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The Costs of Soil Erosion on Java: A Natural Resource Accounting Approach

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ABSTRACT

Soil erosion is analogous to the depreciation of man made assets. Unlike the depreciation of capital assets, however, the effects of soil erosion are not reflected in conventional measures of economic welfare. This occurs because efficient markets seldom exist for soil resources, because of the pervasive influence of externalitites on the true costs of soil erosion, and because systems of national accounts are biased to treat natural resource as free goods. As a result, policymakers do not have the information required to adequately weigh the benefits and costs of alternative soil conservation policies.

The basic requirements for calculating the on-site costs of resource degradation are understanding the dimensions of the physical processes of change, understanding the impact of those processes on the production of valued goods and services, and understanding the ways in which economic activity adjusts to these changing circumstances. for this study, these requirements were met by developing three linked models.

To satisfy the first requirement a geographic information systems based model was used to integrate data on soil type, topography, rainfall and landuse to estimates of levels and distribution of erosion.

To estimate the productivity consequences of erosion a model was developed focussing on rainfed agricultural land. Finally, an economic model of farms response to falling productivity and of farm profitability is used to value the erosion process.

The deposition of soil at downstream locations frequently reduces the benefits from investments in infrastructure such as reservoirs and irrigation systems. An effort was made to identify major categories of potential damage and to locate whatever evidence was available on their economic significance.

For Java, as a whole, it is estimated that erosion costs the economy between $340 and $406 million per year. Of this $315 million are estimated to be on-farm losses of productivity and the balance $25-80 are of downstream damages.

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THE COSTS OF SOIL EROSION ON JAVA -- A NATURAL RESOURCE ACCOUNTING APPROACH

Introduction

Soil erosion is both a physical and an economic process. The physical removal of part of the topsoil and its deposition elsewhere lowers the agricultural potential of a site and thus sets in motion a sequence that ultimately results in a lower economic value of the resource base. Unlike the depreciation of other capital assets, the effects of soil erosion are not normally reflected in measures of economic welfare. This occurs because efficient markets seldom exist for soil resources and because of the pervasive influence of externalities on the true costs of erosion. As a result, policymakers do not have the information required to weigh the benefits and costs of alternative soil conservation policies. In this paper a natural resource accounting approach is used to quantify in economic terms the cost to the economy of watershed deterioration as manifested in soil erosion. This analysis enables policymakers to compare the consequences of upland deterioration with other developments in the economy.[1] To estimate the economic significance of soil erosion it is necessary to develop a model of the physical dimensions of erosion, link these to changes in crop production and farming systems or the production of other goods and services, and finally value these changes. In Section II the process by which the on-site costs of soil erosion on Java were estimated is described. The methodology involves use of a computerized geographic information system (GIS) in which the size of areas equally susceptible to erosion are quantified. Estimates of these levels of erosion and agronomically based estimates of the impact of these levels on crop yields are then combined with data on the predominance of alternative upland farming systems. This yields estimates of reductions in agricultural output due to erosion. Representative farm budgets are used to value those changes. The capitalized sum of the predicted reduction in returns to land that results from this procedure provides an estimate of the on-site cost to the economy of soil erosion. Additional details on the various steps in the methodology are provided in this section along with summaries of the data generated in the process.

In addition to the on-site costs of soil erosion, an attempt is made in Section III to calculate the level of major off-site or downstream costs. These include reservoir and irrigation system siltation and siltation of harbors and waterways. Less data is available on the physical dimension of the off-site consequences of erosion. However, it is possible to get an indication of their economic significance by examining data on maintenance expenditures that are necessary to ameliorate the downstream deposition of silt, or by extrapolating from particular studies of specific investment projects.

1/ For an overview of the concept of Natural Resource Accounting see Lutz and El Serafy (1988). For a discussion of the concept and an application to several sectors of the Indonesia economy see Repetto and others (1989). Readers interested in the economics of soil resources are referred to the works listed in the reference section especially Clark and others (1985), Magrath and Grosh (1985) and Sfeir-Younis (1985).

In Section IV the various costs of erosion are summarized and compared for the regions of Java. The Policy and methodological implications of the analysis are also considered.

Although the analysis does result in an estimate of the cost to the economy of soil erosion it is important to acknowledge the limitations of the currently available information on soil erosion on Java. There are severe limits to the availability of reliable data on the rate at which soil erosion takes place on the different soils, the impact of this erosion on crops, farmer responses and all the other farm and nonfarm factors that determine the social losses caused by soil erosion. Nevertheless, the government of Indonesia as well as multilateral and bilateral donors have allocated millions of dollars to aid in the reduction of erosion. A major aim of the study is to illustrate a logically consistent framework in which the economic significance of a major form of environmental deterioration can be assessed. There remain important weaknesses in our understanding of the physical and behavioral processes that give rise to this deterioration and which make it socially and economically relevant. This paper illustrates the potential usefulness of scientific research on a number of issues in soil science. Until new and more definitive data become available, readers who are skeptical of particular assumptions are free to insert their own and explore their impact on our results.

I. Measures of Land Degradation on Java

Soil degradation is a gradual process that occurs as soil depth declines by erosion leaving progressively less topsoil and lower nutrient concentrations. Data monitoring this process on aggregate levels in Indonesia are not available. In this section alternative indicators of degradation are reviewed along with estimates of their quantitative significance on Java.

The most frequently cited statistic on the severity of soil erosion in Java is the figure of 1.1 million hectares of "critical" land. Critical land is said to be increasing by 200,000 ha per year. According to the rough calculations of Ramsay and Muljadi (1983) land rehabilitated under the Regreening Programme, when adjusted for seedling survival rate, probably amounts to around 125,000 ha. On net, therefore, "critical" land area may be estimated as increasing by some 75,000 ha per year. More recent information from the Ministry of Forestry is that the total area of critical lands is now declining by 10,000 ha per year.

Unfortunately, there does not seem to be a rigorous, generally accepted definition of critical lands. According to Roche (1987: 14) the old Indonesian Directorate of Landuse defined critical land only on the basis of slope. Any land with slope greater than 50% was designated critical. Obviously increments to critical land using this definition is nil. Ramsay and Muljadi (1983) cite the following criteria for critical lands:

- unable to produce cassava yields of more than 500 kg/ha/yr[2]

2/ Presumably below this level cultivation is unattractive even for subsistence agriculture. Java-wide cassava yields are greater than 10 tons/ha.

- unable to act as a regulator in the water system

- unable to fulfill any protective function such as absorb run off.

They further describe critical lands as areas in which all the topsoil has been removed by erosion and in which not more than 25 cm of subsoil remains in place over the parent rock material.

While the amount of land in the critical category is a useful summary of overall seriousness of the soil degradation, it has several severe limitations. The accuracy and precision with which areas of land are designated as critical is open to considerable question. The extent to which the criteria listed above can be, or actually are, used in estimating critical areas is unknown. Discussions with GOI officials suggest that local authorities responsible for making these designations have considerable latitude. Consequently the de facto criteria for defining critical lands probably vary widely.

A perhaps more serious problem with the critical lands concept is the fact that soil degradation is a gradual process that intensifies as soil depth decreases. The binary choice, critical/non-critical, provides only a poor approximation of the level or rate of change in the value of the aggregate soil resource. Long before soil quality falls to the point where agricultural production is completely unprofitable, there are discernible reductions in yields and net income. Only considering land that completely drops out of production will underestimate the severity of land degradation.

Attempt to utilize available time series data on land use does not provide useful insights into changes in soil quality on Java. There are no time series on lands designated as critical (other than could be generated by using the rates reported above). In addition, the critical lands designation is relatively new. Due to these uncertainties, a modelling approach has been taken to estimating erosion levels in Java. In addition to providing greater consistency, this approach allows building on a large number of small area studies and allows for greater flexibility in designing components of the model to mesh with economic components. By making the relationships in the model explicit, it is also possible for users of the model to change variables to explore their consequences.

II. The On-site Costs Of Soil Erosion

A. Estimating the Physical Dimensions of Soil Erosion

The physical dimensions of soil erosion that are of interest for this analysis are the areas of land affected by various levels of erosion and their spatial distribution. In order to generate this data an erosion model based on soil type and slope, land use, and patterns of rainfall intensity was developed. Soil erosion, as with so many other aspects of agriculture and land use, is highly location-specific. In addition, the random processes of nature can affect erosion rates over both time and space. Thus no mathematical model, inevitably limited to a relatively few independent variables, can replace detailed empirical measurements of erosion rates. Unfortunately there are currently no available data that provides an adequate empirically based picture of soil erosion on Java.[3]

Among the data that are available are maps at the scale 1:1,000,000 of three variables that play a major role in determining erosion rates; i.e., soil types and slope, rainfall erosivity and land use. The soil map used for this study was published by FAO (1959) based on the work of Dudal, Supraptoharjo and others. It combines soil units with topography and is useful for visualizing the relations between soils and potential erosion. Twenty-five units are distinguished:

- five units of soils on level to undulating land, with dominant slopes under 8% (units 01-05);

- eleven units of soils on rolling to hilly land, with dominant slopes from 8-30% (units 06-16); and

- nine units of soils on hilly to mountainous land, with dominant slopes over 30% (units 17-25).

Descriptions of the soil types are included in Annex 1, areas of the soils by province are shown in Table 1.

Rainfall erosivity, a measure of the kinetic energy released as raindrops strike the ground, is a major factor contributing to soil erosion, and its inclusion is essential in any assessment of erosion problems. Bols (1978, 1979) has prepared an isoerodent map of Java based on correlations of a measure of the kinetic energy of storms with annual rainfall data, which are available for most of Java over an extended time period. On Bols' map, eleven classes of rainfall erosivity are distinguished at a scale of 1:1,000,000. Area estimates for each erosivity class are shown in Table 2.

Land use data for Java is available in tabular form from the Central Bureau of Statistics; however, these data are of questionable reliability. Their most severe shortcoming is that they provide no means for correlating land use with the other factors that affect erosion. The Ministry of Forestry nonetheless produced a land use map of Java in 1985. On the basis of the map, the following four types of land use (or vegetation cover) have been distinguished for the objective of quantification of the actual erosion:

- Areas of sawahs, including fish ponds. These areas are characterized by low erosion rates and, in fact, in large areas sedimentation prevails over erosion;

- Areas of Tegal (dryland farming), mostly on sloping uplands where erosion rates are very high;

3/ There are a number of small area studies that have been conducted on small watersheds and experimental plots. As explained below, these data, while not comprehensive enough to provide a complete basis for an economic estimate, are used throughout to provide a basis for the parameters in the model.

Table 1
SOILS ON JAVA
(00 ha)

Soil Type	West Java	Central Java	Jogyakarta	East Java	Java
1	86.7	485.1	0.8	213.0	785.6
2	9,203.7	5,514.1	409.6	9,286.5	24,413.9
3	614.0	189.7	52.7	180.5	1,036.9
4	359.8	2,550.6	30.9	2,101.3	5,042.6
5	0.0	271.2	0.0	0.0	271.2
6	0.0	0.0	219.8	535.2	755.0
7	1,714.4	3,482.2	181.3	2,012.2	7,390.1
8	454.3	0.0	0.0	136.6	590.9
9	112.0	1,635.5	0.0	1,457.8	3,205.3
10	6,464.1	3,946.0	0.0	1,902.2	12,312.3
11	666.9	0.0	0.0	0.0	666.9
12	2,232.2	99.1	0.0	42.6	2,373.9
13	1,737.7	0.0	0.0	0.0	1,737.7
14	3,081.4	364.1	817.9	3,835.4	8,098.8
15	0.0	1,941.9	29.5	1,528.2	3,499.6
16	0.0	0.0	0.0	265.9	265.9
17	1,161.2	1,753.2	602.0	2,598.2	6,114.6
18	0.0	71.0	0.0	4,259.0	4,330.0
19	0.0	0.0	0.0	117.7	117.7
20	5,372.1	3,352.3	0.0	3,592.3	12,316.7
21	1,495.1	1,854.1	0.0	2,268.4	5,617.6
22	5,811.9	0.0	0.0	0.0	5,811.9
23	7,688.7	1,311.4	0.0	0.0	9,000.1
24	240.4	1,988.9	339.5	1,903.5	4,472.3
25	1,603.4	860.5	518.9	5,028.4	8,011.2
TOTAL	50,100.0	31,670.9	3,202.9	43,264.9	128,238.7

Source: Calculated from FAO (1959).

Table 2
AREAS OF JAVA SUBJECT TO ALTERNATIVE
LEVELS OF EROSIVITY
(00 ha)

Erosivity Level	West Java	Central Java	Jogyakarta	East Java	Java
A	108.0	76.2	2.1	2,439.1	2,625.4
B	2,582.3	1,949.0	456.0	9,046.8	14,034.1
C	8,184.1	4,407.0	1,158.1	19,390.5	33,139.7
D	7,995.5	7,279.6	891.8	6,877.8	23,044.7
E	6,826.5	6,809.5	362.5	2,103.8	16,102.3
F	10,100.2	4,305.2	332.5	1,743.0	16,480.9
G	7,348.5	2,558.4	0.0	1,253.6	11,160.5
H	6,712.3	2,530.4	0.0	380.5	9,623.2
I	242.6	1,281.4	0.0	29.4	1,553.4
J	0.0	344.7	0.0	0.0	344.7
K	0.0	129.6	0.0	0.0	129.6
TOTAL	50,100.0	31,671.0	3,203.0	43,264.5	128,238.5

Source: Calculated from Bols (1978).

- Forest areas, i.e., areas of natural and planted forest, including perennial plantation crops where erosion is slight; and

- Degraded forest areas, including areas of shifting cultivation and degraded pekarangan (home gardens) where erosion is moderate to high.

These four types of land use or vegetation cover are summarized in Table 3.

Table 4 compares the areas of Sawah and Tegal as shown on the Ministry of Forestry Land Use Map with estimates published by the Central Bureau of Statistics (CBS). The Land Use Map estimates of Sawah area exceed the CBS estimates for every province, estimating almost twice as much Sawah area for Jogyakarta. On the whole of Java, the Forest Map estimates about one third more land in Sawah than the CBS. Forestry Ministry area estimates for Tegal range from 80 to 177 percent of CBS estimates. For West Java the Ministry of Forestry data exceeds that of CBS by 77 percent. For Java as a whole the divergence between the two sources is about 11 percent. The discrepancy over Sawah area is the most troubling. Unfortunately, there is no clear reason to prefer one source to the other. Sawah area is generally thought to be one of the more reliable statistics in the CBS land use data. However, the Forestry Ministry Map is based, at least in part, on airphoto interpretation in which Sawah area is easily and accurately measured. Fortunately, because Tegal land is a more important source of soil loss than Sawah, the discrepancy is considerably smaller for Tegal with the exception of West Java.

Given the Tegal area discrepancy, and because the cost of erosion calculation is performed first on a per hectare basis (see below) it was decided that it was most appropriate to use both sources. The Forestry Map was used in the soil erosion calculation only because it provided a spatial dimension that allowed correlation with the other elements of the soil erosion model. However, because the Central Bureau of Statistics data appear to be somewhat more reliable, these data are used in the final economic calculations.

The three maps described above were digitized and analyzed using the Geobased System by the World Bank's Environmental Operations and Strategy Division.[4] The procedure is essentially an overlaying of the three maps that identifies and provides an estimate of the areas of land characterized by the various combinations of slope and soil type, erosivity, and land use. Given the 25 soil groups, 11 erosivity classes and 4 land uses a total of 1,100 combinations are possible. In order to be able to take into consideration additional agronomic and economic differences, the analysis also divided Java along provincial boundaries resulting in 4400 possible combinations.[5] Maps showing the distribution of the main soil types and slopes, and erosivity and land use are given in Annex 2.

4/ Rounding errors in the Geobased System program result in minor discrepancies in area estimates. Consequently, columns and rows may not add exactly. The errors introduced in this way are insignificant.

5/ West Java, Central Java, D.I. Jogyakarta, and East Java, D.K.I. Jakarta was included in West Java.

Table 3
LAND USE ON JAVA*
(00 ha)

Land Use	West Java	Central Java	Jogyakarta	East Java	Java
Sawah	16,043.8	13,361.3	1,078.5	16,969.6	47,453.2
Forest	5,412.7	6,357.6	0.0	12,075.1	23,845.4
Degraded Forest	3,009.2	340.3	31.5	615.2	3,996.2
Tegal	25,634.4	11,258.2	2,093.0	13,604.5	52,590.1
TOTAL	50,100.1	31,317.4	3,203.0	43,264.4	127,884.9

Source: Calculated from Ministry of Forestry (1985).

*Columns and rows may not add due to rounding. Wetlands excluded from analysis.

Table 4
COMPARISON OF LAND USE ESTIMATES
(00 ha)

	CBS	Ministry of Forestry	Model As Percent
Sawah Area Estimates			
West Java[1]	12,152.74	16,043.8	132
Central Java	10,231.43	13,361.3	131
Jogyakarta	636.20	1,078.5	169
East Java	11,988.43	16,969.6	0
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JAVA	35,008.80	47,453.2	136
Tegal Area Estimates[2]			
West Java	14,402.14	25,464.4	177
Central Java	13,660.78	11,258.2	82
Jogyakarta	1,963.72	2,093.0	107
East Java	17,440.27	13,604.5	78
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	47,466.91	52,420.1	110

1/ Including D.K.I. Jakarta.

2/ House Compound and Surroundings and Bareland/Gorder/Shifting Cultivation.

The estimate of actual erosion rates corresponding to each of the possible combinations is based on measurements under given conditions of plant cover or cropping, and on judgement based on erosion elsewhere under comparable conditions. Several recent projects on Java have yielded valuable data on actual erosion of uplands. These include the successive UNDP/FAO Projects in the Upper Solo watershed, the US-AID Project in the Citanduy watershed, Dutch sponsored projects in the upper Brantas (Kali Konto) and the Upland Agricultural Projects of Jogyakarta and the Jratunseluna and Brantas watersheds financed by U.S.-A.I.D... and the World Bank. Other erosion data have been collected by the Soils Department of the Agricultural University in Bogor, by the Soil Research Centre in Bogor and by the Watershed Management Centre in Solo. Still other erosion measurements have been reported in the literature from before the war and in other publications (see reference section).

On the basis of these studies and observations, and based on judgement of local conditions, estimates of erosion rates of different soils under the influence of prevailing rainfall erosivity and under the major types of land use described above were calculated. The estimated levels of erosion resulting from this procedure need to be used with considerable caution. While they are believed adequate for the purpose of estimating erosion as an input to an estimate of the economic cost of erosion, the procedure is clearly not suited for other uses such as detailed land use planning. The model does not explicitly consider several important factors in determining erosion rates, particularly conservation practices and the considerable differences that can arise in ground cover within the broad categories of land use. For a discussion of the difficulties and pitfalls involved in even thoroughly tested erosion equations, see Wischmeier.

Tables 5 to 8 give predictions for soil loss on the various soil types and land uses for the four regions of Java. Table 9 summarizes this data and shows that Tegal accounts for by far the greatest total amount of gross soil loss.[6] On a per hectare basis soil loss is highest on Tegal land on West Java, followed by Tegal on Central Java. The soils of East Java are least subject to erosion. Predicted soil loss on a per hectare basis is shown in Table 10.

B. Estimating Productivity Effects of Erosion

While it is widely accepted that erosion lowers agricultural productivity, there is little agreement on exactly how productivity is related to erosion or on the quantitative impact of erosion on yields. In part this results from the difficulty of defining fertility, as well as the difficulty of conducting controlled experiments to identify and measure erosion-related yield changes. Erosion involves changes in the availability and relative concentration of nutrients for plant growth, and changes in soil structure which influence root growth and affect the availability of water. Weathering of subsoil, which may be affected by soil management and by the roots of plants, may contribute some replacement of the factors that together constitute land

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6/ This estimate, of course, only provides for soil erosion caused by rain and does not account for other sources of erosion such as mass washing and stream bank erosion.

Table 5
PREDICTED SOIL LOSSES FROM TEGAL BY REGION AND SOIL TYPE
(00 mt)

Soil Type	West Java	Central Java	Jogyakarta	East Java	Java
1	0.0	1,221.9	0.0	0.0	1,221.9
2	15,805.8	3,210.5	473.2	4,939.7	24,429.2
3	1,928.8	647.8	178.0	42.4	2,797.0
4	1,539.2	4,850.7	105.2	1,861.5	8,356.6
5	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	3,516.0	16,707.6	20,223.6
7	99,425.5	117,761.4	1,783.0	42,444.2	261,414.1
8	16,096.9	0.0	0.0	0.0	16,096.9
9	4,446.2	12,986.5	0.0	11,592.2	29,024.9
10	59,124.3	64,917.2	0.0	33,190.1	157,231.6
11	12,506.2	0.0	0.0	0.0	12,506.2
12	41,561.7	909.3	0.0	77.2	42,548.2
13	13,472.8	0.0	0.0	0.0	13,472.8
14	603,786.3	34,840.5	73,412.1	222,954.1	934,993.0
15	0.0	69,924.4	0.0	49,852.1	119,776.5
16	0.0	0.0	0.0	13,346.5	13,346.5
17	22,545.8	77,812.7	18,154.8	41,819.7	160,333.0
18	0.0	3,089.0	0.0	137,128.1	140,217.1
19	0.0	0.0	0.0	5,917.1	5,917.1
20	764,107.1	405,105.4	0.0	92,083.0	1,261,295.5
21	262,923.8	277,731.2	0.0	49,517.6	590,172.6
22	374,987.8	0.0	0.0	0.0	374,987.8
23	1,104,839.3	308,443.0	0.0	0.0	1,413,282.3
24	63,719.6	9,263.7	50,516.2	149,667.8	273,167.3
25	211,543.8	108,459.6	99,344.1	160,692.4	580,039.9
TOTAL:	3,674,360.9	1,501,174.8	247,482.6	1,033,833.3	6,456,851.6

Table 6
PREDICTED SOIL LOSS FROM SAWAH
BY REGION AND SOIL TYPE
(00 mt)

Soil Type	West Java	Central Java	Jogyakarta	East Java	Java
1	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	17.1	1.2	18.3
7	290.6	301.0	36.0	70.7	698.3
8	33.0	0.0	0.0	0.0	33.0
9	9.9	92.4	0.0	48.9	151.2
10	710.0	433.0	0.0	34.8	1,177.8
11	111.5	0.0	0.0	0.0	111.5
12	51.8	0.0	0.0	1.4	53.2
13	1,108.7	0.0	0.0	0.0	1,108.7
14	0.0	7.5	0.0	301.6	309.1
15	0.0	1,080.2	17.8	369.9	1,467.9
16	0.0	0.0	0.0	1.2	1.2
17	1,279.6	990.4	405.8	907.8	3,583.6
18	0.0	58.6	0.0	1,325.0	1,383.6
19	0.0	0.0	0.0	0.0	0.0
20	2,436.2	1,963.2	0.0	948.0	5,347.4
21	632.8	48.2	0.0	76.4	757.4
22	1,637.2	0.0	0.0	0.0	1,637.2
23	1,123.1	49.4	0.0	0.0	1,172.5
24	0.0	567.5	0.0	910.4	1,477.9
25	1,483.4	208.1	34.3	827.7	2,553.5
TOTAL:	10,907.8	5,799.5	511.0	5,825.0	23,043.3

Table 7
PREDICTED SOIL LOSSES FROM FOREST LAND ON JAVA BY REGION AND SOIL TYPE
(00 mt)

Soil Type	West Java	Central Java	Jogyakarta	East Java	Java
1	0.0	0.0	0.0	0.0	0.0
2	17.7	34.3	0.0	0.9	52.9
3	0.8	0.0	0.0	0.0	0.8
4	0.0	10.3	0.0	0.0	10.3
5	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	18.1	18.1
7	0.0	813.5	0.0	176.3	989.8
8	0.0	0.0	0.0	22.8	22.8
9	0.0	58.4	0.0	17.2	75.6
10	857.1	780.4	0.0	68.9	1,706.4
11	0.0	0.0	0.0	0.0	0.0
12	0.0	21.5	0.0	0.0	21.5
13	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	9.5	1,760.4	1,769.9
15	0.0	399.0	0.0	1,944.9	2,343.9
16	0.0	0.0	0.0	2.7	2.7
17	0.0	468.0	0.0	1,781.4	2,249.4
18	0.0	68.9	0.0	1,744.5	1,813.4
19	0.0	0.0	0.0	171.4	171.4
20	0.0	4,314.0	0.0	7,788.5	12,102.5
21	0.0	8,569.4	0.0	14,043.1	22,612.5
22	27,053.1	0.0	0.0	0.0	27,053.1
23	28,507.6	2,571.3	0.0	0.0	31,078.9
24	0.00	18,593.1	0.0	23.8	18,616.9
25	0.0	2,610.1	273.7	24,192.6	27,076.3
TOTAL:	56,436.3	39,312.2	283.2	53,757.5	149,789.2

Table 8
PREDICTED SOIL LOSSES FROM DEGRADED FOREST ON
JAVA BY REGION AND SOIL TYPE
(00 mt)

Soil Type	West Java	Central Java	Jogyakarta	East Java	Java
1	0.0	19.6		10.2	29.8
2	3.1	0.1		6.3	9.5
3	0.0	0.0		0.0	0.0
4	0.0	11.4		0.0	11.4
5	0.0	0.0		0.0	0.0
6	0.0	0.0		0.0	0.0
7	0.0	5,880.6		0.0	5,880.6
8	0.0	0.0		0.0	0.0
9	0.0	0.0		143.6	143.6
10	6,263.3	1,400.1		0.0	7,663.4
11	0.0	0.0		0.0	0.0
12	0.0	0.0		0.0	0.0
13	0.0	0.0		0.0	0.0
14	0.0	0.0		8,953.5	8,953.5
15	0.0	0.0		0.0	0.0
16	0.0	0.0		0.0	0.0
17	0.0	0.0		0.0	0.0
18	0.0	0.0		622.2	622.2
19	0.0	0.0		0.0	0.0
20	0.0	5,393.5		9,997.3	15,390.8
21	0.0	620.9		2,772.1	3,393.0
22	158,993.5	0.0		0.0	158,993.5
23	130,335.2	0.0		0.0	130,335.2
24	0.0	0.0		901.4	901.4
25	4,820.0	0.0		3,473.5	8,293.5
TOTAL:	300,415.1	13,326.2		26,880.1	340,621.4

Table 9
PREDICTED SOIL LOSS BY REGION AND LAND USE
(00 mt)

Land Use	West Java	Central Java	Jogyakarta	East Java	Java
Tegal	3,674,361.0	1,501,174.8	247,482.5	1,033,833.3	6,456,851.5
Forest-land	56,4[illegible]5.2	39,312.3	283.2	53,757.5	149,789.2
Degraded Forest	300,415.1	13,326.1	-	26,879.9	340,621.1
Sawah	10,907.7	5,799.5	511.0	5,825.0	23,043.1
TOTAL	4,042,120.0	1,559,612.7	248,276.7	1,120,295.7	6,970,304.9

Table 10
PREDICTED SOIL LOSS PER HECTARE
BY REGION AND LAND USE
(tons per hectare per year)

Land Use	West Java	Central Java	Jogyakarta	East Java	Java
Tegal*	144.3	133.3	118.2	76.0	123.2
Forestland	10.4	5.4	7.7	4.4	5.8
Degraded Forest	100.4	115.5	-	50.8	87.2
Sawah	0.8	0.4	0.4	0.3	0.5
AVERAGE					

*Areas based on Ministry of Forestry.

productivity.[7] Changes in cultural practices obscure the effects of erosion on farms as well.

Few explicit studies of erosion-yield relationships are available for the soils of Indonesia. Previous estimates of erosion yield effects are given in Table 11. These presumably are intended to reflect yield changes on a variety of soils experiencing different rates of erosion.

The levels of erosion predicted in Section II have different impacts on productivity depending on the soil type on which they occur and the crop grown. Some soils have most of their natural fertility accumulated in the top few centimeters where the soil organic matter is concentrated. Other soils have their natural fertility dispersed over the whole soil profile and may lose a considerable depth without suffering a marked productivity loss. And still other soils have intermediate behavior with respect to soil loss.

Crop response to soil loss is also unequal. Demanding crops, such as tobacco, respond much more drastically to soil loss than non-demanding crops. For the purposes of this study, two groups of rainfed food crops have been distinguished:

- relatively sensitive crops (maize, soybeans, groundnuts, green beans, upland rice)

- relatively insensitive crops (cassava).

Because it is generally accepted that sawah production is not subject to appreciable erosion and in fact benefits from the deposition of nutrients from erosion upstream, no attempt has been made to calculate a cost estimate for sawah areas.

On the basis of the scanty data available from controlled experiments, productivity loss - erosion relationships have been estimated for the 25 soil types considered in this study and for the two groups of crops indicated. These are shown in Tables 12 and 13. Note that soil losses of zero to 15 tons/ha/yr are estimated to result in no loss of productivity. This serves to take into consideration the generation of new soil from the weathering of subsoil.[8]

7/ For discussion of the impact of erosion on various dimensions of productivity see Pierce and others (1983), Lal (1987).

8/ It also takes, at least partially, into account the omission of plant cover and conservation practice in the erosion model.

Applying the erosion rate estimates for tegal to the productivity loss estimates in Tables 12 and 13 and summing yields estimates of the extent and severity of physical productivity loss. These are shown in Tables 14 and 15 which provide summaries of the model's prediction for the area and sensitivity of erosion induced productivity loss for sensitive crops (example, maize) and insensitive crops (example, cassava), respectively. As can be seen, the model predicts levels of productivity losses somewhat higher than cited above, 6.7% per year on a weighted average basis, as measured by sensitive crops and lower losses, around 4.2% per year for less sensitive crops. Predicted productivity declines for sensitive crops show greater variation among the regions than those for insensitive crops. Because the predicted declines are based on the same erosion predictions the ordering of severity of productivity losses is the same for both crops. Jogyakarta is the most severely affected, followed in descending order by West Java, Central Java and East Java.

Table 11
EROSION YIELD RELATIONSHIPS

Area	Annual % Change in Yields	Source
Jogjakarta	1.5	IBRD (1979)
Jratunseluna	2.0	USAID/IBRD
Upper Solo Basin	5.0	Ramsay and Muljadi

Table 12
PRODUCTIVITY LOSS ESTIMATES AS A RESULT OF
SOIL EROSION FOR MAJOR SOILS OF JAVA

Soil Loss Tons/Ha/Year	Soil Types: 1, 17	2, 3, 4, 6, 9, 16	5, 8, 10, 11, 12, 15, 18, 20, 21, 25	7, 13, 14, 19, 22, 23, 24
	Productivity Loss *			
0 - 15	0.00	0.00	0.00	0.00
15 - 60	0.02	0.03	0.05	0.07
60 - 250	0.03	0.05	0.08	0.10
250-600	0.04	0.07	0.10	0.12
Over 600	0.05	0.09	0.12	0.15

* For Maize, Soybeans, Groundnuts

Table 13
PRODUCTIVITY LOSS ESTIMATES AS A RESULT OF
SOIL EROSION FOR MAJOR SOILS OF JAVA

Soil Loss Tons/Ha/Year	Soil Types: 1, 17	2, 3, 4, 6, 9, 16	5, 8, 10, 11, 12, 15, 18, 20, 21, 25	7, 13, 14, 19, 22, 23, 24
	Productivity Loss*			
0 - 15	0.00	0.00	0.00	0.00
15 - 60	0.01	0.02	0.03	0.05
60 - 250	0.02	0.03	0.05	0.06
250 - 600	0.03	0.05	0.07	0.08
Over 600	0.04	0.07	0.10	0.12

* For Cassava

Table 14

AREA AND SEVERITY OF ESTIMATED EROSION-INDUCED
PRODUCTIVITY LOSSES ON TEGAL ON JAVA

	Annual Productivity Loss as a Fraction of Current Total Productivity [a]									
	0.0	0.02	0.03	0.05	0.07	0.08	0.10	0.12	Average	Total Area
	Area (00 ha)									
West Java	5,118.6	32.4	267.6	4,168.0	222.1	4,289.0	8,022.2	3,314.5	0.070	25,634.4
Central Java	1,896.11	15.4	1,205.0	2,163.4	29.4	1,682.8	3,656.9	609.3	0.064	11,258.2
Jogyakarta	186.7	0.0	258.7	2.1	0.7	468.0	1,176.9	0.0	0.078	2,093.0
East Java	1,841.4	446.1	1,294.3	2,668.8	283.4	3,020.6	4,049.1	0.0	0.062	13,604.5
Java	9,042.8	493.9	3,025.6	9,002.3	535.6	9,460.43	16,905.1	4,123.8	0.067	52,590.2

a/ Productivity loss based on maize.

Table 15

AREA AND SEVERITY OF ESTIMATED EROSION-INDUCED PRODUCTIVITY LOSSES ON TEGAL ON JAVA

	Annual Productivity Loss As a Fraction of Current Total Productivity a/									
	0.0	0.01	0.02	0.03	0.05	0.06	0.07	0.08	Average	Total Area
					Area (00 ha)					
West Java	5,118.6	32.4	267.6	4,168.0	4,511.0	6,586.1	1,436.1	3,514.5	0.044	25,634.4
Central Java	1,896.1	15.4	1,205.0	2,163.4	1,712 2	2,009.2	1,647.7	609.3	0.041	11,258.2
Jogyakarta	186.7	0.0	258.7	2.1	468.7	1,176.9	0.0	0.0	0.047	2,093.0
East Java	1,841.1	446.1	1,294.3	2,668.8	3,304.0	3,913.9	136.0	0.0	0.038	13,604.5
Java	9,042.5	493.9	3,025.6	9,002.3	9,995.9	13,686.1	3,219.8	4,123.8	0.42	52,590.2

a/ Productivity loss based on cassava.

These predicted yield declines can only be compared with actual yield trends on Java with considerable caution. Over the last 15 years yields of major dryland crops have consistently risen despite ongoing erosion. However, these yield increases have only been possible through the continued intensification of farming practices. For example, over the period 1972-83 upland rice, maize and cassava yields on Java increased 4.3, 4.7 and 2.8 percent per year, respectively (Roche 1987). However, fertilizer inputs rose in the case of maize from 38 kg/ha to nearly 106 kg/ha and for cassava from 8 kg/ha to more than 16 kg/ha (Central Bureau of Statistics). While data are not available on actual quantities of labor input, real wage costs have also been rising on upland crops at a rate of 2.2% per year for maize and 0.7% per year for cassava (Roche 1987). The release and rapid adoption of high yielding maize varieties (Arjuna, Hibrida C-1) may also have masked declines in the productivity of the resource base.[9] Taking these other changes into consideration, the model's prediction of an underlying 5.0-7.0% per annum soil productivity decline appears quite reasonable.

C. Estimating the Economic Implications of Productivity Declines

Productivity loss due to erosion can have several effects on farming systems; profits can fall as the result of lower output, farmers can be induced to make sometimes radical changes in the mix of crops and the level of input use, and in the extreme, erosion may lead to the complete withdrawal of land from cultivation. In the uplands of Java all three of these impacts are seen and have been reported by numerous observers. McIntosh and Effendi (1983) give the example of Citanduy Upper Watershed where on soils relatively unaffected by erosion farmers use a cropping pattern of corn, upland rice and cassava. As erosion becomes more severe, rice is replaced by peanuts and where soil is almost exhausted only cassava is grown. Roche (1987) discusses shifts in upland cropping systems, in part induced by changing relative prices, but also due to erosion, toward greater reliance on perennials.

Figure 1 illustrates a simple model of the impact of declining productivity on choice of crop mix. In Figure 1a total cost and revenue for two alternative crop mixes are shown as a function of output. Figure 1b plots net income from each of the systems also as a function of output. Revenues decline as output falls for obvious reasons.[10] The assumption that costs also fall is stronger. It is possible that erosion will in some cases lead farmers to work harder, substitute purchased inputs for natural productivity, or otherwise compensate for productivity losses. As discussed above, the increased use of chemical fertilizer on upland crops may be one means by which farmers have compensated for erosion losses. Costs may fall, however, because of

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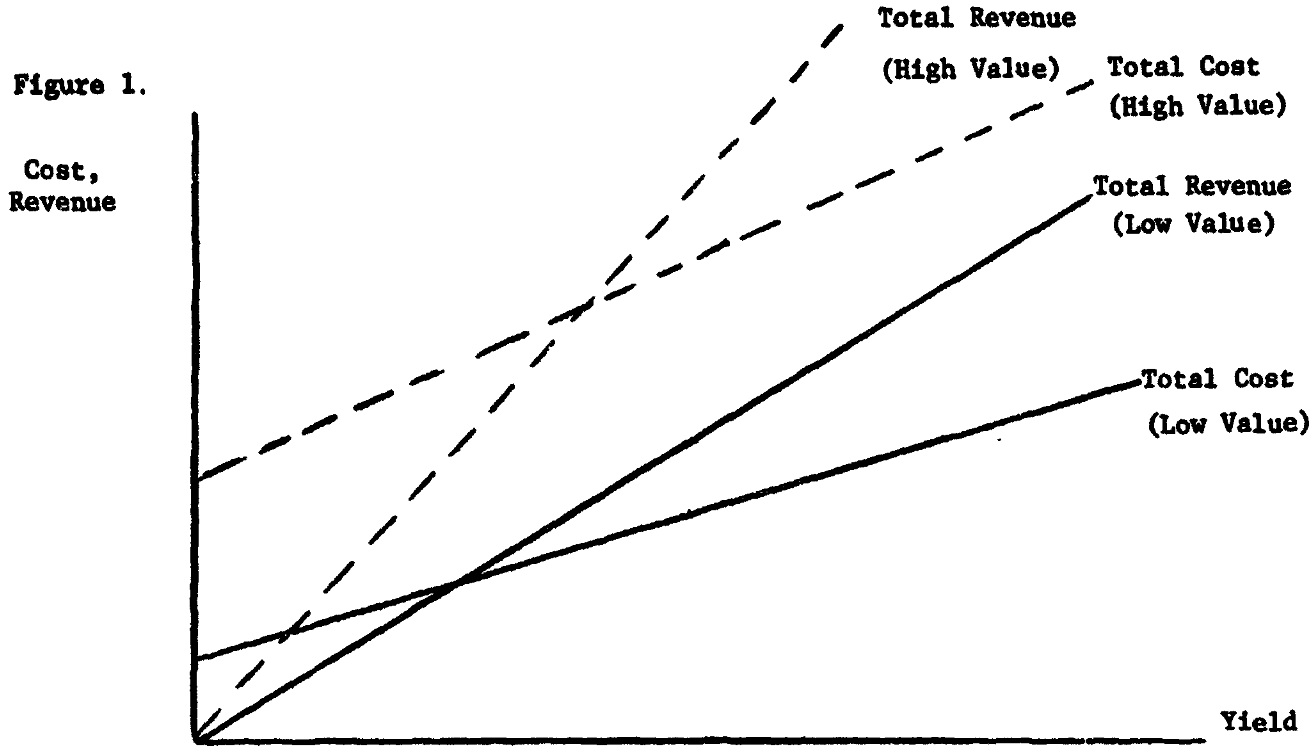
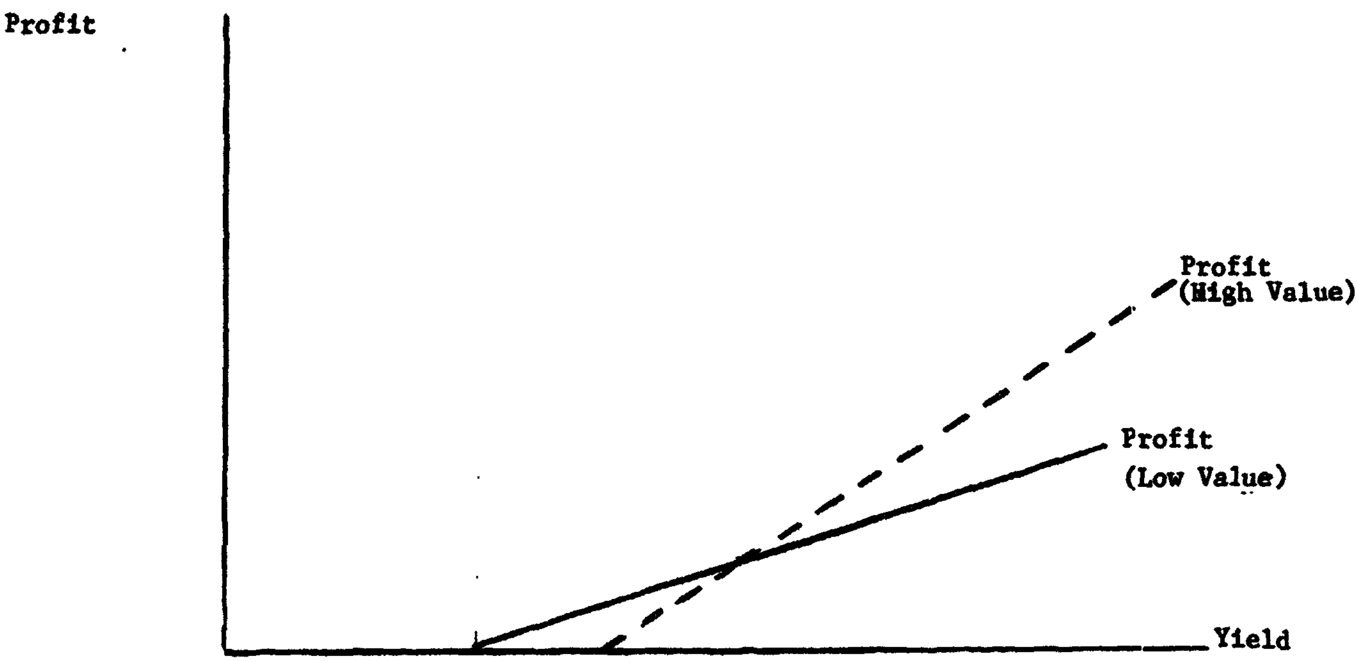
9/ For authoritative treatments of maize and cassava production systems in Indonesia, see, respectively, Mink, Dorosh and Perry (1987) and Roche (1984).

10/ This presumes that price is exogenous.

Figure 1.


Total Revenue
(High Value)
Total Cost
(High Value)
Cost,
Revenue
Total Revenue
(Low Value)
Total Cost
(Low Value)
Yield


Profit
Profit
(High Value)
Profit
(Low Value)
Yield

decreased requirements for harvesting labor, crop transport and other inputs. There is simply no data available to support either assumption on the behavior of costs as erosion proceeds. Assuming that costs do fall results in a slightly more conservative estimate of the cost of erosion and that approach is followed in these calculations. Analysis of available farm budget data suggests that costs that could be expected to fall with output account for a small share of all costs.[11]

Regardless of cost behavior, the overall impact of erosion induced productivity loss is to progressively lower farm profitability, and, in the case of alternative cropping systems, gradually lead to the adoption of less and less profitable crop(s). This prediction is consistent with observations in Java as noted above. Note also that the ability to switch to less productivity demanding, albeit less profitable crop mixes is, in fact, a way to avoid some of the costs of erosion. For example, as output falls on a relatively high productivity cropping mix and before profits fall to zero, farmers will find it desirable to switch to what, at higher levels of productivity, had been an inferior crop mix.

In order to take this cropping systems selection process into account for the four regions of Java, farm level data from a variety of sources were used to develop sets of enterprise budgets representative of the range found in Java's uplands. While there is essentially an infinite number of cropping patterns in the upland areas, it has been necessary to focus on only those for which reasonably reliable data are available and which represent significant shares of upland use. A particular requirement for the farming systems data was that they adequately reflect the role of intercropping in upland agriculture.

Crop budgets for a large number of rainfed crops (palawija) are available for a number of years from the Central Bureau of Statistics. These budgets which are based on relatively large sample surveys, are presented on a per hectare basis, but are calculated and presented on a monoculture basis.[12] Their most severe shortcoming is that they fail to present data on the use of family labor, which commonly accounts for well over half of all farm labor use in Java. Because they probably provide the best aggregate picture of the structure of production cost and because they are available for current years, they were used to provide a basis for identifying variable and fixed costs and to correct for differences in time periods.

11/ If erosion results in declining marginal productivity for most inputs, the expectation would be for farmers to in fact use fewer inputs on the most severely affected land. This would suggest less and less labor-intensive crops (as Roche [1987] suggests is already occurring) and less use of chemical fertilizer. It is possible then that the observed increases in fertilizer use on palawija crops is in part due to more concentrated application on land relatively unaffected by erosion. More labor use could be observed on severely affected land when the income effect from decreased productivity dominates the substitution effect. Off-farm employment opportunities will serve to limit this income effect.

12/ For descriptions of the strengths and shortcomings of the CBS data on the structure of the costs of production, see Roche (1984).

Data obtained for the Survey Agro Ekonomi (Agro-economic Survey) is largely based on single crops and was also used for comparison with the set of budgets prepared by Roche (1983, 1984). Roche's budgets, based on relatively small surveys of farmers throughout Java, appear to provide the best basis for examining intercropping systems in Java. Roche's research involved detailed surveys of farmers in Gunung Kidul Kabupaten in D.I. Jogyakarta, Kediri Kabupaten in East Java and Garut Kabupaten in West Java. Farmers were asked about their use of family and hired labor, purchase inputs, yields. Roche's field work led him to group upland farming systems in the various regions based on the degree of intercropping and the crops grown. He also noted the predominance of the representative systems and whether land was terraced or not.[13]

To simulate the effects of erosion on farm income the budgets published by Roche were updated to 1985 prices and adjusted to reflect yield changes by using the Central Bureau of Statistics crop budget. Data from the Malang Institute for Food Crops (MARIF) also indicated the need for adjusting downward Roche's farm budget to make it more representative of East Java as a whole (Brotonegoro, Laumans and Stavern, 1986). The MARIF data shows that Kediri Kabupaten has yields between 40 and 175 percent higher, depending on crop, than the average for East Java. In addition fertilizer use in Kediri is almost double that of the rest of East Java. The adjusted budgets were used as a basis for estimating changes in net income as yield declines.

Table 16 summarizes the cropping systems for each region and provides an estimate of their relative occurrence.

Insofar as can be determined, the farm budgets are consistent with land values and rental rates for tegal. For example, Roche notes that Tegal in Jogyakarta is frequently lent among farmers at no charge. In other regions, nonzero rents are charged rates that seem to correspond to real rates of return.

The farming systems appeared to be marked by a large proportion of fixed costs. Cost categories in the Central Bureau of Statistics that seemed most likely to vary with output were harvesting labor and transportation. To calculate the impact of erosion induced productivity losses on changes in net farm income it was assumed that as output falls farmers adjust variable inputs in proportion to yield declines and that fixed costs remain fixed. Percentage productivity declines are denominated based on the response of cassava to erosion. To account for the greater sensitivity of maize and other crops to erosion, the output of the crops is reduced proportionately faster as productivity declines. The result of this procedure is a linear decline in profits as productivity falls. The rate of this decline varies by cropping system and and its economic significance varies by cropping system and by region.

The results of these calculations are summarized in the last two columns of Table 17. The ordering of farms by profitability is the same as in Roche (1984) and depends on both the region of Java, and the degree of intercropping. Consistent with Figure 1 and the literature cited above, richer intercrops such as those with legumes and upland rice are more profitable than

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13/ Additional data on the predominance of various cropping systems was taken from USAID/World Bank and D. McCauley (1985).

Table 16
MAJOR FEATURES OF MODEL CROPPING ENTERPRISES ON JAVA

Cropping System	Crops	Estimated Proportion of Tegal (%)	Estimated Current Net Income (Rp/ha)[a]	Estimated Cost of a 1% Productivity Decline (Rp/ha)
West Java				
I	Cassava, Corn Upland Rice & Legumes	58	139,496	4,309
II	Cassava, Corn & Upland Rice	27	49,531	3,616
III	Pure Stand Cassava	15	1,279	1,563
Central Java				
I	Intercropped Corn & Cassava	57	6,698	800
II	Intercropped Corn, Cassava & Legumes	43	10,183	937
Jogyakarta				
I	Intercropped Corn & Cassava	57	8,220	1,011
II	Intercropped Corn, Cassava & Legumes	43	11,279	1,047
East Java				
I	Intercropped Corn & Cassava Level Tegal	30	298,327	4,926
II	Intercropped Corn & Cassava Terraced Hillsides	30	58,130	2,876
III	Pure Stand Cassava Level Tegal	20	145,005	3,746
IV	Pure Stand Cassava Terraced Hillsides	20	27,806	1,816

Source: Adapted from Roche 1984, Central Bureau of Statistics, and data provided by the Agroeconomic Survey, Bogor. See Appendix II.

a/ Returns to land and management.

Table 17
PRODUCTIVITY DECLINES AND CAPITALIZED COSTS DUE TO SOIL EROSION FOR THE PROVINCES OF JAVA

Province & Cropping System	Proportion of Tegal	Area[1] (00ha)	Weighted Production Loss (%)	Annual Cost of one percent Production Loss (Rp/ha)	Total Cost (Rp 000,000)	Capitalized Cost (Rp 000,000)	Total Cost	Capitalized Cost ($ 000)
West Java								
I	.58	8,353	4.4	4,309	15,837	158,370	9,598	95,980
II	.27	3,808	4.4	3,616	6,059	60,590	3,672	36,720
III	.15	2115	4.4	1,563	1,455	10,450	882	8,820
Total Tegal	1.00	14,402	4.4			229,410		141,520
Central Java								
I	.57	7,787	4.1	800	2,554	25,540	1,547	15,470
II	.43	5,874	4.1	937	2,257	22,570	1,367	13,670
Total Tegal	1.00	13,661	4.1			48,110		29,140
Jogyakarta								
I	.57	1,119	4.7	1,011	532	5,320	322	3,220
II	.43	845	4.7	1,047	416	4,160	252	2,520
Total Tegal	1.00	1,964	4.7			9,480		5,740
East Java								
I	.30	5,232	3.8	4,926	9,794	97,940	5,933	59,330
II	.30	5,232	3.8	2,876	5,718	57,180	3,464	34,640
III	.20	3,488	3.8	3,746	4,965	49,650	3,008	30,080
IV	.20	3,488	3.8	1,816	2,407	24,070	1,458	14,580
Total Tegal	1.00	17,440	3.8			228,840		138,630
TOTAL					51,584	515,840	31,503	315,030

1/ Based on Central Bureau of Statistics, Table 4.

simpler, pure stand or corn-cassava intercrops. The data also indicate that terraced tegal is less profitable than unterraced tegal. This probably reflects the fact that farmers only terrace land as last resort after erosion has already lowered productivity.[14]

The estimated cost of a one percent loss in productivity as shown in Table 16 is a function of both the basic productivity of the cropping system and the structure of production costs. The higher the output of the system the greater the losses. However, in addition, the importance of fixed costs relative to variable costs also influences the costs of productivity losses. In cropping systems with relatively large variable costs, farmers are more able to shift resources to other enterprises and thereby reduce the costs of erosion.

Assuming that the farming systems are distributed independent of rates of productivity decline, Table 17 applies the costs of a one percent decline in productivity for each system from Table 16 and the predicted weighted average yield declines, from Table 15 to the Tegal areas allocated to each system.

The loss of soil productivity and its associated cost is calculated on a single year basis. The total value of that cost to the economy also depends on the permanence of that productivity loss and on the social rate of discount (r). As was alluded to above, soil productivity is an elusive concept and the relationship between erosion and productivity is also unclear. Similarly, natural and human argumented processes of soil formation, however slow or expensive, play some role in restoring productivity. Consequently, it is necessary to be explicit about what is being assumed about the future time path of productivity changes in calculating the costs to the economy of soil productivity losses.

Figure 2 shows two possible time paths for productivity (yields) on a particular site. Productivity is assumed to be a function of soil depth alone. In Figure 2-a it is assumed that soil loss is a one-time phenomenon. The loss of soil lowers productivity which is gradually restored by the formation of new soil via the weathering of the subsoil.[15] The value of the temporary productivity reduction shown in Figure 2-a is the present value of area D.

In Figure 2-b it is assumed that soil loss from the site is recurrent. Consequently, assuming that soil loss exceeds soil formation, productivity losses occur with each successive net loss of soil depth. The correct measure of the cost of initial episode of erosion is the capitalized value of the infinite

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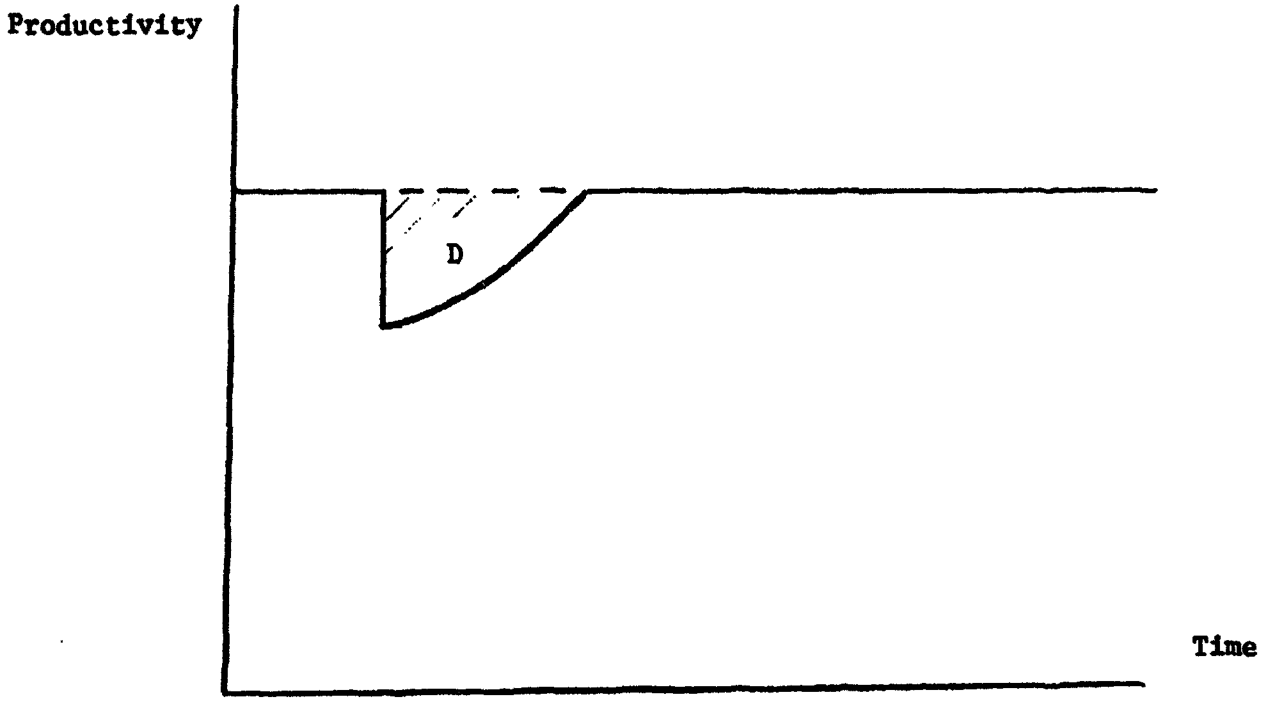
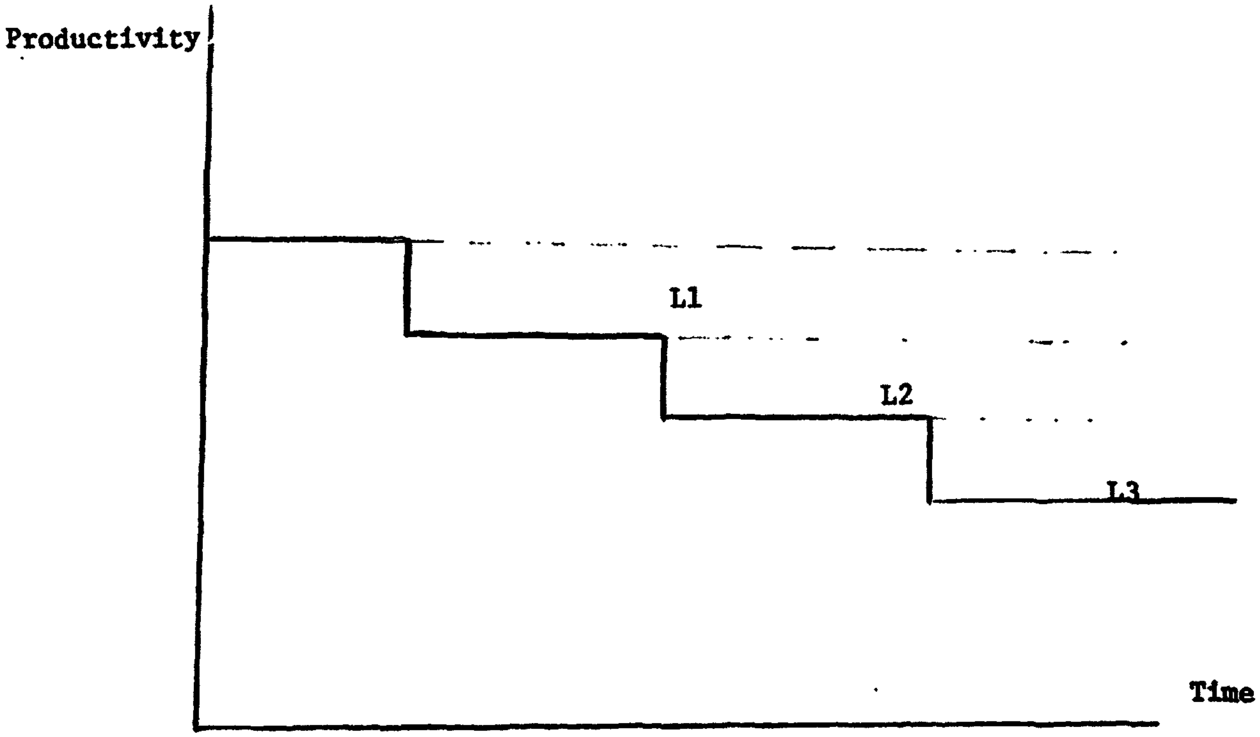
14/ The terraces referred to in these budgets are traditional terraces. This result should not be taken as an assessment of bench terracing systems.

15/ This restoration is likely to be so slow that only very low rates of discount would allow it to be reflected in value estimates.

Figure 2.



a. One Time Reversible Productivity Loss



b. Recurrent Irreversible Productivity Loss stream of productivity losses (area L1) associated with that initial episode (L1/r). Loss of productivity associated with future erosion (say L2) would appropriately be charged against the year in which they first occur.

Technical change, which raises productivity on a site, has no effect on the value of losses unless either technical change is complemented by soil depth or if technical change is in fact driven by soil losses. If technical change and soil depth are complements, as is in fact reasonable to assume, the cost of erosion is larger.[16] See Figure 3. If technical change is driven to compensate for soil losses, as might be proposed by an induced innovation framework the costs of erosion is reduced.

Another way of considering the appropriate treatment of the intertemporal dimension of soil productivity loss is to view it as a form of capital asset depreciation. The value of an asset is the discounted value of the income stream it generates. In the case of land, in the absence of erosion,[17] its value is the capitalized annual net income. Should the asset depreciate, providing less annual net income, its value will fall to equal the capitalized value of the new lower net income stream. The value of real depreciation over a period is the difference between capitalized values at the beginning and end of the period, or more directly the capitalized value of the productivity decline.

In Java it is clear that erosion is a recurrent phenomenon. Thus it is most appropriate to treat productivity losses as permanent. Note that it is true that as productivity falls, land eventually goes out of production so that future incremental losses are nil. However, if for the period of time over which erosion induced losses proceed, the capital value of the resource is depreciated as suggested above, then the ultimate salvage value of the site will be zero. In other words, the capitalized losses summed over the productive life of the soil asset will equal its initial value.[18]

Thus the total one year on-site costs of erosion shown in Table 17 are capitalized to obtain a total present value loss of Rp 534.4 billion (US$323 million). To put this figure into perspective Table 18 shows the approximate value of output of six major rainfed crops at 1983/84 prices. The discounted value of a perpetual stream of that output for Java is approximately Rp 13,443 billion. For Java the annual capitalized cost of erosion is approximately 4 percent of that value.

III. Off-Site Costs of Soil Erosion

Erosion obeys the first law of thermodynamics. Soil particles are not destroyed by erosion, they are only moved from one place to another. The delivery of sediment to low-lying areas is, in some cases, a benefit. In Java, for example, the nutrients deposited in sawah provide an important source of

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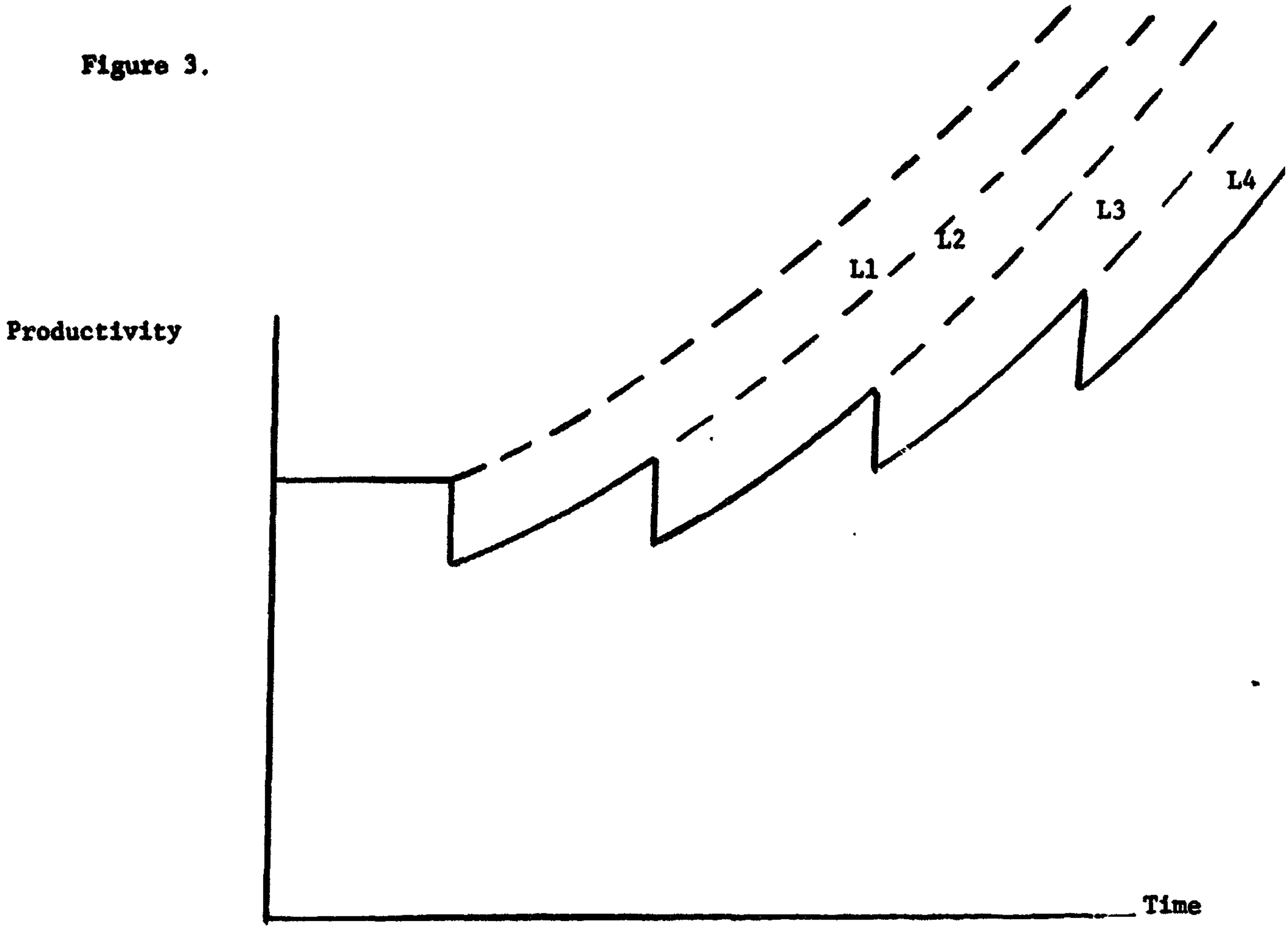
16/ Put another way, technological progress is slower and/or more expensive.

17/ Or technological change, or secular price changes.

18/ Barring revaluations based on productivity and price changes.

Figure 3.



Impact of Technical Change on Cost of Erosion

Table 18
COST OF EROSION COMPARED TO THE VALUE OF OUTPUT OF SIX MAJOR RAINFED CROPS
(Rp 000,000)

	West Java	Central Java	Jogyakarta	East Java	Java
Dry Rice	46,533	18,194	12,682	26,358	103,767
Maize	21,809	123,596	15,061	262,981	423,447
Cassava	81,041	109,148	22,410	134,962	347,561
Sweet Potatoe	22,191	12,131	542	15,331	50,195
Peanuts	44,916	56,475	18,340	74,615	194,346
Soybeans	17,807	45,398	37,664	124,171	225,040
Total	234,296	364,942	106,699	638,419	1,344,356
Discounted value	2,342,960	3,649,420	1,066,990	6,384,190	13,443,560
Discounted value Erosion losses	229,410	48,110	9,480	228,840	515,840
Erosion Cost as a fraction of value of Agricultural output	0.10	0.01	0.01	0.04	0.04

fertility. More commonly, however, the off-site effects of soil erosion are thought to be negative. Silt clogs irrigation channels, obstructs ports and harbors, and lowers the capacity of water storage reservoirs. Some of the same factors that contribute to erosion, deforestation, removal of ground cover, poor road design and so on, also contribute to other downstream costs such as flooding and reduced recharge of groundwater aquifers.

Assessment of the economic costs of these consequences is in its infancy. The first major effort to study these costs was reported for the United States by Clark, Haverkamp, and Chapman as recently as 1985. Their approach, which is roughly followed here, was to identify major categories of potential damages and to locate whatever evidence might be available on their economic significance. Due to the availability of data and time for this study it was only possible to estimate the costs of irrigation system siltation, siltation of harbors and major waterways, and reservoir sedimentation.

There has been no effort to reconcile the soil loss estimates generated in the last section with the implicit estimates of soil accumulating at, and obstructing, the various downstream sites dealt with in this section. In addition to the losses from rainfall erosion, which is estimated by the soil loss sub-model, off-site costs of erosion may arise from mass wasting, poor road construction methods and design and other sources. In addition, because the transport and delivery of sediment is not an instantaneous process, there is no simple way to accurately relate erosion to sedimentation. Moreover, there is no need to because, while still quite limited, there is adequate data on which to estimate costs directly from the damages done by siltation. No distinction is drawn between human induced and geologic erosion because, from the point of view of downstream damage, costs are the same whether human or natural forces originally dislodged the offending soil.

A. Siltation of Irrigation Systems

The deposition of silt in irrigation channels results in either higher operation and maintenance (O&M) expenditures or lower operating efficiencies which result in decreased returns to irrigation investments. Studies by the World Bank and others have shown that increased spending on O&M yields high rates of return. Therefore, it is probable that increasing O&M to remove silt costs less than the decline in output due to impaired performance. The correct measure of cost to the economy is the lower of the two, although in practice institutional weaknesses in the funding of O&M probably results in significantly higher actual costs.

There are few definitive data on the costs of siltation of irrigation systems. The few analyses that are available on irrigation O&M employ cost categories such as wages, equipment, and supervision and not on the functional composition of O&M works (i.e., silt removal, weeding, etc.). At this time there is not even any information on the physical volumes of silt either accumulating in or removed from irrigation systems.

It is possible, however, to get an indication of the cost of siltation by analyzing total operation and maintenance costs. Costs of irrigation operation and maintenance in Java and Bali for 1986/87 are shown in Table 19.

These data reflect the actual level of expenditures on O&M. It is generally accepted that O&M is severely under-funded and that to achieve an "efficient" level of operation an increase in spending from Rp 15,691/ha to Rp 25,000-30,000/ha is warranted (see World Bank 1987).[19] This would result in Java-wide spending of Rp 69.19-83.0 Billion (US $41.9- 50.3 million). It is appropriate to measure cost to the economy on the basis of the level required for efficient O&M. Otherwise it would be necessary to factor in the losses due to reduced system efficiency.

As a preliminary estimate World Bank engineers estimate that the portion of O&M expenditures due to silt removal is between $3- 4/ha or 15-20% of cost.[20] Indonesian irrigation authorities estimate that silt removal costs are closer to 50% of all O&M. Data provided by the Directorate of Irrigation, East Java show silt removal budgeted at Rp 1500/m^3. The result of applying these to the Java-Bali totals is shown in Table 20.

Data from the East Java Irrigation Project (1982-83) suggests silt removal costs of about Rp 1100/cubic meter (US $.67).[21] Calculating backward the $3-4/ha suggests actual annual removal of silt of 12.5-16.6M cubic meter and for complete removal (enough to maintain "efficient" operation) 23.3-27.9 M cubic meter.[22] Annual O&M spending during the second and third five-year plans are shown in Table 21.

The results of assuming that 15 percent of O&M costs over the period 1974-1987 is due to silt removal are shown in Table 22, along with the result of assuming that an efficient level of silt removal would cost twice as much.

19/ Efficient is defined as the level of O&M that would maintain the system indefinitely.

20/ These values are not consistent, $3-4/ha works out to be 32-42% of the Java average. There is disagreement over the share of O&M costs to attribute to silt removal. Bottrall (1978), reviewing O&M costs in East Java, reports that "the bulk of expenditures is incurred on silt and weed clearance". (Comparative Study of the Management and Organization of Irrigation Projects Report No. 5 Field Study in Indonesia; Jembes Section, Pekalen Sampean Region, East Java, World Bank Research Project No. 671/34 July 1978).

21/ This is close to the 70 cents used by Goldberg in his calculations on the "Indicative Economics of Soil Conservation Works".

22/ Additional data on irrigation O&M is available in case study reports prepared by Gadjah Mada University (1980), West Cirebon (1983) and under the World Bank East Java Irrigation Project (1986).

Table 19
OPERATION AND MAINTENANCE
OF IRRIGATION SYSTEMS

Province	Area of Irrigation	Billion Rupiah	Rp/ha	Million US$ ($1=Rp 1650)
West Java	897,125	18.499	20,620	11.212
Central Java	756,909	8.819	11,651	5.448
D.I. Jogyakarta	65,377	1.542	23,588	0.935
East Java	968,247	13.119	13,549	7.951
D.K.I. Jakarta	20,202	0.300	10,003	0.182
Bali	59,922	1.150	11,682	0.697
	2,767,782	43.429	15,691	26.321

Source: World Bank Irrigation Subsector Project SAR (Green cover) July 1987.

Table 20
IRRIGATION O&M COST DUE TO SILT REMOVAL

	$3-4/ha (Rp 4950-6600/ha)	15-25%	50%
Actual O&M			
Billion Rp	13.7-18.27	6.5-10.9	21.8
Million US $	8.0-11.1	3.9-6.6	13.2
"Efficient" O&M			
Billion Rp	25.6-30.7	10.4-20.8	41.6
Million US$	15.0-18.6	6.3-12.6	25.2

Source: See text.

Table 21
ANNUAL IRRIGATION O&M SPENDING

	1974/75	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81	1981/82	1982/83	1983/84
Jakarta	19,451.2	29,000	25,000	30,000	45,000	55,000	100,000	100,000	220,000	220,000
West Java	1,287,368	1,297,000	1,852,000	2,211,725	2,525,037	3,100,000	4,150,000	4,558,000	5,550,000	5,750,000
Central Java	1,177,147.2	1,182,000	1,149,000	1,391,129	1,519,874	2,220,000	3,200,000	3,743,000	4,350,000	4,500,000
D.I. Jogyakarta	101,473.6	102,000	78,000	117,000	191,791	275,000	370,000	577,000	700,000	860,000
East Java	1,436,155.2	1,460,000	1,546,000	1,782,994	2,205,499	2,700,000	3,900,000	4,400,000	5,200,000	5,300,000
TOTAL	4,021,595.2	4,070,000	4,650,000	5,532,848	6,487,201	8,330,000	11,720,000	13,378,000	15,970,000	16,630,000

Source: Department of Public Works Directorate General of Water Resources, July 1984.

Table 22

ESTIMATED RANGES OF COSTS OF SILTATION IN IRRIGATION SYSTEMS

	Total O&M	Estimated Siltation Cost		Approximate Cost of "Efficient" Silt Removal	
		15%	50%	15%	50%
	-------------(000 Rp)	-----------		---------(2X)---------	
1974/75	4,021,595	603,239	2,010,797	1,206,478	4,021,594
1975/76	4,070,000	610,500	2,010,797	1,221,000	4,070,000
1976/77	4,650,000	697,500	2,325,000	1,395,000	4,650,000
1977/78	5,532,848	829,927	2,766,423	1,659,854	5,532,846
1978/79	6,487,201	973,080	3,243,600	1,946,160	6,487,200
1979/80	8,330,000	1,249,500	4,165,000	2,499,000	8,330,000
1980/81	11,720,000	1,758,000	5,851,000	3,516,000	11,712,000
1981/82	13,378,000	2,006,700	6,689,000	4,013,400	13,378,000
1982/83	15,970,000	2,395,500	7,985,000	4,791,000	15,970,000
1983/84	16,630,000	2,494,500	8,315,000	4,989,000	16,630,000
1984/85	n.a.	n.a.			
1985/86	n.a.	n.a.			
1986/87	43,429,000	6,514,350	21,714,500	13,028,700	43,429,000

Note: n.a. = not available.

B. Siltation of Harborr and Dredging

Port dredging needs have been neglected due to the poor financial conditions of the agencies responsible for carrying out this work. The dredging fleet has an annual capacity of around 40 million cubic meters, however only about 15 million cubic meters are actually removed. Of the 75 million cubic meters dredged during Repelita III, 51.9 million cubic meters was maintenance dredging (intended to keep harbors clear) and 23.6 million was capital dredging (expansion of existing ports or development of new parts).[23]

The following data were provided by the Directorate of Ports and Harbors, Ministry of Communications. Estimated average costs of dredging are Rp 720-850/m3 for fairway dredging and Rp 1750/m3 for Inner Harbor dredging. The portion of dredging due to soil erosion in upland areas is not known. At least some dredging is due to movement of shoreline and natural ocean bottoms (littoral drift).

Following completion of the High Dam at Wonogiri there is reported to have been a decline in the required annual dredging of the channel at Surabaya from about 2,000,000 m3/yr. to 800,000 m3/yr. (Directorate of Ports and Harbors, personal communication). This is not reflected in the written data provided by the same source. Use of dredgings for land reclamation provided some offsetting benefit.

Table 23, based on data provided by the Directorate of Harbors and Dredging, shows the level of dredging in the major harbors of Java during the third Repelita. The breakdown of this dredging between fairways and inner harbors is not known, therefore costs are calculated for high and low value in Table III.B2 and III.B3. In 1985/86 dredging of ports and harbors costs between Rp 847-2059 million. Given that budgetary restrictions have limited dredging below desired levels, the true cost of harbor degradation to the economy probably exceeds the high end of this range. The balance of the damage consists of reduced port efficiency. However, as noted above, soil erosion in upland areas account for an unknown portion of this total.

C. Reservoir Sedimentation

Siltation of reservoirs is often listed as one of the important off-site consequences of soil erosion in Java. Developing an estimate of the economic costs of this process again requires data on the physical dimensions of soil movements, on the consequences of siltation on the production of valued outputs such as hydropower and irrigation water, and on the prices of those outputs. Unfortunately, the available information on which to base such an estimate for Java's reservoirs is spotty at best. In this section some of the

23/ Based on Draft Maritime Sector Review, G. Tharakan and A. Faiz, AEPTR, December 1986.

Table 23

OFF-SITE COSTS OF SOIL EROSION

SILTATION OF HARBORS

PORT	79/80	80/81	81/82	82/83	83/84	84/85	85/86	85/86 Revised
I. Total Dredging (m^3)								
Tg. Priok	419,725	500,000	465,000	500,000	700,000	500,000	150,000	143,154
Sunda Kelapa	228,260	226,000	250,000	250,000	230,000	185,000	76,000	72,532
Cirebon	254,765	250,000	250,000	250,000	215,000	165,000	85,000	81,121
Semarang	226,450	226,950	285,000	125,000	335,000	300,000	1,100,000	880,000
Tegal	70,000	80,000	75,000	65,000	50,000			
Surabaya	2,360,000	2,100,000	2,202,625	2,400,000	2,300,000	2,100,000		
Gresik	100,000	100,000	100,000	100,000	140,000			
Panarukan		100,000	100,000					
Pasuruan			490,000	50,000				
Probolingo		100,000						
TOTAL	3,659,140	3,682,950	4,217,625	3,740,000	3,970,000	3,250,000	1,411,000	1,176,807
II. Low Cost Estimate (Rp 000)								
Tg. Priok	302,202	360,000	334,800	360,000	504,000	360,000	108,000	103,071
Sunda Kelapa	164,347	162,720	180,000	180,000	165,600	133,200	54,720	52,223
Cirebon	183,388	180,000	180,000	180,000	154,800	118,800	61,200	58,407
Semarang	163,044	163,404	205,200	90,000	241,200	216,000	792,000	633,600
Tegal	50,400	57,600	54,000	46,800	36,000	0	0	0
Surabaya	1,699,200	1,512,000	1,585,890	1,728,000	1,656,000	1,512,000	0	0
Gresik	72,000	72,000	72,000	72,000	100,800	0	0	0
Panarukan	0	72,000	72,000	0	0	0	0	0
Pasuruan	0	0	352,800	36,000	0	0	0	0
Probolingo	0	72,000	0	0	0	0	0	0
TOTAL	2,634,581	2,651,724	3,036,690	2,692,800	2,858,400	2,340,000	1,015,920	847,301
III. High Cost Estimate (Rp 000)								
Tg. Priok	734,519	875,000	813,750	875,000	1,225,000	875,000	262,500	250,520
Sunda Kelapa	399,455	395,500	437,500	437,500	402,500	323,750	133,000	126,931
Cirebon	445,734	437,500	437,500	437,500	376,250	288,750	148,750	141,962
Semarang	396,288	397,163	498,750	218,750	586,250	525,000	1,925,000	1,540,000
Tegal	122,500	140,000	131,250	113,750	87,500	0	0	0
Surabaya	4,130,000	3,675,000	3,854,594	4,200,000	4,025,000	3,675,000	0	0
Gresik	175,000	175,000	175,000	175,000	245,000	0	0	0
Panarukan	0	175,000	175,000	0	0	0	0	0
Pasuruan	0	0	857,500	87,500	0	0	0	0
Probolingo	0	175,000	0	0	0	0	0	0
TOTAL	6,403,495	6,445,163	7,380,844	6,545,000	6,947,500	5,687,500	2,469,250	2,059,412

Source: Directorate of Ports and Harbors, Ministry of Communications.

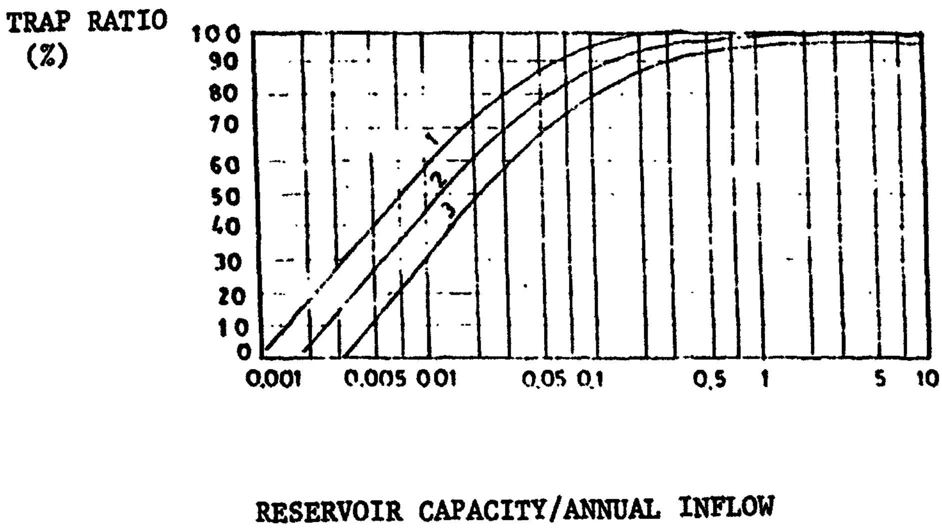
issues involved in estimating the costs of reservoir sedimentation are reviewed, data on rates of siltation are presented and tentative estimates of the related costs are presented.

Reservoirs are often a major depository of soil particles eroded from upstream catchments. Typically only a small portion of total gross soil loss from a catchment is captured in a reservoir. This proportion depends on the so-called sediment delivery ratio (SDR). A catchment's SDR is the percentage of gross erosion actually delivered to a reservoir. A catchments SDR is in part determined by catchment size and topography. The proportion of total soil erosion captured also depends on the trap efficiency of the reservoir, which is related to the size of the reservoir and the rate of flow of water. Generally, larger, flatter catchments deliver a lower portion of gross soil loss to reservoirs than smaller, steeper ones. Reliable estimates of SDRs for catchments in Java are unavailable.

Trap efficiency is the share of silt retained in the reservoir divided by the total amount delivered. High flow rates into small reservoirs serve to keep more silt in suspension and thus have lower trap efficiencies than large reservoirs receiving lower river flows. Figure 4 shows an estimate of the relationship between trap efficiency and the ratio of reservoir capacity to annual inflow. The Karangkates reservoir in East Java has a capacity of 343 million m^3 and a mean annual inflow of 2,400 million m^3. Accordingly, the ratio of capacity to inflow is approximately 0.14. Figure 4 indicates a trap efficiency of approximately 95%. Estimates of trap efficiency are not available for many reservoirs in Java. Estimates of trap efficiency for the Wonogiri reservoir in Central Java, for example, vary widely. Based on discussions with Department of Public Works, trap efficiency of the Wonogiri reservoir is probably also in the order of 90% or more. One problem with the ore of SDR's, trap efficiencies and estimates of suspended sediment loads is that bedload, the material carried by stream flow along river bottoms, is neglected. This leads to an underestimation of sedimentation that can be overcome by monitoring of reservoir capacity by soundings and other measurement techniques.

Sediment delivered and captured by the reservoir can come to rest in various locations on the reservoirs' bottom. Engineers use the concept of live and dead storage to deal with the issue of sedimentation. However, these are not economic measures and often poorly reflect the hydrologic processes actually at work in reservoirs. In theory a portion of the total storage capacity of a reservoir is allocated to the eventual storage of silt. This portion, referred to as dead storage, is often estimated by dam planners based on overly optimistic or poorly documented estimates of historic sediment loads combined with some judgment as to the life required for the dam. For example, if a 50 year life is required (a frequently used figure), dead storage is simply fifty times mean annual sediment loads adjusted for trap efficiency. The dead storage calculation may also be used to position outlets in the dam so as to be clear of sediment accumulations until the end of the predicted life. The Figure

Figure 4



Notes (1) Upper Limit
(2) Average
(3) Low Limit

Source: Sunarno and Sutadji (1982)

exhaustion of dead storage is thus often incorrectly taken as synonymous with the economic life of the reservoir.[24]

The actual location of sediment deposition in reservoirs, and hence reservoir life, may be quite different than that implied by the specification of dead storage as volume below the outlets of the dam. For example, in the Wonogiri Reservoir of total storage of 703 million m^3, 120 million m^3 is designated as dead storage. Because of the configuration of the reservoir, long and flat, sediment entering the reservoir settles almost immediately and less than an estimated 10% reaches dead storage near the dam. Estimates by FAO are that as sedimentation proceeds in the upper reaches of the reservoir, the percentage reaching designated dead storage will gradually rise. Because sediment is accumulating away from the intakes of the dam, a volume of sediment greater than that designated as dead storage can accumulate without actually obstructing the inlets. Therefore, the actual economic life of the reservoir will exceed that given by the simple calculation of the time until designated dead storage is exhausted.

It is true that the benefits derived from a reservoir are not entirely independent of the remaining volume of storage. Even before "dead" storage is exhausted, these effects may become visible. The precise way in which irrigation and hydroelectric benefits are affected depends on remaining capacity and are also affected by the operating rules of the reservoir, the type of dam and associated equipment and the hydrology of the river system. Consequently, a precise estimate of the erosion-caused reductions in outputs requires detailed engineering studies of individual reservoirs.[25] However, in order to get some indication of the costs of reservoir depletion on a Java-wide basis, it is possible to crudely assume that changes in the flow of benefits are proportioned to changes in storage volume.[26] The calculations that follow are performed using both total and live storage. This approach seems likely to bracket the true cost of reservoir depletion.

Data on reservoir capacity reductions are subject to considerable uncertainty. The standard approach in measuring sedimentation is to compare the profile of a reservoir as measured by soundings with topographic maps of the reservoir made before flooding. Soundings may be made by sonar or other methods. Sophisticated methods are available, and are in use in Indonesia, to use electronic aids in navigation to ensure accuracy in running transects across

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24/ The economic life of reservoirs is a frequently and imprecisely used term. For a discussion of some of the economic issues involved in reservoir management, see W.B. Magrath and M.E. Grosh "An Economic Approach to Watershed Management With Emphasis on Soil Erosion" paper presented at the Ninth World Forestry Congress, Mexico City, Mexico, August 1985.

25/ For an example, see Douglas Southgate "The Off-farm Benefits of Soil Conservation in a Hydroelectric Watershed" paper presented at the American Agricultural Economics Association Meetings, Reno, Nevada, August (1986).

26/ Simulation trials performed by the Department of Public Works (Solo), indicated that this is reasonably valid for the Wonogiri Reservoir.

reservoirs. Less reliable are estimates based on sediment loads of rivers flowing into reservoirs and calculated trap efficiencies. Sediment load sampling is subject to a variety of weaknesses, not the least of which is the almost insurmountable difficulty of accurately measuring bed load.

Even when advanced techniques are used to monitor reservoir status, uncertainty remains. For example, repeated measurements of the Wonogiri reservoir by several different agencies have produced widely varying estimates of sedimentation rates. Similar experience has been noted with repeated measurements of the Selorejo.[27]

Based on available data for nine major reservoirs on Java, Table 24 summarizes losses of storage capacity due to sedimentation. Dead storage estimates are available for only five reservoirs. In these, dead storage accounts for 20% of total storage. This percentage is applied to the total initial capacity of reservoirs in Java to obtain annual total and dead storage loss estimates of 0.5 and 2.3 percent, respectively.

Table 25, based on data from the Department of Public Works and World Bank reports on energy investments, provides an indication of the capacity of major reservoirs to provide hydroelectric power and irrigation services. Total installed hydroelectric generating capacity in Java is estimated at 571.4 megawatts (MW). This figure does not include the planned Saguling installation (350 MW) or the planned Kedung Ombo (22.5 MW). Assuming a capacity utilization factor of 0.5[28] electricity generation is about 2,738,412 MWh.

Irrigation command area (assuming a cropping intensity of 2.0) for these reservoirs is estimated at 277,671 ha.

Current electricity prices in Java are estimated by the World Bank to be Rp 95.75/KWh peak and Rp 38.2/KWh off-peak. Assuming an average value of Rp 70/KWh, the annual cost of a 0.5 percent loss in hydroelectric output is Rp 958.44 million (US$580,875). If loss of hydropower is more closely tied to loss of dead storage volume, the annual cost of a 2.3 percent loss is Rp 4,408.8 million (US$2.67 million).

The value of irrigation water can be estimated by comparing net returns to land with and without irrigation. Table 26, based on data in the appraisal report for the proposed Wonogiri Soil Conservation Component, illustrates this approach. With irrigation, double cropping of irrigated paddy results in net income of Rp 1.9 million per hectare. Without irrigation, average annual returns are Rp 610,000 per hectare. The difference, Rp 1.2 million/hectare, is a measure of the economic value of irrigation services. Applying this figure to the estimated area of reservoir irrigation and annual losses due to sedimentation from Tables 25 and 26 yields estimates of Rp 1.727 billion and Rp 7.944 billion, with losses based on total and dead storage, respectively.

27/ See, for example, the conflicting estimates produced by Fish for Hydraulics Research (1983) and those of a team from Bogor University. These are discussed in 'Ministry of Forestry's Final Report, Second Phase, The Kali Konto Upper Water Project, April 1985.

28/ This is based on the actual capacity utilization factor of 0.54 for nine major dams accounting for 456.5 MW (80%) of installed capacity.

Table 24

STORAGE LOSSES DUE TO SEDIMENTATION OF MAJOR RESERVOIRS ON JAVA

	Year Completed	Initial Capacity (000 m^3)	Average Sed. Rate (000 m^3)	Annual Total Storage Loss (%)	Initial Dead Storage (000 m^3)	Annual Dead Storage Loss 3/ (%)	Designed Life (Yrs.)	Revised Life Total Storage (Yrs.) (1-2)	Revised Life Dead Storage 3/ (Yrs.) (4-2)
Wonogiri CJ	82	718,000	9,750	1.35	120,000	8.1		74	12
Selorejo EJ	70	62,000	373-744	0.6-1.2	12,000	3.1-6.2	100	83-166	16-32
Jatiluhur WJ	64	3,000,000	2,600	0.1	600,000 2/	0.09		1,154	231
Karangkates EJ	72	343,000	3,997	1.2	90,000		4.4	100	86
Cacaban CJ	56-58	90,000	2,143	2.4	18,000 2/	11.9	-	42	8
Malhayu CJ	37-40	69,000	629	0.9	13,800 2/	4.6	-	109	22
Penialin CJ	33	9,500	38	0.4	1,900 2/	2.0	-	250	50
Saguling WJ	86	982,000	4,000	0.4	200,000	2.0	750	246	
Wlingi EJ	?	24,000	1,085	4.5	18,800	5.8	-	22	17
		5,297,500	24,801	0.5	1,074,500 (20%) 1/	2.3			

1/ 20% is based on share of dead storage in those reservoirs for which data is available.

2/ Calculated based on 20% dead storage.

Sources: Department of Public Works Annual Statistical Yearbook.
" " " Malang Office (For Selorejo, Karangkates, Wlingi).
" " " Solo Office (for Wonogiri).
World Bank Staff Appraisal Report - Tenth Power Project (for Saguling).

Table 25
POWER AND IRRIGATION CAPACITY AND UTILIZATION OF
MAJOR RESERVOIRS ON JAVA

	Installed Capacity (MW)	Annual Output (MWh)	Command Area (Ha)	Effective Area (Ha)
West Java				
Ubrug	25.0	109,500	-	-
Plengan	5.2	22,776[2]/	-	-
Lamajan	39.2	171,696[2]/	-	-
Jatiluhur	125.0	700,000	120,000[3]/	240,000
Cipancuh	-	-	2,760[3]/	5,520
Darma	125.0	700,000	18,460[3]/	36,920
Situpatok	-	-	800[3]/	1,600
Cipanunjang	-	-	-	-
Cileunca	5.5	1,000	-	-
Saguling[1]/	350.0	1,533,000[2]/	-	-
Subtotal	324.9	1,704,972	142,020	284,040
Central Java				
Wonogiri	13.0	28,200	23,000	46,000[3]/
Garung	28.0	122,640[2]/	-	-
Cacaban	-	-	40,000[3]/	80,000
Nglangon	-	-	375	750
Plumbon	-	-	773[3]/	1,545
Delingan	-	-	-	-
Tempuran	-	-	462	923
Gembong	-	-	2,473[3]/	4,945
Gunungrowo	-	-	1,806[3]/	3,612
Nawangan	-	-	147[3]/	294
Parangloho	-	-	325[3]/	650
Kedung Umbo[1]/	22.5	74,000	59,340	-
Jelok	n.a.	n.a.		
Ngancar	-	-	750[3]/	1,500
Sempor	1	6,000	5,310[3]/	10,620
Penjalin/Malahayu	-	-	10,000	75,241
Subtotal	42.0	156,840	85,421	170,842

	Installed Capacity (MW)	Annual Output (MWh)	Command Area (Ha)	Effective Area (Ha)
East Java				
Selorejo	4.5	52,400	2,850 3/	5,700
Wlingi	55.0	161,000	6,800 3/	13,600
Siman	10.8	47,304 3/	-	-
Lodyo	5.0	21,900 3/	-	-
Karangates	105.0	488,000	17,000 3/	34,000
Mandalan	22.0	96,360 2/	-	-
Tlogo Negebel	2.2	9,636 2/	5,200 3/	10,400
Pacal	-	-	13,035 3/	26,010
Prijetan	-	-	4,305 3/	8,610
Lahor	-	-	-	-
Klampis	-	-	1,040 3/	2,080
	204.5	876,600	50,230	100,460
TOTAL	571.4	2,738,412	277,671	530,520

1/ Not in service, not included in totals.

2/ Calculated assuming .5 capacity utilization factor.

3/ Assumes cropping intensity of 2.0.

Sources: World Bank Energy Project Appraisal Reports (various projects).
Dept. of Public Works Statistical Yearbook.
Dept. of Public Works, Solo Office.
Dept. of Public Works, Malang Office.

Table 26

CALCULATION OF RETURNS TO IRRIGATION

(per hectare)

	Unit	Unit Price (Rp)	With Project Irrigated Paddy	Without Project Paddy Irrigated	Without Project Paddy Non-Irrig.	Without Project Palawija[a]/
Yield						
Paddy	kg	226	5,500	4,000	3,000	
Maize	kg	170				1,500
Inputs						
Seed - Paddy	kg	283	40	40	40	
Seed - Maize	kg	287				60
Urea	kg	400	200	180	100	50
TSP	kg	423	100	75	50	25
Crop Protection	Rp	-	12,000	10,000	8,000	5,000
Farm Labor	Manday	812	210	210	190	125
Value of Production	(Rp 000)		1,243	904	678	258
Production Cost	(Rp 000)		316	296	235	154
Net Benefit	(Rp 000/ per ha)		927	608	443	101
Cropping Intensity			2.0	0.7	0.3	0.5
Total Net Benefits Per Ha	(Rp 000)		1,854	426	133	51
Incremental Net Benefits Per ha (Return to Irrigation)	(Rp 000)			Rp1244/ha		

a/ Maize used as proxy

Source: Based on World Bank Indonesia Forestry Project, Soil Conservation Working Paper (Draft).

Calculations for both irrigation and hydroelectric losses are summarized in Table 27. The losses calculated in Table 28 are essentially permanent losses and need to be capitalized to reflect total losses to the economy. At 10% the present value of losses due to reservoir siltation are between R 27 and 123.5 billion per year (US$ 16.2-74.8 million).

D. Other Off-Site Costs of Erosion

It has not been possible to gather sufficiently complete data on the costs of all of the consequences of upland soil degradation. This should not at all be taken to imply that they are unimportant. Among the costs that have been omitted are flooding and stream flow irregularities that result from deforestation and other forms of poor land use.

In addition to the difficulty of obtaining complete data on the extent and cost of flooding, a complete examination of flooding due to erosion costs would have to consider the relationship between land use changes and the frequency and severity of flooding. Similarly, the costs of interrupted stream flows which have caused temporary plant closures in Java, are also difficult to value. In industrial applications a great variety of responses to irregular water flows are possible and the time available for this study has not allowed for their systematic analysis. Based on other information, these costs and others such as pesticide and fertilizer pollution from runoff, and damage to coastal fisheries are clearly important in Java. Future research, which could follow the approach used in this paper, could more correctly document and qualitatively estimate these costs.

IV. Summary and Conclusions

Tables 28 and 29 summarize total on- and off-site costs of soil erosion as established in this paper. For Java, as a whole, these amount to Rp 558,688 billion (US$340-406 million) which is slightly less than .5% of total GDP. Over 95 percent of these costs are the on-site costs of declining soil productivity. In addition to these costs, as noted in Section III, important and probably quite large costs related to soil erosion have not been qualified. These include flooding, damage to coastal fisheries, disrupted urban and industrial water supplies, and pollution from fertilizer and pesticide runoff.

There are several important observations that must be made about this estimate. One is that it must be accepted as having a wide confidence interval, the width of which can not even be estimated. However, even if the costs estimated here are substantial overestimates, they are large enough to clearly demonstrate that land use practices in Java constitute a significant mining of the resource base.

Accepting this conclusion, the data provide only a partial guide to policymakers on how to manage and reduce these costs. For example, it may seem odd, given the estimate that 75-90% of the cost of erosion are agricultural productivity losses, that two-thirds of GOI expenditures are for off-farm sediment management structures such as check dams. Nonetheless, the skewed distribution of costs and investment may be economically rational. The relevant question is the relationship between the net benefits of investments on-and off-farm. It is conceivable that currently available on-farm soil conservation technologies are less socially profitable than off-farm measures. The relative

Table 27
ESTIMATED ANNUAL COSTS OF IRRIGATION AND HYDROELECTRIC POWER LOSSES DUE TO SEDIMENTATION OF RESERVOIRS

	Hydropower (Annual)	Irrigation (Annual)	Total Capitalized Value
Estimated Output	2,738,412 MWh	277,671 ha	
Value (Rp/unit)	70/KWh	1,244,000/ha	
<u>Annual Losses Due to Sedimentation</u>			
Based on Loss of Total Storage (0.5)			
Lost Output	13,692 MWh	1,388 ha	
(Rp)	958,440,000	1,726,672,000	26,851,120,000
(US$)	580,873	1,046,468	16,273,410
Based on Loss of Dead Storage (2.3%)			
Lost Output	62,983.5	6,386 ha	
(Rp)	4,408,800,000	7,944,184,000	123,529,840,000
(US$)	2,672,027	4,814,657	74,866,840

Table 28
TOTAL ESTIMATED COSTS OF SOIL EROSION ON JAVA
(Rp 000,000,000)

	West Java	Central Java	Jogyakarta	East Java	Java
On Site	229.4	48.1	9.5	228.8	515.8
Off Site					
Irrigation System Siltation	2.8--9.4	1.3--4.4	0.2--0.8	2.0--6.6	13.0--43.4
Harbor Dredging (1984/85)	0.6--1.5	0.2--0.5	---	1.5--3.7	2.3--5.7
Reservoir	14.8--68.1	5.8--26.9	---	6.2--28.5	26.8--123.5
TOTAL	247.6--308.4	55.4--79.9	9.7--10.3	238.5--267.6	557.9--688.4

Table 29
TOTAL ESTIMATED ANNUAL COSTS OF SOIL EROSION ON JAVA
($ 000,000)

	West Java	Central Java	Jogyakarta	East Java	Java
On Site	141.5	29.1	5.7	138.6	315.0
Off Site					
Irrigation System Siltation	1.7--5.7	0.8--2.7	0.1--0.5	1.2--4.0	7.9--12.9
Harbor Dredging (1984/85)	0.4--0.9	0.1--0.3	---	0.9--2.2	1.4--3.4
Reservoir Sedimentation	9.0--41.3	3.5--16.3	---	3.8--17.3	16.3--74.9
TOTAL	152.6--189.4	33.5--48.4	5.8--6.2	144.5--162.1	340.6--406.2

economics of different soil conservation techniques is beyond the resources available for this study but is an important area for future research.

Further study of the implications of the absence of markets for silt and the pervasive tendency to ignore erosion is also needed. For example, reservoir siting and sizing should take sedimentation rates into account and planners should probably be more demanding of data quality and analysis in the feasibility and prefeasibility stages of large infrastructure investment. The cheapest way to reduce some of the off-site costs of soil erosion may be to avoid construction of what will turn out to be short-lived reservoirs and high maintenance irrigation systems in erosion prone areas.

Even in a world of perfect planning not all the costs of erosion are avoidable. The disturbance of land that accompanies crop production, forestry and road construction, and the forces of nature will inevitably lead to erosion and sedimentation. The problem facing policymakers is to balance the damage done by erosion with the benefits of upland use and the costs of ameliorative action. Data and analysis such as illustrated in this paper should play an important role in the search for solutions.

REFERENCES

Brotonegoro, Soetarjo, Q. J. Laumans, and J. Ph Van Stavern, Palawija Food Crops other than Rice in East Java Agriculture (Malang Research Institute for Food Crops: Malang) 1986.

Burman, P. ed., "Red Soils in Indonesia", Agricultural Research Report 889, Centre for Agricultural Publishing and Documentation, Wageningen, 1980.

Carson, Brian and Wani Hadi Utomo, "Erosion and Sedimentation Processes in Java", The Ford Foundation/KEPAS, Jakarta, n.d.

Central Bureau of Statistics, Statistik Indonesia, Jakarta (various years).

--------------, Cost Structure of Farms Paddy and Palawija, Jakarta (various years).

Clark, Edwin H., Jennifer Haverkamp, and William Chapman, Eroding Soils: The Off-farm Impacts (Conservation Foundation: Washington) 1985.

Department of Public Works, Directorate General of Water Resources Development, Directorate of Irrigation, General Information on: Irrigation Operation and Maintenance Activities in Indonesia, Jakarta, July, 1984.

Fagi, Achmal M. and Cynthia Mackie, "Watershed Management in Upland Java Past Experience and Future Directions", paper presented at the Conference on Soil and Water Conservation on Steep Lands, Soil Conservation Society of America San Juan, Puerto Rico, March 22-27, 1987.

Falcon, Walter, William O. Jones and Scott R. Pearson, The Cassava Economy of Java, (Stanford University Press: Stanford) 1984.

Fish, I. L., "Reservoir Sedimentation Study, Selorejo, East Java, Indonesia", Hydraulics Research Station, Wallingford, 1983.

Gadjah Mada University, "Study of Regional Capability to Finance the O+M Costs for Irrigation Systems in the Prosida Projects in the Pemali-Comal Area, Central Java and in the Bantimurung and Lanrae Project Areas, South Sulawesi", Ministry of Public Works, Directorate General of Water Resources Development.

Gauchon, M. J., "Some Aspects of Watershed Management Economics", Upper Solo Watershed Management and Upland Development Project (Food and Agriculture Organization: Solo), 1976.

Goldberg, J. "Indicative Economics of Soil Conservation Works" World Bank Office Memorandum, December 22, 1980.

Lal, Rattan "Effects of Soil Erosion on Crop Productivity" CRC Critical Reviews in Plant Sciences 5:4 303-367, 1987.

Lutz, Ernst and Salah El Serafy "Environmental and Resource Accounting- An Overview", Ahmad, Yusuf J., Salah El Serafy and Ernst Lutz, eds., Environmental Accounting Sustainable Development, World Bank: Washington 1989.

MacDonald, Sir M. and Partner Asia, "East Java Irrigation Project, Notes Regarding Efficient O+M", Ministry of Public Works Directorate General of Water Resources Development, February, 1987.

Magrath, William B. and Margaret Grosh, "An Economic Approach to Watershed Management with Emphasis on Soil Erosion" paper presented to the World Forestry Congress, Mexico City, Mexico, August 1985.

McCauley, David S., "Upland Cultivation Systems in Densely Populated Watersheds of the Humid Tropics. Opportunities and Constraints Relating to Soil Conservation: A Case from Java, Indonesia", Working Paper East-West Evironment and Policy Institute, 1985.

Mink, Stephen D. and Paul A. Dorosh, "An Overview of Corn Production", in Timmer, ed., 1987.

Mink, Stephen D., Paul A. Dorosh and Douglas H. Perry, "Corn Production Systems", in Timmer ed., 1987.

Molster, H. C., "Methods of Estimating Fertilizer Response with an Application to Urea Use on rice in Jogjakarta, Indonesia", Agricultural Research Report 877, Centre for Agricultural Publishing and Documentation, Wageningen, 1978.

Montgomery, Roger, "Maize Yield Increases in East Java", Bulletin of Indonesian Economic Studies, vol. 18 no. 3, November 1981, pp. 74-85.

Muryadi, Amir, "Catchment Management and its Role in Water Resources Development in Indonesia", paper prepared for the ESCAP Seminar on Catchment Management for Optimum Use of Land and Water Resources, Hamilton, New Zealand, March 15-19, 1982.

Pierce, F. J., W. E. Larson, R. H. Dowdy and W. A. P. Graham, "Productivity of Soils -- Assessing Long Term Changes Due to Erosion", Journal of Soil and Water Conservation, vol. 38 no. 1, January--February, 1987, pp. 39-44.

Reppeto, Robert, William Magrath, Michael Wells, Christine Beer and Fabrizio Rossini, "Wasting Assets", World Resources Institute, Washington, 1989.

Republic of Indonesia, Directorate General of Reforestation and Land Rehabilitation, "Final Report, Second Phase, The Kali Konto Upper Watershed Regional Development, Trends and Issues", Malang, April, 1985.

Roche, Frederick C., "Production Systems" in Falcon and others, 1984.

-------------, "Sustainable Farm Development in Java's Critical Lands: Is a 'Green Revolution' Really Necessary?" (unpublished manuscript), Cornell University, 1987.

Roedjito, D. M. and H. Soenaro, "Sediment Management", paper prepared for the Workshop on Integrated River Basin Development and Watershed Management, Jakarta, March 22-29, 1986.

Sfeir-Younis, Alfredo, "Soil Conservation in Developing Countries, A Background Report", World Bank, 1985.

Southgate, Douglas, "The Off-Farm Benefits of Soil Conservation in a Hydroelectric Watershed", paper presented at the Annual Meeting of the American Agricultural Economics Association, Reno, Nevada, July 1986.

Sunarno and Sutadji, "Reservoir -- Sedimentation Technical and Environmental Effect", Proceedings of the International Commission on Large Dams, Rio de Janeiro, 1982, pp. 489-508.

Tampubulon, S.M.H., and B. Saragih, "'Model Farm' Upland Farming Technology In the Citanduy River Basin: A State of the Art", USESE, Ciamis, 1976.

Timmer, C. Peter, ed., The Corn Economy of Java, Cornell University Press: Ithaca, 1987.

Turner, R. Eugene, "The Sagara Arakan Reclamation Project: The Impact on Commercial Fisheries" reports to Engineering Consultants, Inc., Denver, Colorado, 1975.

U.S.A.I.D./World Bank "Indonesian Upland Agriculture and Conservation Project", 1984.

Wischmeier, W. H., "Uses and Misuses of the Universal Soil Loss Equation" Journal of Soil and Water Conservation Jan/Feb 1976, Vol 31 no 1, pp 5-9.

A. Soils: Twenty-five map units from the Exploratory Soil Map of Java and Madrua are listed. The map was prepared by Soil Research Institute at Bogor, supported by FAO-Rome, 1959. Scale 1:1,000,000.

Soils on Level to Undulating Land (0 to 8% Slope)

1 - Organic soils and hydromorphic alluvial soils from marine and lake deposits; level plains or bottom land.

2 - Alluvial soils from marine river and lake deposits; level or bottom land.

3 - Regosols from dune sand; rolling.

4 - Grumusols from heavy-textured sediments; level.

5 - Hydromorphic soils and planosols from heavy-textured sediments; level.

Soils on Rolling to Hilly Land (8 to 30% Slope)

6 - Regosols and lithosols from sedimentary rocks; hilly.

7 - Regosols and lithosols from marls and limestone; hilly.

8 - Regosols from acid igneous rocks; hilly.

9 - Grumosols from sedimentary and igneous rocks; rolling.

10 - Latosols from basic and intermediate igneous rocks; rolling to hilly.

11 - Latosols from basic and intermediate igneous rocks; rolling to hilly.

12 - Andosols from basic and intermediate igneous rocks; rolling.

13 - Red-yellow podzolic soils from acid sedimentary rocks; rolling.

14 - Red Mediterranean soils and grumusols from sedimentary limestone; hilly.

15 - Red Mediterranean soils and grumusols from basic and intermediate igneous rocks; hilly.

16 - Non-calcic brown soils from basic and intermediate igneous rocks; undulating.

Soils on Hilly to Mountainous Land (Over 30% Slope)

17 - Regosols from basic and intermediate igneous rocks; hilly to mountainous.

18 - Regosols and latosols from basic and intermediate igneous rocks; hilly to mountainous.

19 - Lithosols and latosols from basic and intermediate igneous rocks; hilly to mountainous.

20 - Latosols and andosols from basic and intermediate igneous rocks; hilly to mountainous.

21 - Andosols and regosols from basic and intermediate igneous rocks; mountainous.

22 - Red-yellow podzolic soils from sandstone and acid igenous rocks; hilly to mountainous.

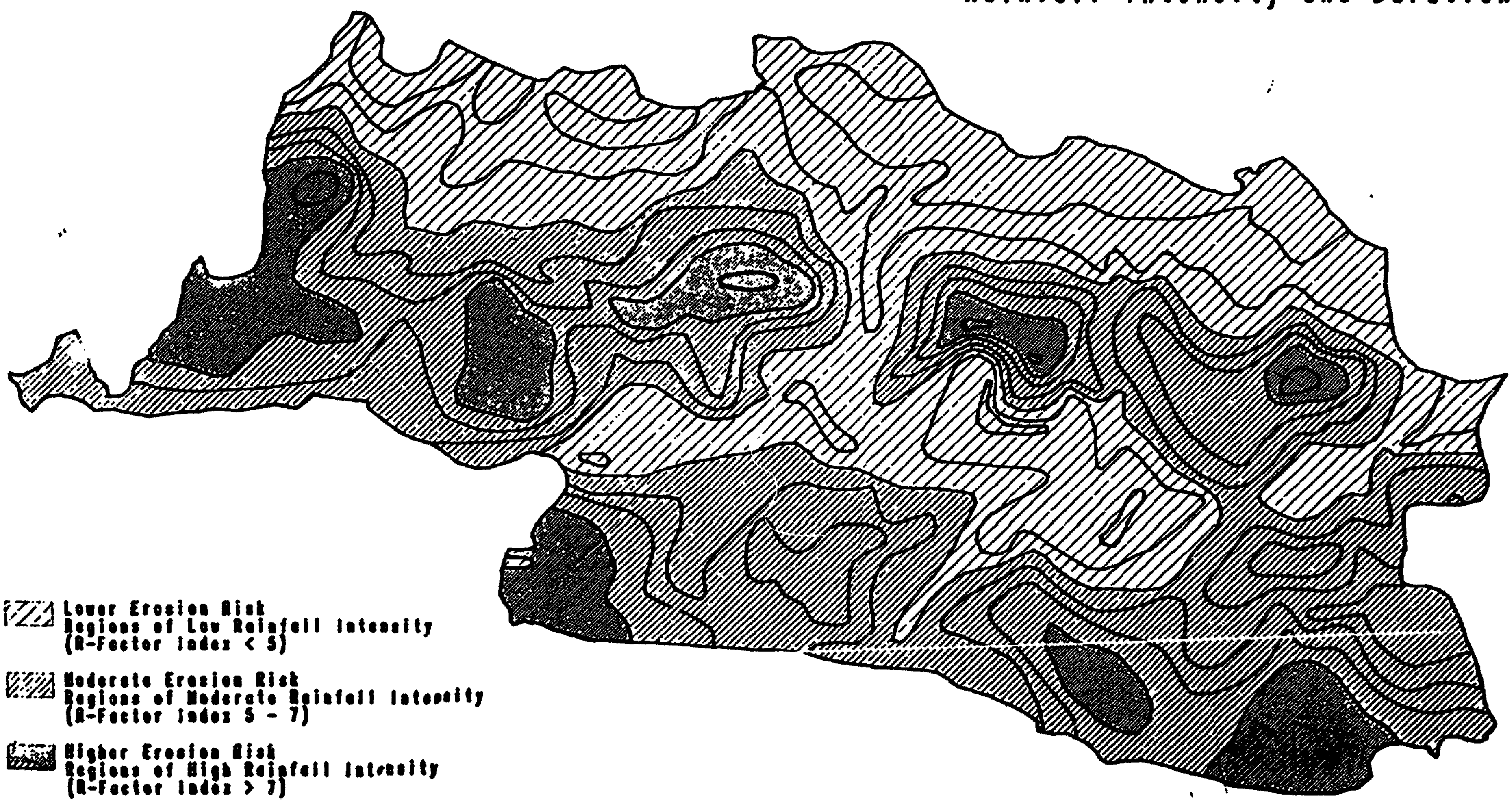
23 - Soil complex including mainly latosols, red-yellow podzolic soils and lithosols from sedimentary and igenous rocks; hilly to mountainous.

24 - Soil complex including mainly red Mediterranean soils, grumusols and regosols from sedimentary rocks; hilly to mountainous.

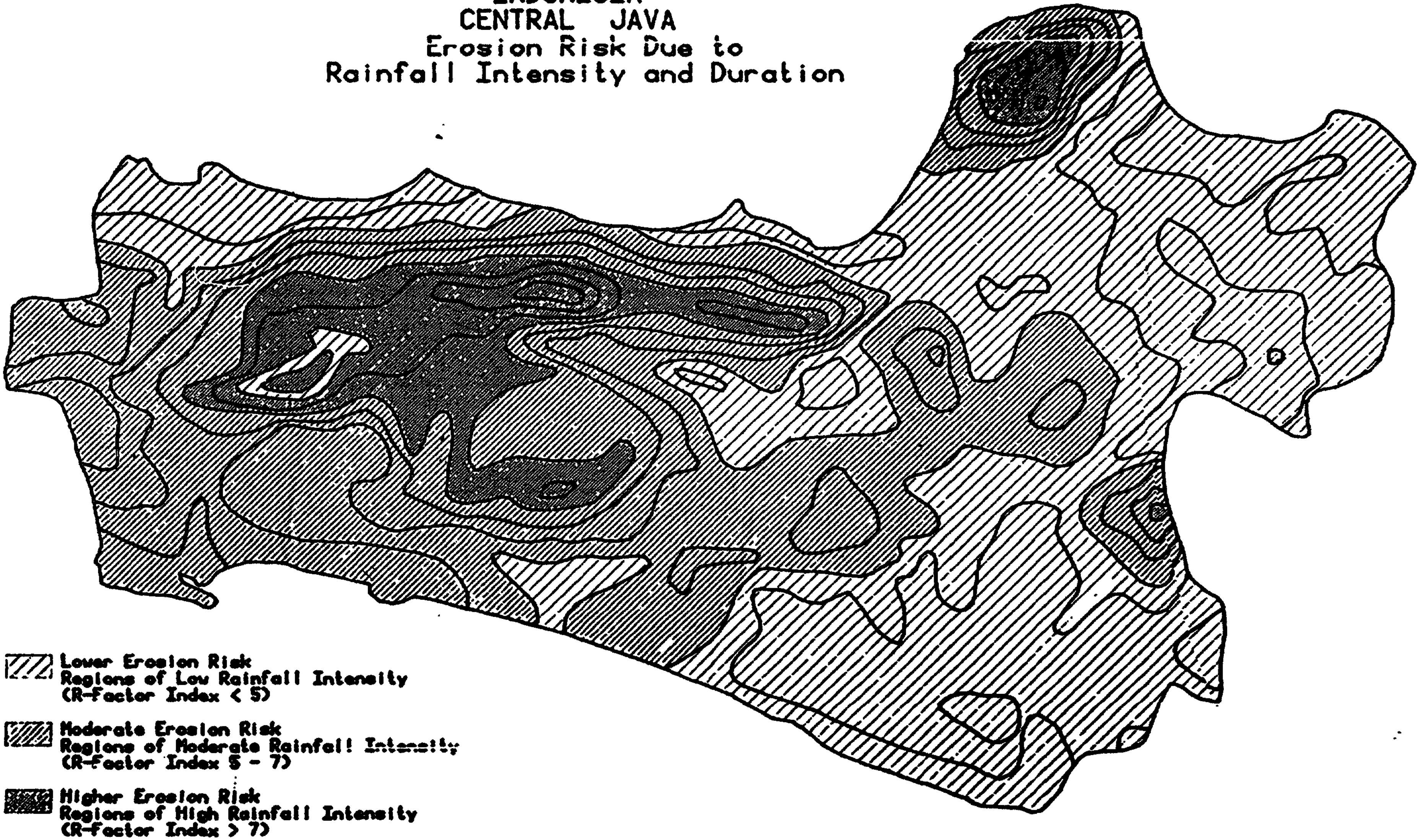
25 - Soil complex on mountainous land.

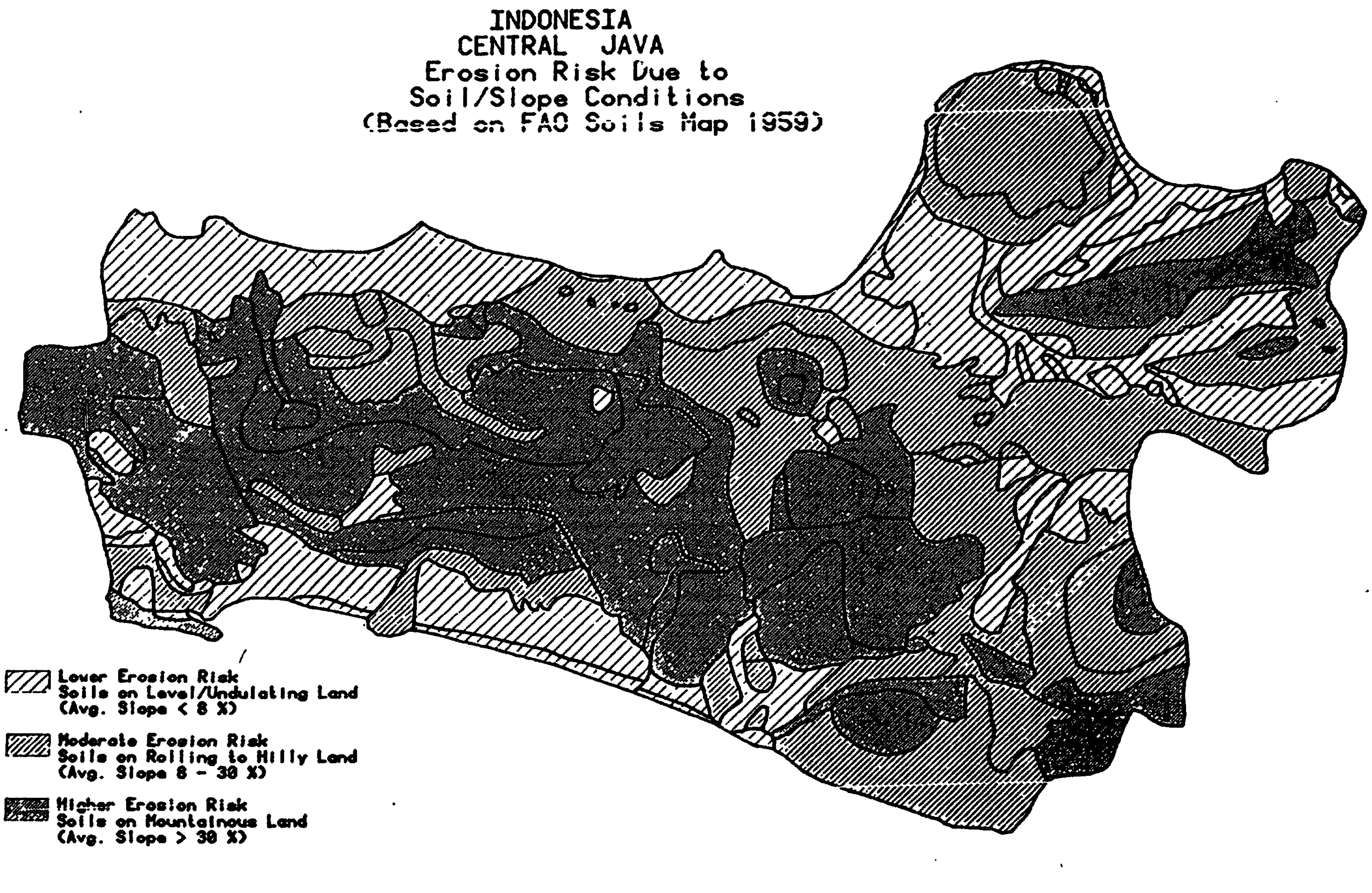
Appendix 2

INDONESIA
WEST JAVA
Erosion Risk Due to
Rainfall Intensity and Duration

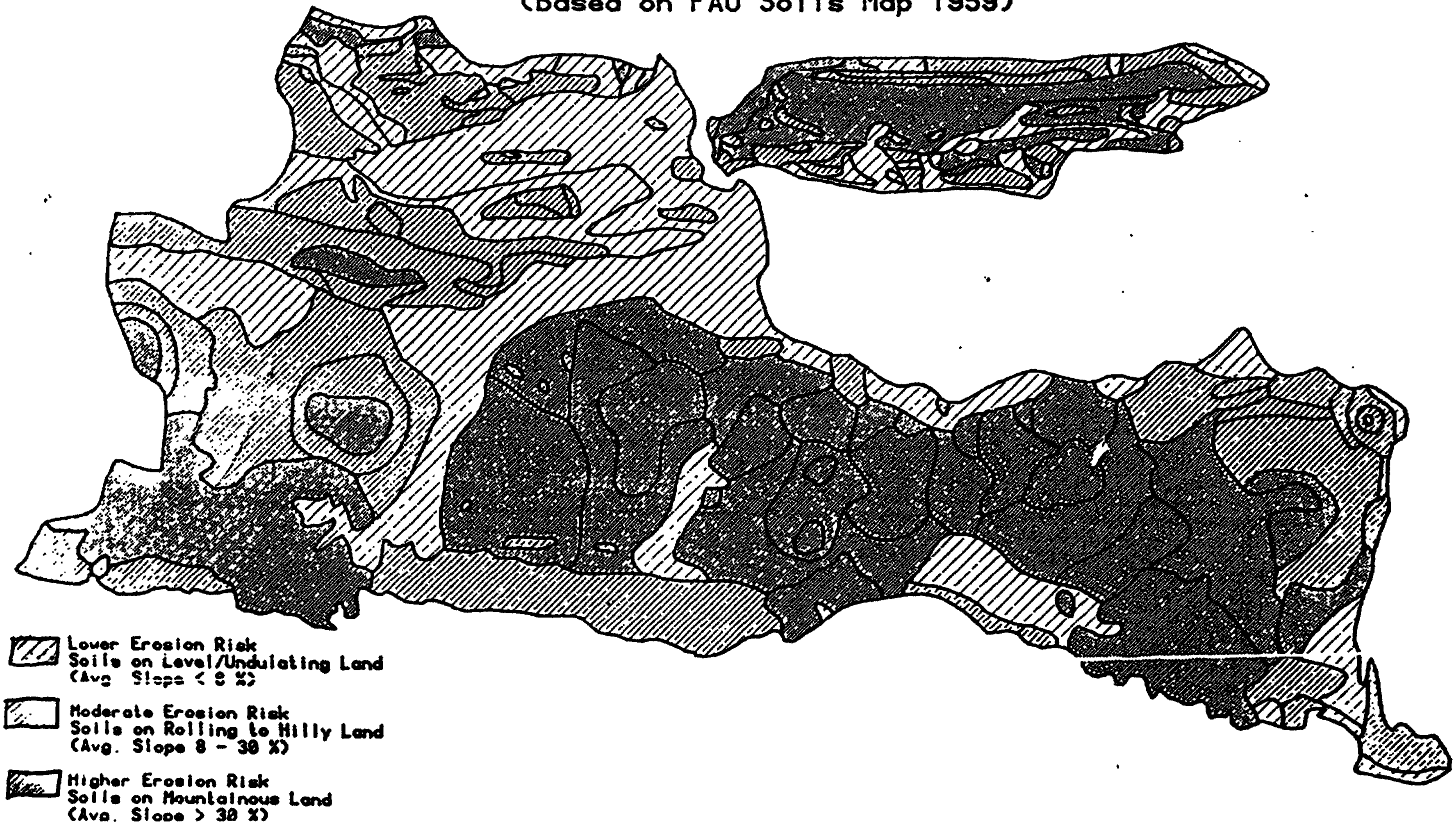


INDONESIA
CENTRAL JAVA
Erosion Risk Due to Rainfall Intensity and Duration

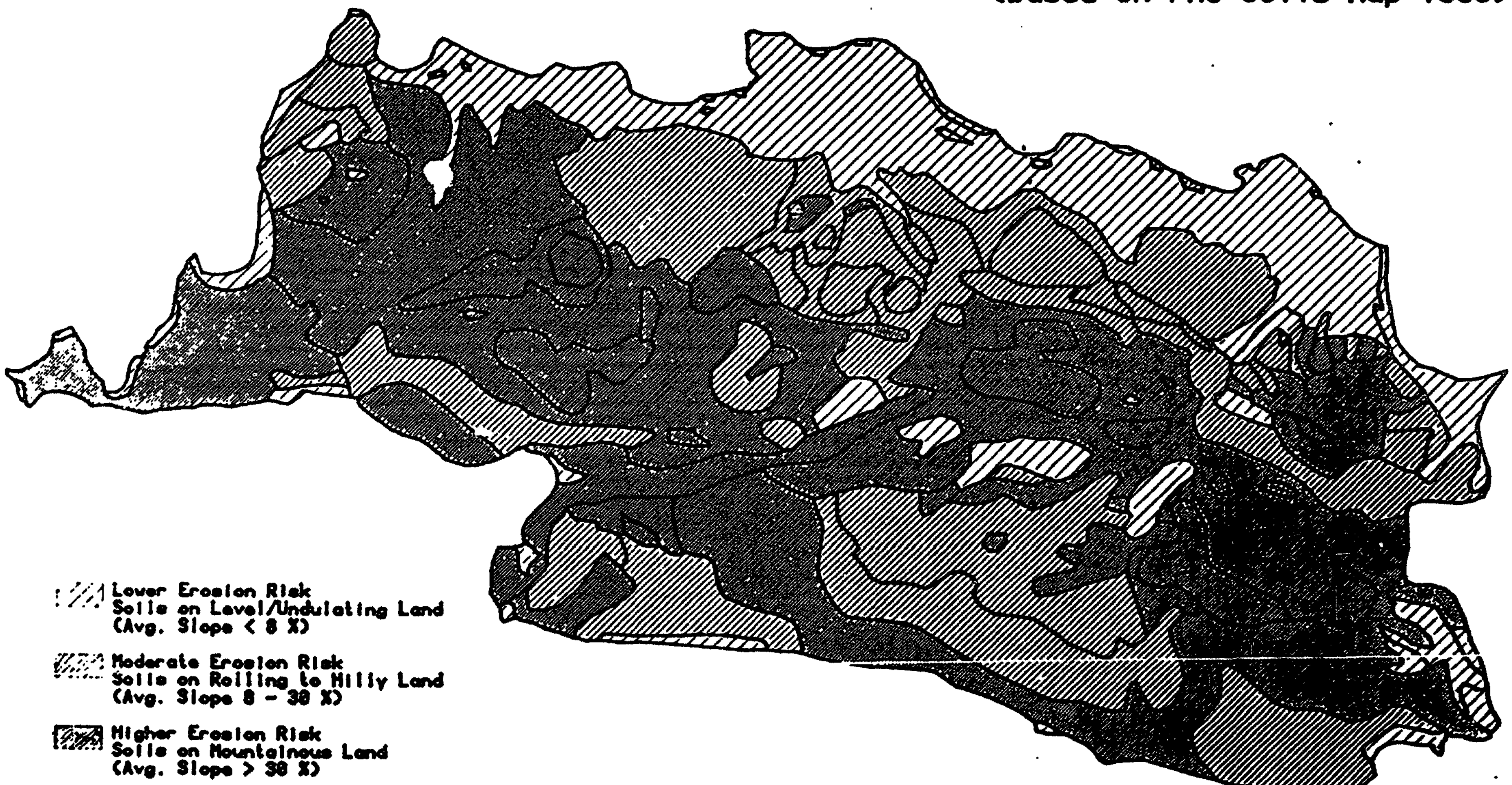



INDONESIA
CENTRAL JAVA
Erosion Risk Due to
Soil/Slope Conditions
(Based on FAO Soils Map 1959)
Lower Erosion Risk
Soils on Level/Undulating Land
(Avg. Slope < 8 %)
Moderate Erosion Risk
Soils on Rolling to Hilly Land
(Avg. Slope 8 - 30 %)
Higher Erosion Risk
Soils on Mountainous Land
(Avg. Slope > 30 %)

INDONESIA
EAST JAVA
Erosion Risk Due to Soil/Slope Conditions
(Based on FAO Soils Map 1959)



INDONESIA
WEST JAVA
Erosion Risk Due to Soil/Slope Conditions
(Based on FAO Soils Map 1959)



INDUNESIA
EAST JAVA
Erosion Risk Due to Rainfall Intensity and Duration