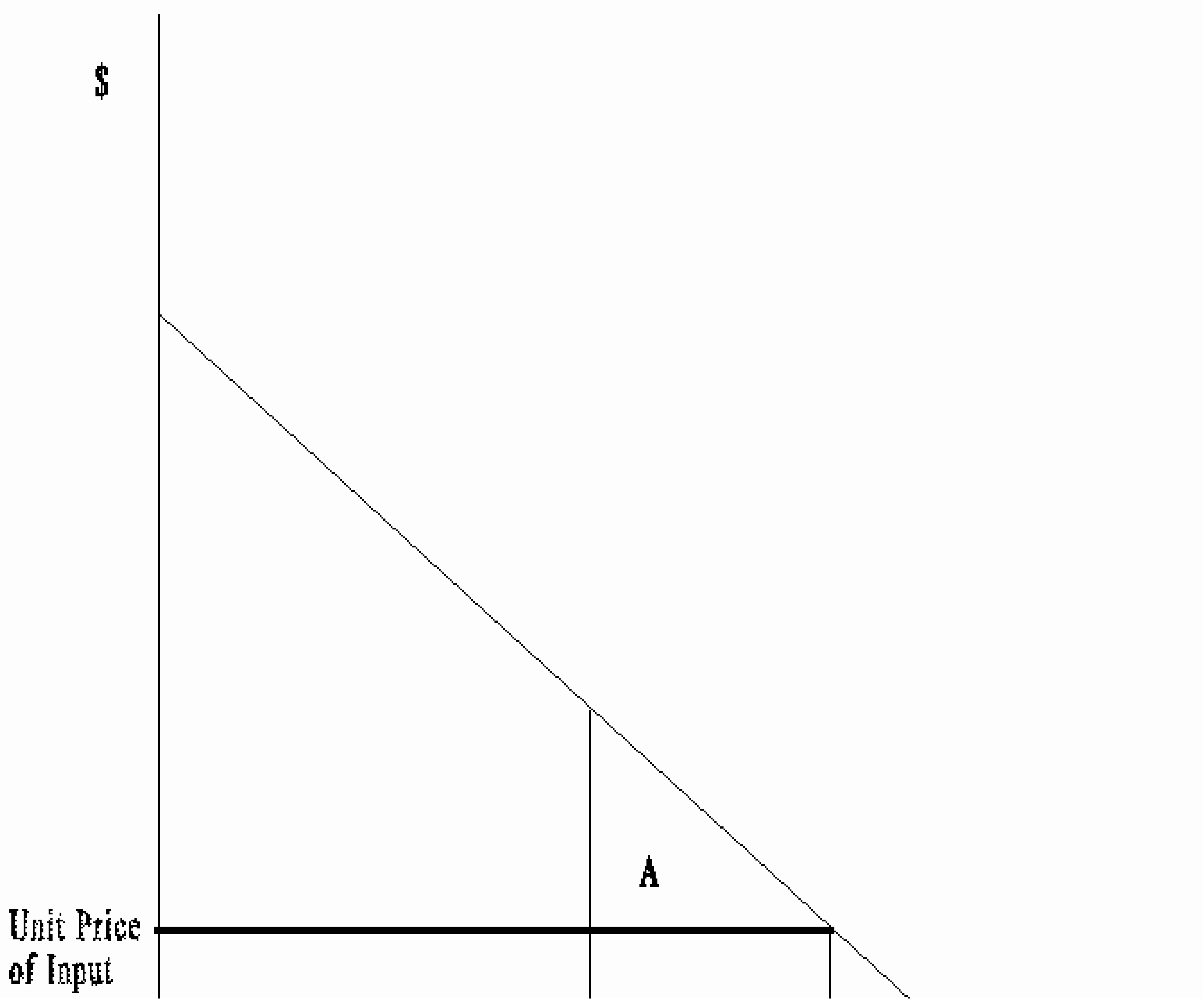


Figure 3. Replacement Cost Approach to Measuring On-Site Costs of Soil Erosion



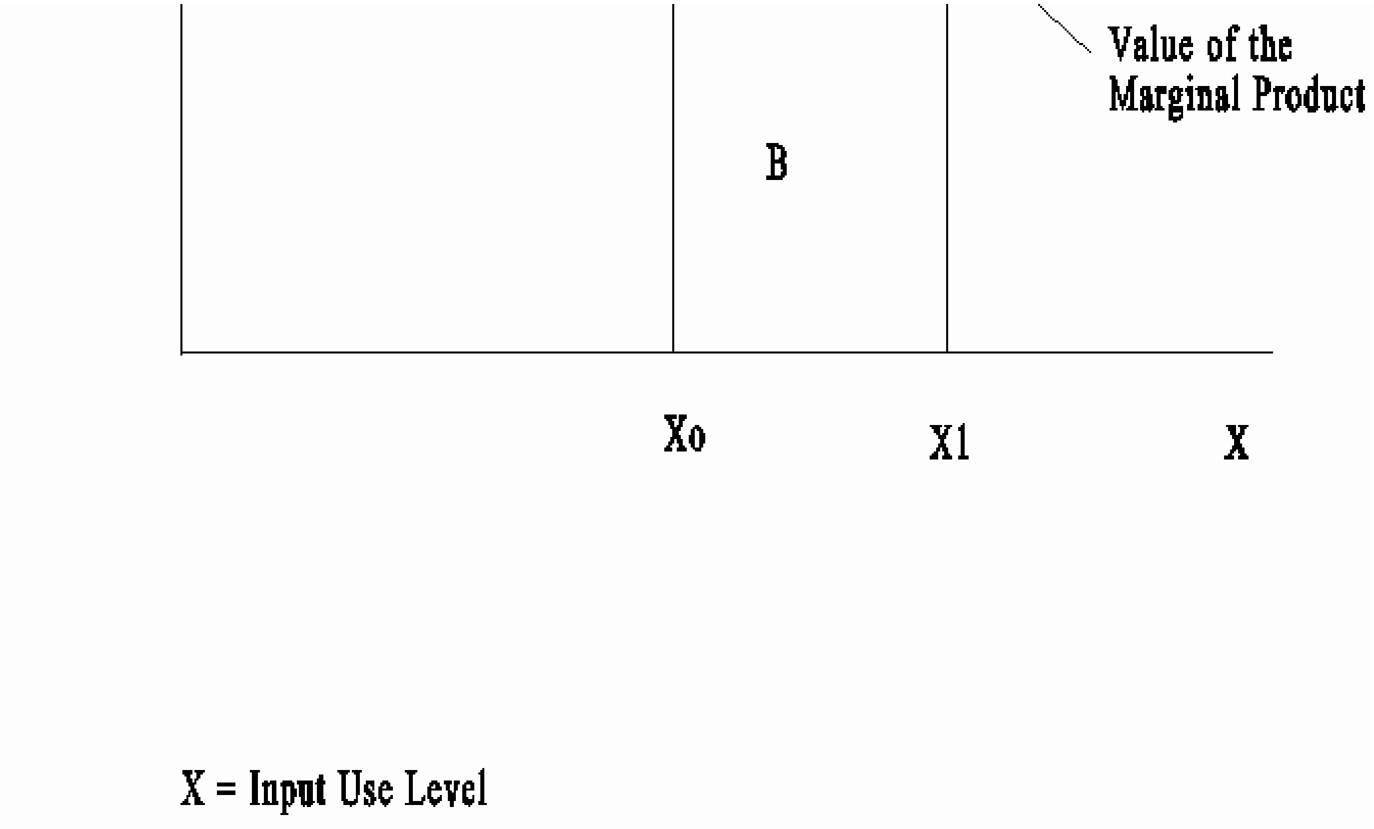


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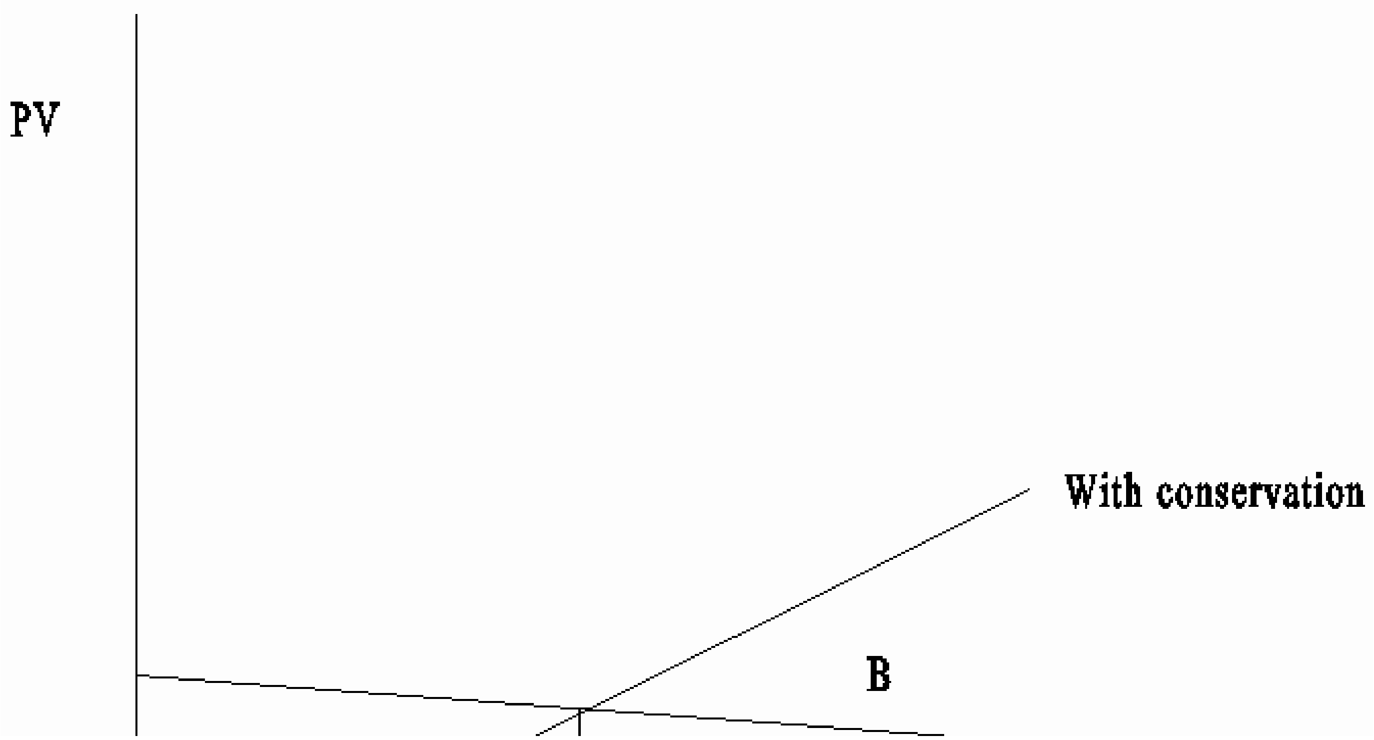
Figure 4. Correct Approach to Measuring On-Site Costs of Soil Erosion



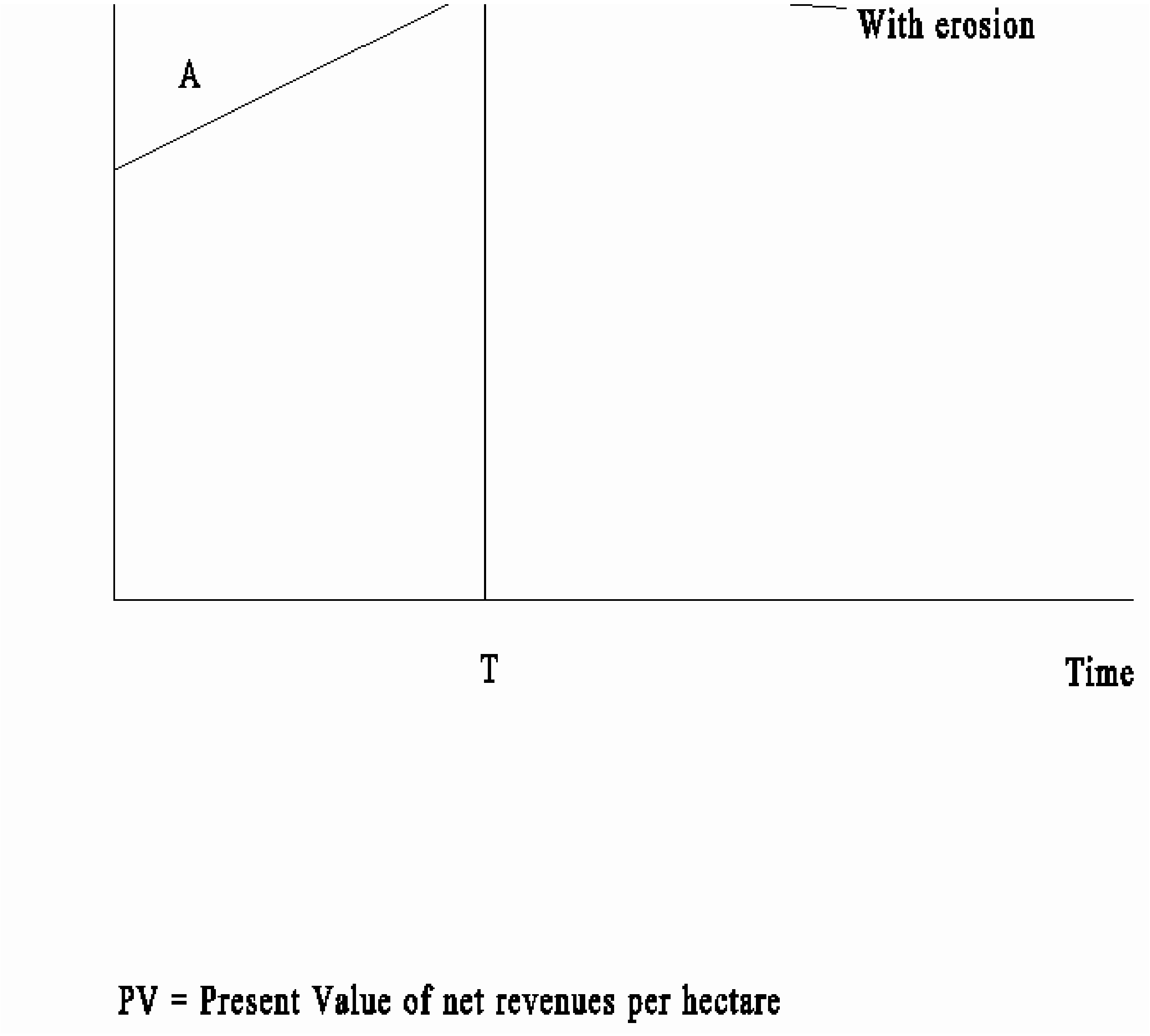


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Table 1. On-Site Costs of Soil Erosion on Java, 1985

(Indonesian Rupiah (Rp) 1650 = US$ 1)

	Dryland Area (>000 ha)	**Estimated Current Net Farm Income (Rp/ha)**	**Weighted Production Loss (%)**	**Annual Cost of a 1% Productivity Decline (Rp/ha)**	**Single Year Cost (Rp million)**	**Capitalized Cost (Rp million)**	**On-Site Cost as % of Total Dryland Crop Value**
West Java	1,440	95,039	4.4	3,718	23,508	235,080	10%
Central Java	1,366	8,196	4.1	859	4,810	48,100	1%
Jogyakarta	196	9,531	4.7	1,026	948	9,480	1%
East Java	1,744	141,499	4.1	3,453	24,690	246,900	4%
ALL JAVA	**4,747**	**83,649**	**4.3**	**2,686**	**53,956**	**539,560**	**4%**

Source: Magrath and Arens (1989); Repetto *et al.* (1989).

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Table 2. On-Site Costs of Soil Erosion, Magat Watershed, the Philippines, 1988

(Phillipine Peso () 21.3 = US$ 1)

		Valuationwith use of	
	Quantity **(kg)**	**Nominal Price** ()	**Shadow Price** ()
Urea		3.60/kg	9.86/kg
- price		11.09	30.37
- amount lost/ton of soil eroded	3.08	677.23	1,854.96
- amount lost/ha of affected land	118.13		
Solophos (P_2O_5)		2.50/kg	6.20/kg
- price		1.98	4.90
- amount lost/ton of soil eroded	0.79	176.63	438.03
- amount lost/ha of affected land	70.65		
Muriate of Potash (K_2O)		4.20/kg	8.28/kg
- price		2.39	4.72
- amount lost/ton of soil eroded	0.57	214.49	422.86
- amount lost/ha of affected land	51.07		
All Fertilizers			**39.99**
- cost/ton of soil eroded			**2,715.85**
- cost/ha of affected land		**15.46**	
		1,068.35	

Source: Cruz, Francisco and Conway (1988).

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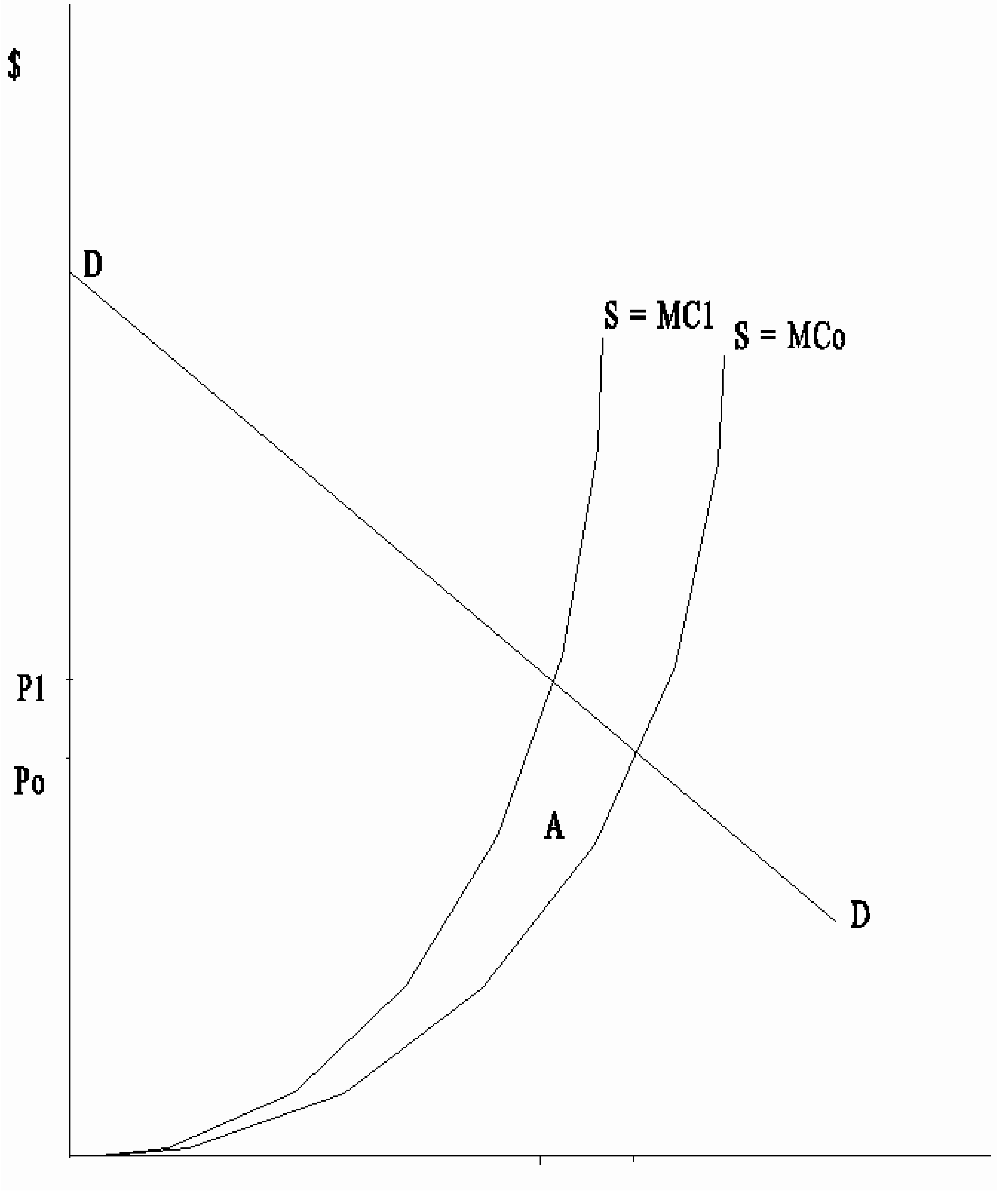
Figure 5. Off-Site Costs of Dam Reservoir Sedimentation



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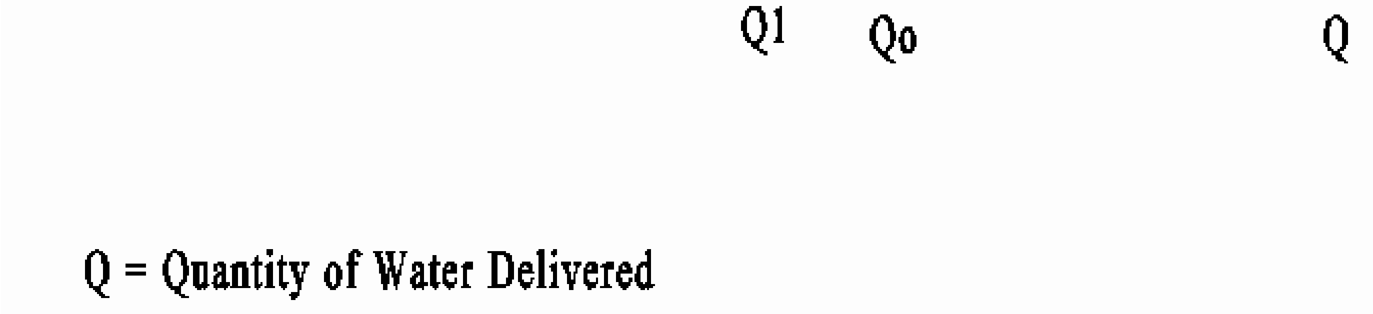

Table 3. Off-Site Costs From Sedimentation of Major Reservoirs on Java, 1985

A. Storage Losses

	Initial Capacity (000 m^3)	**Average Sedim. Rate (000 m^3)**	**Annual Total Storage Loss (%)**	**Initial Dead Storage (000 m^3)**	**Annual Dead Storage Loss (%)**
Avg all nine resevoirs, Java	5,297,500	24,801	0.47	1,074,500	2.31

B. One-Year Hydropower and Irrigation Losses

(Indonesian Rupiah (Rp) 1650 = US$ 1)

	Hydropower	**Irrigation**	**Total Capitalized Value (Rp 000)**
Estimated Output **Value (Rp/Unit)**	2,738,412 Mwh 70/Kwh	277,671 ha 1,244,000/ha	
Based on Loss of Total Storage (0.5%) - Lost Output - Annual Cost (Rp 000)	13,692 Mwh 958,440	1,388 ha 1,726,672	26,851,120
Based on Loss of Dead Storage (2.3%) - Lost Output - Annual Cost (Rp 000)	62,984 Mwh 4,408,800	6,386 ha 7,944,184	123,529,840

Source: Magrath and Arens (1989).

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Table 4. Off-Site Costs of Sedimentation of Magat and Pantabangan Reservoirs, the Philippines

(Phillipine Peso () 21.3 = US$ 1)

	Annual Sedimentation Cost () 1/ Per Hectare Per Ton			
	Pantabangan	**Magat**	**Pantabangan**	**Magat**
Reduction in Service Life 2/	1.11	0.10	0.02	0.01
Reduction in Active Storage	12.99			
- for irrigation	2.91			
- for hydropower			1.19	
			0.15	
Opportunity Cost of Dead Storage for Irrigation	575.55	365.61	28.78	18.00
Total Cost	592.56	365.71	30.14	18.01

Notes: 1/ The prices used for Patabangan are late 1970s prices; for Magat early 1980s prices are used.

2/ The Pantabangan estimates are based on the assumption that 75% of sediments settle in dead storage and 25% in active storage. For Magat, the assumption is that all sediments go to dead storage.

Source: Cruz, Francisco and Conway (1988).

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