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THE MANAGEMENT OF SEDIMENTS IN DEVELOPING COUNTRIES
Briefing Note III

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The main objectives of this note are: (i) to create awareness about the potentially negative effects of sedimentation; (ii) to illustrate the extent and magnitude of sedimentation rates in developing countries; (iii) to state the need to establish proper sedimentation management schemes; and (iv) to discuss some of the socioeconomic problems involved.

Sedimentation cannot be divorced from the nature and scope of the erosion process which takes place upstreams. The linkage between erosion and sedimentation sheds light on the nature of sediments as a natural resource (if one can define them in this way); on the factors determining the effectiveness of sedimentation management interventions; and on defining alternative options in terms of both investment and policy.

An important conclusion is that the nature of sedimentation management is not only a technical problem and, thus, management schemes economic problems. A multi-dimensional approach to management is suggested, which will provide a firm basis for a better understanding of the trade-offs among alternative investments and policies open to governments.

Several concepts already explained in Briefing Notes I and II are used here; those concepts will not be elaborated here.
I. PROBLEM DEFINITION

Introduction

The excessive concern with increasing agricultural productivity in developing countries has distracted policy makers from the environmental implications of different styles of development.

- It is well recognized that a precondition for the "take-off" in many developing countries, requires major investments in infrastructure or in productive assets (e.g., roads, irrigation schemes, hydroelectric power plants). The main objective being the transformation of existing natural resources into economic goods and services. This view is still prevalent with regard to the allocation and use of such resources as soil and water.

- In the past, there have been substantial benefits associated with the expansion of the investment frontier. However, the next development stage ought to focus on those elements that determine the sustainability of existing productive resources and of existing physical assets. Therefore, without necessarily suggesting a deceleration of existing investment rates, developing countries are and will be faced with a new development stage: "the sustainable management of resources and assets (SMA)."

As shown later on, the rate of sedimentation is reaching alarming levels in developing countries. These high rates are often translated into the constant diminution of the productivity of many economic activities taking place downstream.

Sedimentation is a complex process. Several basic elements of this process should be distinguished: generation or detachment of soils (i.e., erosion), transport, and deposition and compaction.

- Generation or detachment occurs due to erosion somewhere upstream, transport relates to the movement of soil particles via water and wind, and deposition and compaction entail the final settlement of these particles somewhere else in the system.

- Sedimentation as a natural phenomenon is very complex, and its dynamic aspects determine the way in which any given soil or sediment particle is moved and transported at any given point in time. Several physical, chemical, hydrological, and environmental factors influence the outcome.

Therefore, a comprehensive analysis of sedimentation would require to focus on those underlying factors which provide the basis for assessing the potentially beneficial effects of sedimentation management programs.
For expository purposes this note uses the word "sediments" in a very general way. However, sediments have several characteristics and properties and, therefore, sediments are not a uniform commodity.

- Sediments are of different "qualities." Sediments vary depending on their size, shape, volume, weight and density. For some specific purposes, the degree of chemical concentration may also become an important characteristic.

- Each characteristic, or any combination of them, will greatly influence how and where transport and deposition takes place (other things being equal). By reorganizing these characteristics, policy makers and analysts will, in turn, be able to assess the potential effects that higher sedimentation rates have on productivity.

**Effects of Sedimentation**

- One may characterize the effects of sedimentation in many different ways. However, given the objectives of this note, a typology which includes three groups of effects will suffice; i.e., on-farm effects, inter-farm effects and downstream effects.

- **On-farm effects** would include mostly the effects of soil detachment and sediment deposition within a farm unit. Soil detachment, or erosion, would cause major effects on productivity. As the top layer of the soil profile is eroded, crop yields will diminish due, for example, to losses in nutrients, soil moisture capacity, soil depth and changes in soil texture and structure. Sediments deposited on a farm may have both beneficial and detrimental effects depending on the circumstances. Sediments deposited will increase the productivity of existing soils of that area. However, depending on where and how those sediments are transported and deposited, several negative effects may occur, e.g., destruction of terraces, clogging of irrigation infrastructure.

- **Inter-farm effects or regional effects** would include damages to other farms as well as to physical infrastructure standing in the region. Changes in the volume of sediments will affect roads, bridges, houses, and several other on-farm assets (e.g., fences, buildings, livestock). Other such characteristics as size, shape and chemical content of sediments will also create problems in the region, for example, via water quality effects (e.g., sediments with high chemical content--fertilizers, pesticides will follow the groundwater).

- **Downstream effects** would include all those effects that occur in economic activities operating outside the project area. Increased volume of sediments will compete for space with water, resulting, for example, in floods, excessive siltation of irrigation infrastructure, sedimentation of dams, tanks and canals. Sediments deposited in dams will decrease the amount of water that can be
stored and therefore it will impair the system from producing hydroelectric power, controlling floods and supplying water for both irrigation and drinking water purposes. Sediments of a particular shape and size will cause major abrasive effects, diminishing the life span of hydroelectric equipment (e.g., turbines). Sediments with high levels of chemical concentration will change the quality of water used by activities somewhere else in the system, will damage spawning and breeding grounds for fisheries and wildlife, will accelerate the growth of weeds, and will pollute surface and groundwater supplies. Sediments deposited in the downstream area of rivers and ports will have negative effects on riverine and sea transport systems.

These are just a few examples.

* The distinction among those three types of effects is important at least for the following reasons:

- It will enable decision makers to properly identify the true benefits and costs of alternative sedimentation management interventions.
- It will provide a framework for the design and implementation of the necessary organizational arrangements for sedimentation control.
- It will help in establishing cause-effect relationship which are important for the design and evaluation of economic policy incentives.
- It will enable economists to define and assess external costs due to higher rates of erosion and sedimentation. And
- It will avoid fragmented policy interventions.

Causes of Sedimentation

* As stated earlier, the generation of sediments (or the "production" of sediments) is basically related to the nature and scope of the erosion process upstream.

* Erosion and sedimentation are natural phenomena, in the sense that these will occur even in the absence of human interventions (e.g., geologic erosion). However, it has been clearly documented in the literature that changes in styles of development in existing watersheds is now the main cause of these problems. Uncontrolled deforestation, to satisfy the need for fuelwood and to expand the agricultural sector frontier, is one of the major causes of erosion and sedimentation. Factors that contribute to these are the lack of adequate land tenure and property rights systems, the low level of income of farmers upstream (overexploitation of the land to satisfy subsistence needs), the absence of price (cost) signals to assess the real social cost of sediment production, and many others.
It is important to note that changes in agricultural development patterns upstream is not the only cause of erosion and sedimentation. Inadequate systems for the construction of roads and other infrastructures are also to blame for the excessive erosion and sedimentation rates.

Sediment as a Natural Resource

Sedimentation results in both positive and negative effects. Several valleys in the world have become highly productive due to sediment deposition (geologic or human induced). There are many examples where communities facing land constraints in the past, have invested in the construction of dams or in other assets with the sole purpose of trapping sediments. The newly created lands became an important source of agricultural growth.

Though there are many examples of the potentially beneficial effects of sedimentation, this note mainly focuses on the negative impacts of this process.

Within this context, several characteristics of sediments as a natural resource are worth mentioning:

- Sediments are abundant. Potentially every soil particle could be detached, transport and deposited in another part of the system.

- Sediments are of different qualities. Given the characteristics of sediments outlined earlier, these are not a uniform commodity. This quality factor has often been ignored in the economic analysis of many investment and policy decisions.

- Sediments are a by-product of other economic activities. Sediments are "produced" by a unit(s) in the economy though these sediments are "consumed" (or stored) by other units in the economy. Given the land tenure situation in developing countries, the number of production units tends to be very large and difficult to control. Consuming units (or those affected) are fewer in numbers (e.g., deposition in a water reservoir). In other words, there is a "concentration effect" downstream.

- Sediments have more social value in-situ (on the ground or whenever they are not "produced"). Therefore, from a social standpoint it is desirable to reduce erosion from upstream.

- Sediments may be produced at a very low cost (or zero). This is due to market failure since there are no recorded market transactions between producers and consumers of sediments.

- Sediments are seldom traded in the market. This non-tradeability element poses specific problems in assigning monetary values to benefits (and costs) of sediment control program.
Sediments are a mobile resource. The sedimentation process does not respect political boundaries. Both, decision making and management interventions, often have to face different types of unit of account (e.g., 90% of the catchment areas of major rivers going through Bangladesh are located in neighboring countries).

These characteristics determine the very peculiar nature of sedimentation management schemes.

The fact that sediments are abundant, coupled with a low cost of production, makes the managers' tasks very difficult to carry out. Because the units that produce these sediments are not the same ones that are affected by the damages, there are no regular incentives to stop the production of sediments (i.e., market failure). In addition, it becomes very difficult to define adequate policy goals and standards.

The dichotomy between "production" and "consumption" units (source and incidence) creates a unique concern for efficiency and equity considerations in management. If no decision is made to internalize the costs of damages caused to downstream economic activities (e.g., by taxing upstream farmers), the system will tend to misallocate scarce economic resources (e.g., building larger and more sophisticated dams, sediment ponds). In other words, downstream activities would continue to act as "followers."

The "concentration effect" makes management activities more complex and costly since it is difficult to deal with each producing unit in its own right. The cost of the damage, supposedly generated by one sediment production unit, is so small compared to the total damage that even from a legal point of view (e.g., the cost of law enforcement is prohibitively high), it becomes too costly to control production. This problem calls for important organizational and institutional reforms (e.g., for farmers participation).

The extraction cost is so low that major intervention in the systems will be required. Market signals are inadequate to substantially change farmers behaviors if at all.

The mobile nature of the resource; i.e. not respecting jurisdictional boundaries (both within a country and across countries), calls for the formulation of interventions where the unit of account should be redefined (see Briefing Note I for details). An extreme example is that of a country having "control" of a very small portion of a given catchment area. The extent to which that country located downstream will be able to effectively implement sedimentation management practices will critically depend on what the neighboring countries do.

There are many other implications (again, see Briefing Note I).
Control of Sedimentation

It is perhaps premature at this stage to address the question of control. Even at the risk of repeating some of the material presented later on, it is important to outline a few issues here.

Sedimentation control could be conceived purely as an engineering problem. The unit of account for decision making assumes, in this case, the production of sediments as given. In other words, the basic assumption is that the rate of sedimentation is out of the direct control of downstream activities. Therefore, it follows that investment decisions are of "curative" rather than of "preventive" nature. Most efforts will be directed towards the mobilization of resources to build the necessary infrastructure to avoid damage from floods, improve the quality of water (e.g., water treatment plants), create a larger dead capacity of reservoirs, and the like. This way to conceive the problem has been practiced in the past, (i.e., as stated earlier downstream activities act as "followers"). However, evidence has shown that this approach has been expensive and, to some extent it has resulted in gross misallocation of resources.

The sedimentation control problem could also be conceived as a hydrological problem. This approach expands the unit of account for investment and policy decisions; the boundary of management activities is determined by the hydrological unit, in this case, the catchment area. This is a better approach. However, this approach suffers from limitations resulting from the way in which administrative boundaries are set. This is to say that in order for this approach to work in practice important institutional reforms will be needed.

The sedimentation control problem could also be conceived as a socio-economic problem. A problem which arises out of inadequate incentives, be it market incentives (e.g., prices) or non-market incentives (e.g., land tenure, property rights). Economic policy in this regard would be designed to change the behavior of all actors in the economy: upstream and downstream units.

Certainly most people will argue that all these approaches should be merged into one unified framework. However, in practice, this framework has seldom being implemented. Major dams are being constructed with no account for watershed management programs. Policies to increase on-farm productivity are formulated (e.g., intensification of fertilizer use) without due consideration of downstream effects (e.g., eutrophication of rivers, water pollution).

Another major issue regarding sedimentation control is that of establishing "standards" (e.g., acceptable sedimentation rates, water quality standards). In this regard, a very hard look at the multiple uses of soil and water is required. Establishing standards is a major task in decision making. Development objectives are important and, therefore, one is faced with a multiple-objective decision-making process where many trade-offs are to be assessed. Sedimentation control means different things to different productive units in the economy. Probably one example will suffice: water of a certain level of quality may still become a potentially productive input to, let say, irrigation, but, the same level of water quality may be unacceptable from the view point of developing fisheries downstream.
II. SEDIMENTATION IN DEVELOPING COUNTRIES: AN ASSESSMENT

This section of the note will make a brief presentation of existing data on sedimentation effects. Since there are many types of effects (e.g., floods, water quality, health, fisheries), the main emphasis here will be only on sedimentation of water reservoirs.

The outline of this section is as follows. First, a description of alternative methods of quantification; second, a presentation of data at the country level; third, a discussion of alternative scenarios; fourth, a discussion of some of the limitations related to the framework used; and finally, an outline of the major implications.

Quantification of Sedimentation Rates

The quantification of sedimentation rates (or total volume) is not an easy task. This is mainly due to the complexities associated with simulating this hydrological phenomenon. First, most variables that would enter into the analysis are environment specific. Second, while "sufficient" data to simulate the detachment of soil often requires cross-section surveys, simulation of the transport and deposition requires time-series data. Finally, data collection and processing, to arrive at some meaningful results, demands interdisciplinary teams and sophisticated hardware and software (e.g., meteorological stations, computer simulation).

The definition of the terms, "sediment delivery ratio (SDR)" is necessary before explaining the types of assessment methods most oftenly used. This ratio is defined as the proportion of soil that reaches a nearby water course, to the total amount of soil that is detached. This ratio is an important parameter in almost all methods used to predict sedimentation rates. Empirical studies have shown that the value of the SDR is inversely correlated with the size of the drainage area of a catchment: the larger the drainage area the smaller the value of the SDR (i.e., the lesser the amount of soil detached that reaches a water course). The value of the SDR is expressed by a number between 0 and 1.

There are three basic methods or framework used in predicting sedimentation rates or volume:

- The upstream method which predicts sedimentation rates based on simulating soil detachment or, simply, erosion. Once the amount of erosion or soil detachment is estimated, a SDR is applied to assess the total amount of sedimentation. The most well-known used method to assess volumes of soil detachment is called the Universal Soil Loss Equation (USLE).
The midstream method which predicts sediment loads based on sampling carried out in rivers and irrigation canals. Once the total volume of sediments have been estimated the analyst could eventually go back and compute an "equivalent" erosion rate by using the appropriate SDR (based on the size of the drainage area and the value of the SDR). Computation tasks are now available to carry out such conversions.

The downstream method which predicts sedimentation ratio based on sampling carried out where sediments are finally deposited (e.g., tanks, sediment ponds, water reservoirs).

There are many advantages and disadvantages associated with the use of these methods. The purpose and scope of the assessment often determines which method to use. However, experts in the field prefer to use the midstream method whenever equivalent erosion rates need to be estimated. Those interested in the details, that explain why this is so, should consult specialized technical books and reports.

Assessment at the Country Level

To present data on a country by country basis goes beyond the scope of this note. However, a few cases will be reported here with the view to illustrate some important issues (for a detailed presentation of existing information, see A. Sfeir-Younis; Soil Conservation in Developing Countries: A Background Report. AGR, Forthcoming).

The literature which focuses on this type of assessment is very sparse. To be able to have a relatively comprehensive picture of the sedimentation problem in developing countries, one has to review documents published by economists, soil scientists, agronomists, hydrologists, irrigation engineers, etc. This is a very vast field of expertise. In addition, the statistics that could be used to illustrate the seriousness of the situation can be presented in two different ways: using erosion-rate equivalence or volume of sediment loads in river, or sedimentation rates proper. This note will mainly present data on sediment loads and equivalent erosion rates.

The sediment load carried by major rivers of the world is alarming. In thousand tons the suspended load of sediments for the five major river basins of the world (i.e., Ganges, Yangtze, Amazon, Congo and Nile River), vary from 59,000 in the Congo to 1,600,000 in the Ganges. The equivalent erosion rates (given the size of the drainage area of these rivers), vary between 2.8 tons/ha/year and 302 tons/ha/year. So called "tolerable" levels are often believed to be 10 tons/ha/year!!

Rivers in China (PRC) and in India show one of the highest sedimentation rates of the world. In particular, the Lo and Ching rivers in China have a sediment loads which translate into erosion rate equivalent of 1,610 and 1,500 tons/ha/year, respectively.

These sediment loads get deposited in major and minor water reservoirs and tanks. Major dams that are suffering from high rates of sedimentation are the Aswan (Egypt), Tarbela and Mangla (Pakistan), and Hirakud (India).
Under these circumstances, the total loss in reservoir capacity is very large. In India, for a selected number of reservoirs, the accumulated loss in reservoir capacity is nearly 25%. The average actual (or observed) rate of sedimentation is several times higher than the assumed (or predicted) rate of sedimentation (that rate used during constructions). In the Nizmasgar Reservoir the ratio of observed to assumed rate of sedimentation is nearly 23!! This high rates affect the economic life of reservoirs: water reservoirs are becoming “sand boxes.”

Sedimentation Rates Worldwide

A few attempts have been made to assess global rates of sedimentation. These studies have estimated that the volume of suspended loads fluctuate between 3,867,633 and 72,807,185 thousand tons per year. The equivalent erosion rates are 9.7 and 182.6 tons/ha/year, respectively.

We have estimated these parameters based on the use of a worldwide method. The results show that suspended loads (again in thousand of tons) is nearly 23,000,000 with an equivalent erosion rate of 57.4 (average for the world). These estimates vary by region, the highest in Asia and the lowest in Africa. Variations across continents and countries are significant.

In addition to the above-mentioned estimation exercise, a simple simulation model was developed to analyze the potential impact of sedimentation on available water reservoir capacity worldwide.

Data on reservoir capacity of 200 major dams was analyzed (e.g., volume of water, starting date). The data was organized on a decade-to-decade basis starting in 1940. Very interesting results were found.

First, mapping the number of reservoirs that were made available between 1940 and 1980, one finds that the “number of reservoirs” grew at an increasing rate between 1940 and 1970. However, the growth rate declined quite significantly afterwards. A speculative inference from this simple relationship might be telling us that the number of available dam sites is decreasing. A reminder: dam sites are irreplaceable assets!!

Second, instead of organizing the data on a “number of dams” basis, we map the volume of water that was made available in each decade. The analysis shows that the overall capacity increased at a faster rate during the whole period (1940-1980). These results probably suggest that the “average size of dams” built in the last couple of decades has increased substantially: we are building larger dams.
To assess the potential impacts of alternative sedimentation rates on available reservoir capacity (in a worldwide basis), a scenario analysis was carried out. The first scenario was defined as being characterized by a uniform sedimentation rate of 1% per year against the existing live storage capacity of those reservoirs. The second scenario assumes an increasing rate from 1% to 4% in each of the decades under analysis. These two scenarios were compared with one where sedimentation rates only affect the dead storage capacity of reservoirs; i.e., the net loss in productive capacity being zero. This analysis shows that:

- By the year 2000, the simulated scenario characterized by flat rate of 1% per year shows that the world will lose approximately one-third of the total reservoir capacity available.

- By the year 2000, under the second scenario (of increasing sedimentation rates) the total loss of reservoir capacity will be approximately two-thirds of the total!!

A few implications with regard to sedimentation management should be noted at this stage:

- If the number of dam sites available is decreasing (or to say that the number of future options is decreasing), the management of sediments (e.g., decreasing sedimentation rates) has to be an important consideration in development planning. Otherwise major development constraints will arise.

- If the type of dams being constructed are larger in size, this would suggest that policies regarding the management of sediments will have a more significant impact than these ever had in the past.

- If the size of these dams is somehow correlated with the size of the drainage or catchment area--catchment areas characterized by very high population density--the above-mentioned results suggest that management schemes will become more complex in the future. This is due mainly to the "concentration" effect. Managers will be confronted with trying to change the behavior of a large number of sediment production units, large number of climatic conditions, and the like. The effectiveness of management interventions will tend to decrease unless comprehensive programs are carried out.

- Needless to say that the distributional impacts (in this case we refer to negative impacts) will be greater, and the financial commitments from the part of Government will be larger. In a world characterized by acute financial constraints, these findings are of critical importance.

Limitation of This Framework

The data base used to illustrate some of the perceived effects of sedimentation suffers from several shortcomings. Therefore, the discussion presented earlier should be thought as very tentative.
The use of equivalent erosion rates may be misleading if policy makers are concerned with the potential impacts on soil productivity. Even when erosion rates are very high, it is not fertility. Fertility depends on too many other factors. (With the same token, erosion rates which may be considered to be "low" may result in major declines in soil fertility. This will happen in areas characterized by shallow soil).

Implications

Despite the very aggregate nature of the framework used to illustrate the potentially negative impacts of sedimentation, several implications may be worth noting.

- The potential impacts of failing to design adequate sedimentation management schemes will have major detrimental effects in developing countries.

- As population growth increases, management schemes will become more complex. More people are moving upstream, land tenure is not secure, and farming systems are developed in more economically fragile soils (i.e., soils that are prone to erosion).

- The design of investment and policy packages for the development of agriculture upstream should consider the potentially damaging effects to productive activities downstream.

- Data systems for decision making should be improved.

- Because dam sites are irreplaceable assets, the absence of adequate management schemes would result in more costly investments even if the economy is to produce the same level of output (hydroelectric power, food crops, drinking water supplies).
III. OPTIONS AND CONSTRAINTS

Sedimentation Management Matrix (SMM)

This section reiterates a few important points presented earlier. The word "matrix" is used here to emphasize the fact that there are several dimensions in dealing with any sedimentation management problem.

The spatial dimension. This is one of the most important given the nature of the natural resources in question and the presence of market failures (i.e., externalities). The economic units involved (be it "producers" or "consumers" of sediments) cannot be looked at in isolation. The understanding of the inter-sectoral linkages is vital if management schemes are to succeed. This has been referred to as the "unit of account" problem or as the "source and incidence" problem.

The intertemporal dimension. The distribution of benefits and costs of management interventions, regarding the production/detachments, the transport and the deposition of sediments, presents a particular set of problems. Most often than not, benefits will be accrued far in the future while the costs of these interventions have to be born today.

The SMM has at least two other dimensions. One dimension of the matrix would focus on how the sedimentation problem is defined as an upstream, midstream, or downstream problem. The literature, perhaps reflecting actual practices, has been biased towards defining sedimentation purely as a downstream problem. Another dimension of the matrix is defined by the multiple aspects involved in sedimentation management: technical aspects (e.g., defining tolerance levels, design standards), organizational aspects (e.g., land tenure), financial aspects (e.g., who is to pay, government budget allocation), economic aspects (e.g., economic incentives, policies, investments), etc.

These dimensions make sedimentation management a complex task. Each cell in the matrix should be carefully studied to select management instruments that will eventually be most effective in controlling sedimentation.

Another important aspect that comes to light when recognizing the multi-dimensionality of the SMM is related to the establishment of standards. Important conflicts arise when standards are established in response only to one characteristic or to one cell of the matrix (i.e., done in isolation from the other cells). Three examples may illustrate these conflicts.

Water quality standards. What may be defined as an acceptable level of water quality for irrigation purposes (i.e., a given level of chemical concentration of nitrogen in sediments) may be unacceptable for drinking water supply purposes.
Erosion versus sedimentation rates. Because of the concentration effect, the definition of a tolerable erosion rate on a per hectare basis, based upon soil fertility considerations, may still be unacceptable in terms of the total volume of sediments generated in the system downstream.

Economic policy recommendations. To internalize existing externalities (i.e., spatial and intertemporal) decision makers may decide to recommend the establishment of economic incentives (e.g., tax those who produce sediments). For example, a program that would subsidize fertilizer use upstream, with the view to increase soil fertility, may end up increasing the eutrophication rate of rivers whose waters are used for drinking water supply purposes in cities located downstream. Who should pay for the cost of eutrophication, the farmers upstream or the people who are consuming that water downstream?

Alternative Options

* There are several options open to policy makers in developing countries. The economic and social merits of alternative options will basically depend upon country circumstances (e.g., climate and ecology, stage of development, natural resources available, policy framework, development objectives). However, there are several generalizable statements one could outline at this particular juncture.

Location of assets. The development of a river basin, for example, often require the construction of such physical assets as dams, roads, bridges, ports, infrastructure for riverine transport, and the like. The criteria for the location of these assets is an important issue since substantial ecological transformations may take place.

Type of assets and policies for the downstream economy. As explained earlier, there are several trade-offs between control of sedimentation upstream or downstream. Options are open to many countries, particularly in those watersheds that have not been developed yet. These trade-offs cannot be disregarded since, as explained earlier, major social costs will occur. However, countries will have the options of avoiding potential damages to assets downstream by constructing sediment ponds, dams with the proper mechanism to wash away (flushing) sediments, purchasing dredging equipment, expansion of the dead and live storage areas of existing reservoirs, expanding the water-flow capacity of major irrigation infrastructure, building water treatment plants, etc. These investments should be accompanied by a set of policies that will change the economic behavior of downstream units.

Type of assets and policies for the upstream economy. This will include investments in roads with adequate drainage facilities, bridge which will minimize the impoundment of sediments, implementation of adequate land clearance methods, etc. In addition, at the farm
level, several such investments as gully control structures, sediment traps, drainage and irrigation infrastructures are also important. At the farm level, engineering as well as biological erosion control practices should be considered (e.g., forestry programs, changes in cropping patterns, terracing, drainage, strip cropping, minimum tillage). Decisions regarding the type of investments to be financed will depend on their economic and social impacts as perceived by different actors in the economy.

Policies designed to change the behavior of productive units located upstream are of vital importance. These policies will mainly focus on the necessary incentives to adopt soil conservation practices (e.g., subsidizing terrace construction, assigning land rights). An important issue, however, is to assess the economic impacts of these policies to avoid further deterioration of the environment.

As regards management schemes, there are several options open, although, it is extremely important to take into consideration the "unit of account" for design and implementation. As it has been advocated here and in the Briefing Note 1, a Total Catchment Management Approach is necessary to avoid substantial social costs and to design and implement fragmented interventions. These management practices should be supported by adequate data gathering and processing systems. The data base is very weak at present and, consequently, there is a vacuum regarding the potential changes of many advocated management interventions.

**Projecting Alternative Options**

It would not be difficult to package projects or programs which will be aimed at managing sedimentation in developing countries. These projects or programs will include a long list of investments and policy interventions that would achieve a set of well-defined development targets. Perhaps a major constraint will be in the area of organizational arrangements necessary for these programs to succeed.
IV. ECONOMIC EVALUATION

Nature of the Evaluation Process

This section will focus on those aspects of the economic evaluation process that seem to be specific to the type of investments and policies under consideration. Given the main objective of this briefing note, the presentation here will not have much analytical depth. In fact, there will be many subject matters which will be totally ignored. (For more details see A. Sfeir-Younis, 1981, 1983, and forthcoming.)

The first question one has to ask oneself is what does it make these sedimentation management projects so different from other projects (e.g., the economic evaluation of a shoe factory)? A few important characteristics are:

- **Presence of spatial-externalities.** This relates to the fact that actions from upstream economic agents affect downstream ones and that the market fails to provide the necessary signals.

- **Distributional impacts.** Since the source of sedimentation is different from the incidence, projects and policies are bound to have major income distribution impacts.

- **Intertemporal externalities.** Because of the pattern in the distribution of benefits and costs and the difference between private and social preferences, decisions regarding the management of sediments will affect both the present and the future generations.

- **Difficulties in Monetary Valuation.** The lack of Markets, demands specific methods of valuation, particularly of benefits (the subject of the next few sections). And

- **Presence of Irreversibilities.** Excessive sedimentation will cause irreversible damages. This requires the calculation of corresponding social value since future development options will be constrained.

The benefits of sedimentation management, or the avoided costs, are therefore composed of several elements. Expressed in more technical terms, the "marginal opportunity cost" or the value to society of producing one additional unit of sediments, has the following components (see D. Pierce, The Cost of Natural Resource Depletion, 1985):

1. **Marginal cost of production (very low),**
2. **The value to society of...**

1/ A copy of this paper may be obtained from OPS/PPD.
marginal external cost (i.e., spatial externality), (iii) marginal user cost (i.e., intertemporal externality) and (iv) marginal disaster cost (i.e., irreversibility).

**Integrating Technical and Economic Frameworks**

The economic evaluation process is geared, in this case, towards simulating a complex natural system (i.e., "with" and "without" project or policy interventions). To carry out this process, cause-effect relationships need to be identified (e.g., effects of sedimentation on flood control). The magnitude of potentially damaging effects of sedimentation depend upon the way in which these relationships are expected to behave: caused by changes in both the volume and the quality of sediments.

The economic analysis invariably begins with establishing some notion of productivity.

In assessing potential changes in productivity of the land, the economic analysis begins with the notion of "crop yields" (in physical terms). Yields are expected to change "with" and "without" a project (or policies). The set of physical relationships affecting the level of crop yields are rather complex and these relationships are part of the technical framework of analysis. Lack of understanding of how changes in these relationships affect yields will clearly limit the quality of the economic analysis.

Sedimentation effects on floods is another example. The economist is basically concerned with how floods affect the productivity of activities located downstream. However, floods, as a hydrological phenomenon, are very complex and their characteristics (e.g., frequency, timing, routing, depth, nick flood, datum flood) will greatly influence how economic productivity will change.

There is a need to integrate technical frameworks (simulating changes in the physical aspects of a natural phenomenon) with economic methods and procedures. The point of integration is this notion of productivity. If integration does not take place, the economic evaluation process will be incomplete, and the information provided by the natural scientist will be of little or no use to the economist. With the same token, if the economist does not understand the nature of existing technical frameworks—and how these frameworks are designed to simulate changes in the physical environment—the ability to have an operational definition of productivity will be very limited.

There are several steps one could follow to achieve this integration:

**Step one:** Identifying the most important effects of sedimentation;
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- Step two: developing the physical characteristics of the phenomena under consideration (probably accompanied with physical flow tables);

- Step three: defining the basic units with which the evaluation team will analyze sedimentation effects;

- Step four: defining the type of welfare estimates the economist plan to use based on the type of physical parameters mentioned earlier;

- Step five: developing value estimates to quantify the gains and losses of different interventions;

- Step six: defining the criterion (or criteria) for investment and policy decisions; and

- Step seven: analyzing the perceived project risks.

Identification of Benefits and Costs

* Most of the introductory sections of this note emphasized the nature and scope of the potential effects of sedimentation. The proper identification of benefits and costs is of vital importance.

* From a practical point of view, it is often stated that "conservation" projects are not attractive in a traditional economic sense (i.e., based on the so called traditional benefit-cost analysis sense). Another way to express this concern is by saying that the expected rate of return of these types of projects is too low to attract financial capital. One of the main reasons for this to happen is the failure to properly identify the true range of benefit and costs.

* From an analytical point of view, if benefits and costs are not properly identified, the true magnitude and value of the "marginal external costs" are not accounted for. When these external effects are not an integral part of the analysis a big chunk of potential benefits are disregarded. In addition, failure to identify these items will result in important trade-offs being overlooked, and in a very sub-optimal design of sedimentation control projects.

* The same principles apply to policy changes. Decision makers are often confronted with assessing the potential effectiveness of alternative policy interventions. If the benefits (or costs) are not adequately identified, major efficiency and equity problems will arise.

Monetary Valuation of Benefits and Costs

* Because sediments are not a tradeable commodity and because market failures are present, specific methods are to be used to assess the economic merits of these projects/policies.
The assignment of values to different attributes of projects and policies is not a problem. There have been many approaches suggested by the literature covering, for example, the area of environmental impact statements. However, for the economist the assignment of monetary values to benefits and costs has to be consistent with a body of knowledge called "welfare economics." Monetary valuation methods should be consistent with the basic principles of welfare economics. To discuss here the nature of these principles goes beyond the scope of this note.

The presentation that follows will only outline a framework for the monetary valuation of benefits and costs and will put together a list of methods which are consistent (under a given set of assumptions) with the basic principles of welfare economics. Very little detail will be given here.

Earlier in this note, we suggested several characteristics of these projects, which are rather unique, when compared with other projects. These characteristics were then related to the main components of the marginal opportunity cost concept. The main emphasis here will be on aspects related to the monetary valuation of the marginal cost of production and of the marginal external costs. Little will be said here about the marginal user cost and the marginal disaster cost. In other words, the presentation will focus mainly on extensions of traditional benefit cost analysis and nothing will be said here about inter-generational equity (e.g., changing the discount rate).

The process of monetary valuation suggested here is composed of several elements. First, instead of referring to sediments in an aggregate in an abstract sense, one has to look into their intrinsic characteristics. This is to say that the analyst has to focus on his different environmental attributes, and on how the changes in these attributes (e.g., volume, size and shape of sediments), affect the production process of a tradeable commodity. Another way to state this problem is by saying that the appraisal process should consider environmental attributes (or characteristics) as factors of production.

Second, establish a clear relationship between changes in these characteristics (e.g., higher or lower volume of sediments, more or less concentration of chemicals) and perceived changes in the productivity of tradeable commodities, or changes in quantity or quality of other inputs which, in turn, will affect the productivity of tradeable commodities.

Third, determine how these changes will affect economic behavior. Often these changes will be reflected via changes in net income, profits, total cost, marginal cost, input cost, and input and output supplies.

Finally, assess these changes in economic terms using the economic prices and quantities of the tradeable commodities affected.
The following valuation methods are often used: (i) valuation based on observed economic behaviors (e.g., changes in the value of output, use of surrogate markets, travel cost approach, replacement cost approach, shadow project approach, prevention cost approach, hedonic value approach, and income foregone approach); (ii) valuation based on elicited responses; and (iii) valuation based on synthesized or simulated economic behavior (for a detail presentation, see Sfeir-Younis, 1984, forthcoming).

These methods may also provide a useful evaluation framework when dealing with alternative policy options. The basic principles also apply, and details were presented in the Briefing Note II.
V. POLICY CONDITIONALITY AND ACTION PROGRAM

Policy Conditionality

* Within a program designed to deal with sedimentation problems in developing countries, the nature and extent of policy conditionality will vary depending on the existing: (i) macroeconomic policy environment; (ii) organizational arrangements at the public sector level; and (iii) development goals and objectives the countries aim to accomplish.

* Because of the nature of sedimentation, policy conditionality to achieve a given set of objectives will have to be framed and assessed not only based on traditional macroeconomic aggregates (e.g., employment, income, foreign exchange), but on how such conditionality affects land allocation and use. This will require to set standards related to both changes in the quantity of existing natural resources (e.g., soil, water) and standards related to changes in the quality of these resources (individually and in the aggregate).

* The assessment process requires a definition of a larger analytical boundary. A boundary that goes beyond an individual production unit which forms the basis for aggregation: a change in the unit of account (see Briefing Note I). The assessment has to be carried out under the umbrella of a Total Catchment Management Approach. This approach will center policy conditionality on several issues outlined below.

* Policy conditionality should consider at least the following areas of inquiry:
  
  - establishment of standards in terms of acceptable sedimentation rates;
  - organizational changes that would enable a more centralized management of catchment areas;
  - pricing and incentive policies which will change the behavior of those exploiting the catchment upstream; and
  - establishment of mechanisms for the assessment of both spatial and intertemporal externalities.

Action Program

* It is difficult to draft in the abstract an action program for a country. Besides outlining the basic elements (e.g., investments and policies), the action program should focus on organizational and institutional reforms, macroeconomic policies, resource mobilization and fiscal impacts, and it should define who is to participate in such a program.
There are good examples of the type of action programs which have emerged when policy makers are concerned with sedimentation management. The river basin development authorities in the USA and in other countries have produced comprehensive action programs.