Sediment and the Environment (Proceedings of the Baltimore Symposium, May 1989)
IAHS Publ. no. 184, 1989.

Cost impacts of sediments in South African rivers

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ABSTRACT Soil erosion is a serious problem in South Africa. Erosion rates have increased considerably due to human impacts. Off-site damages as a result of high sediment yields from drainage basins are discussed in terms of loss of reservoir storage capacity, damage to agricultural land and crops, enhanced water treatment costs and impacts on the aquatic environment. From a hydrographic survey data base for 170 reservoirs an average storage loss rate of 0.35 percent per year is indicated. The total off-site cost impact, excluding the environmental damage, is estimated at R90 million per year (R1 = US$ 0,40). This is an order of magnitude higher than the annual national expenditure on soil conservation.

INTRODUCTION

Soil erosion is a serious problem on the African continent, including southern Africa. In South Africa observed average sediment yield per unit area varies for different catchments between less than 10 to more than 1000 t km^{-2} $year^{-1}$. The total amount that is presently taken away annually from South Africa, Swaziland and Lesotho is estimated at between 100 and 150 million ton (Rooseboom, 1978). Deterioration of South Africa's productive soil is a serious threat (du Plessis 1985). Furthermore 60% of the grazing land is in a poor condition due to overgrazing (van Niekerk 1984). Soil conservation actions are mainly related to these on-site problems. Off-site, downstream impacts like reservoir storage losses or increased water treatment costs are usually accepted as given in the planning process and are accommodated in the design and operation of schemes. Off-site environmental damages are probably even more serious in the long run, but have so far not been expressed in economic terms and thus also have very little bearing on land management decisions.

The objectives of this paper are: (a) to place the South African soil erosion problem in a world perspective (b) to provide first estimates for off-site damages in South Africa (c) to evaluate these damage estimates in relation to similar information from the United States and (d) to discuss the damage estimates in terms of the national expenditure on soil conservation.

EROSION RATES AND SEDIMENT YIELD IN SOUTH AFRICA

Independent studies by Hawthorne (1975) and Martin (1987) calculated average erosion rates of 0.5 - 1.4 cm 10^{-3} years for the last 120 million years for South Africa. However, these rates are not applicable anymore. Ever increasing population and stock numbers and poor cultivation practices during the last couple of decades resulted in overgrazing (van Niekerk, 1984), large-scale disappearance of wetlands (Begg & Carser, 1988) and other erosion accelerating factors. More recent erosion rates are listed in Table 1.

Table 1 Recent erosion rates in South Africa and some other areas

Area	Erosion rates in cm 10^{-3} years	Source
South Africa		
Republic of South Africa	12.00	King (1967)
Bulbergfontein 1942-1971	2.75	le Roux & Roos (1979)
Bulbergfontein 1972-1978	3.46	le Roux & Roos (1979)
Upper Orange and Vaal Rivers	20.00	King (1967)
Kenya	0.80- 8.00	Dunne (1979)
Tanzania (overgrazing)	20.00-73.00	Rapp (1975)
Mississippi Basin	4.20	Menard (1961)
Whole world	3.00	Stoddart (1969)

Martin (1987) states that the erosion rate in Natal increased by a factor 12-20 compared to average geological erosion rates. For the Tugela river the factor 15 was calculated. As a result of the high sediment loads brought down seasonally by the Tugela and other Zululand rivers, the coast line north of the Tugela mouth is progressing at an increasing rate (Weisser & Backer, 1983) (Fig. 1).

The advancement rate increased from 1.25 m year^{-1} during 1937-1957 to 5.67 m year^{-1} during 1965-1977 (Weisser & Backer, 1983).

The highest sediment yielding areas on the African continent, e.g. 1000-5000 t km^{-2} year^{-1}, are in the mountainous Maghreb region of Morocco, Algeria and Tunesia (Walling, 1984). For South Africa, Rooseboom (1978) also maps yields in excess of 1000 t km^{-2} year^{-1}

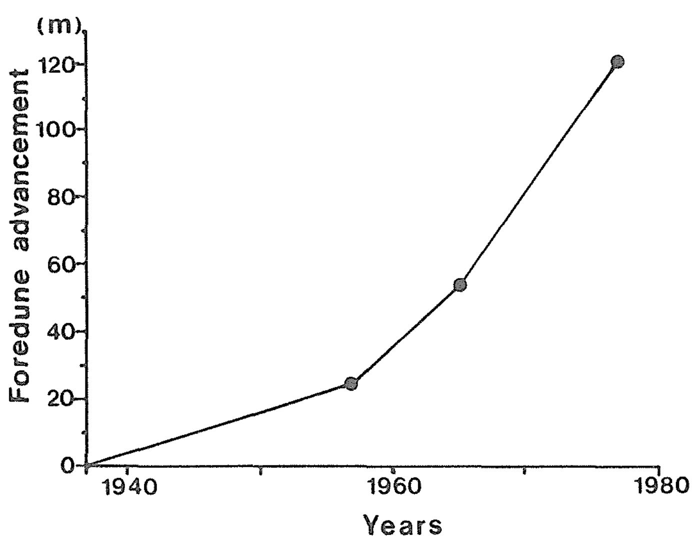

Fig. 1 Beach and foredune advancement at Twinstreams farm north of the Tugela mouth.

and shows the highest measured yield as 890 t km^{-2} $year^{-1}$ for a 13000 km^2 upper drainage basin of the Caledon River. In the arid west of the country, yields generally do not exceed 200 t km^{-2} $year^{-1}$ (Rooseboom, 1978). This can be compared with a generalized figure of 12 t km^{-2} $year^{-1}$ for Western Europe (Milliman & Meade, 1983) and 164 t km^{-2} $year^{-1}$ for India (Narayana & Babu, 1983).

ON-SITE LOSSES DUE TO SOIL EROSION

By the turn of the century the Republic of South Africa will only have 0.32 ha arable land per person compared to 4.69 ha in central Africa, 0.8 ha in the United States and Canada and the minimum requirements of 0.4 ha to feed one person (Verbeeck, 1976). According to du Plessis (1985) the normally accepted soil loss tolerances between 3 and 10 t ha^{-1} $year^{-1}$ are already too high for the large proportion of shallow soils in South Africa (effective depth less than 300 mm). Sediment yield figures from large drainage basins, as reflected in sediment deposited in dams, are often considerably higher (Rooseboom, 1978). Going with soil erosion from cultivated lands is a large loss of fertilizer. Du Plessis (1985) estimates the phosphorus loss alone to be R26.4 M $year^{-1}$.

Soil erosion on natural veld (grazing land), which makes up 86% of all agricultural land, is also recognized as a serious problem. According to van Niekerk (1984) 60% of the veld in the RSA is in a poor condition requiring urgent attention and only 10% is in a good condition.

Information on the agricultural production losses due to soil loss is not readily available.

IMPACTS OF SEDIMENT

Deposition of sediment in reservoirs

Large overyear balancing reservoir storage is essential for water resources management in the predominantly low precipitation, high potential evaporation regions of the world. Existing major dams in South Africa already have a capacity equivalent to 50% of the total mean annual runoff (MAR) (Department of Water Affairs, 1986). Reservoir capacities for the large storage dams in many cases exceed the mean annual runoff of their contributing drainage basins and storages up to five times the mean annual runoff have been built. According to Brune (1953), reservoirs of this capacity will trap more than 95% of incoming sediment and storage as little as 10% of MAR will already trap 80% of incoming material.

Resurveys of reservoirs are carried out routinely in South Africa since the 1960s to determine storage loss. In 1976 echo-sounding equipment was introduced to speed up the work. For the major dams such information is already available since the 1920s. To date a resurvey data base is available for 170 reservoirs ranging in size from 0.5 to over 5000 Mm^3 (Hydrographic survey, 1988). The total storage loss and mean loss rates for different reservoirs are summarized in Table 2 and the ranges of this information in Table 3.

The mean reservoir storage loss rate for the different regions in South Africa is 0.35% $year^{-1}$ and the median 0.21% $year^{-1}$. Table 3 also shows that 25% of reservoirs surveyed have a sediment

Table 2 Reservoir storage loss in South Africa

Region	Present total storage capacity (Mm^3)	Storage loss* Mm^3)	Mean storage loss rate** (% $year^{-1}$)
Western Transvaal	1009	70	0.33
Eastern Transvaal	2892	27	0.18
Vaal River	8083	400	0.31
Orange River	9290	378	0.41
Western Cape	2280	69	0.43
Eastern Cape	1511	280	0.46
Natal	4843	103	0.33
Total	29908	1327	

* Only where resurveys are available
** Diversion type structures with high sedimentation rates not included in the mean

Table 3 Range of reservoir storage loss and loss rate in South Africa

Storage lost		Storage loss rate	
% of reservoirs	storage lost (less or equal %)	% of reservoirs	loss rate (less or equal % $year^{-1}$)
10	0.6	10	0.04
25	1.7	25	0.10
50	5.1	50	0.21
75	13.3	75	0.55
90	26.9	90	1.02
95	41.2	95	1.63
99	56.6	99	4.6

* Only where resurveys are available
** Diversion type structures with high sedimentation rates not included in the mean

deposition rate of equal or less than 0.10% $year^{-1}$. On the other hand 10% of reservoirs have a loss rate of 1.02% $year^{-1}$ and 1% of reservoirs a loss rate of 4.6% $year^{-1}$ or more. The last-mentioned are the diversion structures with low capacity to inflow ratios. These storage loss rates can be compared with an average for the United States of 0.2% $year^{-1}$ (George et al, 1975) or a median of 0.62% $year^{-1}$ for 107 reservoirs in the State of Illinois, USA (Stall & Lee, 1980).

Replacement of lost storage can be achieved by construction of new storage, through raising the dam wall or at a new site, and by removal of sediment. Present South African construction costs range between R0.10 and R1.30, with an average of R0.50, per cubic meter storage volume, compared to dredging costs of R1.40 m^{-3} (all at 1988 prices; R1 = US$ 0,40). However the new storage option may diminish in future because of complete lack of a suitable site or the escalating construction costs as less suitable dam sites have to be considered.

Based on total present storage and mean loss rate the total storage lost per year is 105 Mm^3. This presents a financial loss of R53 M $year^{-1}$.

Not included in this figure is the storage loss in the thousands of private farm dams built for stock watering and supplementary irrigation, ranging in size from 5000 m^3 to over $1Mm^3$. In many regions they already represent a total storage of more than 10% of basin MAR. Based on contractors quotations after the major floods in 1987 the sediment dredging costs for these smaller sturctures can go up to R10 m^{-3}.

Besides the storage loss, sedimentation of reservoirs also has other cost impacts. Increased capital costs derive from:

- special provision for sediment scouring to keep outlet structures free;
- increased spillway design capacity due to loss in reservoir flood absorption capacity;
- consideration of sediment pressure in the structural design
- of the dam wall;
- raised high flood levels and consequent higher dam basin expropriation costs.

Increased operational costs result from:

- water loss due to need for sediment scouring from reservoirs;
- downstream impacts of scouring;
- special maintenance at outlet works;
- use of bronze instead of stainless steel pumps.

Damage to agricultural land

Sedimation damage to agricultural land resources can be related to overwash of infertile material, impairment of natural drainage, and swamping due to channel aggregation, associated floodplain scour and bank erosion (Task Committee, 1969).

The best and most differentiated flood damage information in South Africa is available through the damage surveys undertaken after the major floods in 1974 (Spies, 1977 and Viljoen et al., 1977). This and other flood damage information is shown in Table 4.

The category "Damage to agricultural lands and crops" in table 4 consists of the items damage to lands (repairable/permanent) and damage to plants and crops (Spies, 1977). Damage due to erosion products is not identified separately. Similar surveys are presently undertaken of the 1987 and 1988 flood damage, but results are not available yet.

Deposition of sediment is probably the most widespread form of flood damage in the drier regions of South Africa. This is born out by the description of the 1971 Gamtoos River, 1981 Buffalo River and 1984 Mfolozi River floods (Table 4). Based on this observation and the relation of agricultural damage to total flood damage, the flood damage due to high sediment loads can be approximated conservatively by 20% of total flood damage. At 1988 costs this is estimated at R30M $year^{-1}$. The effect of a changed flooding regime, due to human impacts in the drainage basin and river channel and the channel aggregation effects are not included in the above damage figure. In the United States a Task Committee (1969) saw this damage as accumulative compared to the recurrent flood damage and assessed it as 2.5 times the sedimentation damage normally included in flood damage.

Table 4 Sedimen ation component of flood damage in South Africa

Flood event	Total damage (million Rand)	Damage to agricultural lands and crops (million Rand)	Descriptive	Source
1971 Gamtoos River	-	-	Damage to 60% of floodplain area under irrigation; 11% of cultivated land destroyed by erosion; 24% severely damaged by heavy sediment; 25% submerged without permanent damage.	Alexander (1971)
1974 Great Fish River and tributaries	10.0	2.8		Spies (1977)
1974 Orange River and tributaries	42.2	25.8		Viljoen <u>et al</u>. (1977)
1974 Sundays River	1.9	0.7		Spies (1977)
1981 Buffels River	10.0*		Sediment deposits up to 3m deep in town. Downstream agricultural lands completely covered by sediments.	Kovacs (1981)
1984 Mfolozi River		112.0	2000 ha of sugar cane lands completely ruined by a 2m thick deposit of sand.	Pretoria News (1984)
1987 Natal	400		River courses scoured out; Newly cut river banks devoid of vegetation; Highly productive land adjacent to rivers swept away; Low lying lands inundated.	Pretoria News (1988) Agricultural News (1987)
1988 Orange River and	850	214**	Erosion of cultivated lands, damage to irrigation canals.	Pretoria News (1988) Agricultural News (1988)

* Only town of Laingsburg urban damage
** Includes private roads and bridges

<u>Impact on infrastructure</u>

No information on cost impact of sedimentation on infra-structure such as harbours, roads, bridges and culverts and water distribution networks is readily available for South Africa. This impact is again related to flood events. As a first estimate a figure of 10% of the damage to agricultural lands is assumed, amounting to R3M year^{-1}.

<u>Impact on water treatment</u>

Most impoundment waters in South Africa are highly turbid (Walmsley & Bruwer, 1980). This turbidity is largely suspended inorganic material and can be related to sediment production in drainage basins. Drinking water supply has stringent turbidity requirements. In the United States, for example, a turbidity of 1 nephelometric turbidity unit (NTU) may not be exceeded and up to 5 NTU is allowed providing that the higher level does not interfere with disinfection (Postgate, 1978). High turbidities are therefore a cost factor in water treatment. Capital costs are increased by increased capacity requirements of the works and special design requirements such as presedimentation tanks and special sediment removal equipment. Operational costs are due to increased flocculent and disinfectant requirements. Disposal of sediment is also becoming a major problem and cost factor. The effect of turbidity on costs of chemicals for range of South African water treatment works can be seen in Table 5 (Department of Water Affairs, 1985).

Table 5 Cost of chemicals for a range of South African water treatment works (1985 information)

	Caledon	Suid Ndebele	Hendrik Verwoerd	Saldanha	Potgietersrus
Turbidity (NTU)					
Min.	260	16	73	6	0.1
Max.	5600	365	75	125	8
Water supplied (Mm^3 $year^{-1}$)	24.7	2.5	0.4	4.2	1.7
Operating costs					
Chemicals (c m^{-3})	6.84	3.15	2.04	1.66	0.85

The annual capital outlay on water treatment in South Africa is estimated at R100M. The capital cost increment due to higher than normal turbidities is estimated at 2% of total capital costs, amounting to R2M. The increment in chemicals cost for the approximately 2100Mm^3 $year^{-1}$ treated water supplied is estimated at R6M $year^{-1}$.

<u>Impact on the aquatic environment</u>

Human impact in the fresh water environment has not been as big an issue in South Africa as it has been in the Northern Hemisphere, with its big commercial interests in freshwater fisheries. Recent surveys do however indicate problems in this regard. Begg (1979) found serious degradation of virtually all the estuaries on the Natal coast over the last 50 years. Sediments from drainage basin erosion are the greatest single factor contributing to the problem. Depth and water areas have been greatly reduced and water turbidity increased. Some esturaries have disappeared completely. These estuaries form an integral part of the attraction and socio-economic benefits of the Natal coast and furthermore fulfil a vital role as nursery areas for many marine organisms. In the inland, similar problems are reported for all the rivers of the internationally important Kruger National Park. These damages have to date not been expressed in economic terms. The importance of maintaining freshwater ecological processes can, however, be gauged from the earmarking of 11% of the total South African water demand in the year 2000 for maintenance of estuaries (Department of Water Affairs, 1986).

In terms of eutrophication problems, turbidity of impoundment waters can be regarded as a benefit. Walmsley and Bruwer (1980) show that the trophic status of turbid impoundments is not only a function of phosphate loading but is directly related to the water transparency. The off-site impact of sediment as a mobilizer and carrier of plant nutrients from diffuse sources is not yet a major issue in South Africa, as most eutrophication problems can still be related to point sources of pollution (Grobler, 1988).

SUMMARY AND DISCUSSION OF OFF-SITE SEDIMENT DAMAGE

The information on off-site cost impact of sediments in South African rivers as developed in the previous paragraphs is summarized in Table 6.

Table 6 Estimate of mean annual off-site sediment damage in South Africa (1988 figures; (R1 = US$ 0,40)

	Million Rand year^{-1}
Deposition of sediment in reservoirs	53
Sedimentation component of flood damage (agricultural lands and crops)	30 +
Sedimentation component of flood damage (roads, bridges, culverts, harbours, water distribution networks etc.)	3
Additional water treatment costs	8
Degradation of aquatic environment	?
Total cost	94 +

For comparison of relative impacts, similar information from the United States is shown in Table 7.

More recently the US Soil Conservation Service, as quoted in Lee and Guntermann (1976) has estimated that silt and sediment cause about $350M year^{-1} in damages.

When adding indirect costs to the above direct costs to assess total economic damage, these figures could be an order of magnitude higher. Based on preliminary data supplied to the US Congress in 1983 the economic damage caused by sediment and its associated pollutants was estimated to be more than $3000M year^{-1} (Clark quoted in Duda, 1985). If damage to fish and wildlife is included, the estimate of actual damage might exceed $6000M year^{-1} (Duda, 1985).

Comparison of the South African estimates with the United States

Table 7 Average annual damage from sediment and sedimentation in the United States (Task Committee, 1969)

	Million US$ Year^{-1}
Deposition of sediment in reservoirs	50
Damage to agricultural land resources linked to river aggregation	50
Sedimentation damages partly or wholly included in flood damages	20
Maintenance costs of drainage ditches and canals	17
Maintenance costs of irrigation canals	10
Maintenance costs of harbours and navigable channels	12
Cost of water treatment as a result of excess turbidity	5
Other losses (infrastructure, commercial fisheries. wildlife amd recreation)	11 +
Total sedimentation damage	175 +

information indicates that the relative magnitude of the sedimentation component of flood damage may be an under-estimate and the additional water treatment costs and overestimate, accepting that the reservoir sedimentation figure is the best estimate in the South African data set. The comparison furthermore indicates that an assessment of economic damage rather than just the direct costs is necessary. This may increase the actual damage by an order of magnitude. Lastly, the impact on the aquatic environment may have by far the highest economic implications, possibly of the same order of magnitude as all the other damages together.

GOVERNMENT EXPENDITURE ON SOIL CONSERVATION

Government support for soil conservation in the RSA is through various subsidy schemes in terms of the Conservation of Agricultural Resources Act. The emphasis so far has been on cultivated lands. However, agriculturalists are becoming concerned that natural veld, which makes up 86% of all agricultural land in the RSA, is still deteriorating. This has lead to the National Grazing Strategy in 1985. It entails limiting of livestock to the proclaimed long term grazing capacity as determined by climate, soils and vegetation. In terms of the strategy no financial help in the form of subsidies for conservation schemes or aid during droughts will be granted to farmers who do not meet these stocking and other requirements. The most important water source areas in the country are managed in terms of the Mountain Catchment Areas Act. Trustland is managed by the Department of Development Aid. Annual expenditure through these channels for soil conservation measures is summarized in Table 8.

Table 8 Public sector expenditure in the RSA on soil conservation measures (1987/88 figures)

	Million Rand year^{-1}
Department of Agricultural Economics and Marketing	
– Subsidies	5.6
– Key conservation works	1.3
Department of Development Aid	
– 1988/89 budget	1.2
Department of Environment Affairs	
– Management of mountain catchments (approximately 20% for soil conservation)	1.8
Total	9.9

The above expenditure data does not include the self-governing and independent states making up South Africa. In their under-developed rural areas soil erosion and vegetation destruction are particularly serious problems due to population pressures, socio-economic conditions and traditional patterns in conflict with land capability. Here soil conservation can only succeed if it takes place within a framework of integrated rural development to reverse current trends towards increasing ecosystems disequilibrium (Erskine, 1985).

CONCLUSIONS

(a) There are strong indications that soil erosion rates in South Africa have increased considerably due to human impacts and that these increases may be an order of magnitude in some parts of the country.

(b) No comprehensive information on on-site or off-site damages due to soil erosion and sedimentation is available for South Africa.

(c) Off-site damages may amount to more than R90 million per year. If indirect costs are also taken into account the total economic impact would be considerably higher. Environmental damage is also not included in the figure and has to date never been expressed in economic terms. Similar information from the United States indicates that these damages may be of the same order of magnitude as all other damages together. Serious degradation of the Natal coast estuaries points to a high economic impact.

(d) The annual public sector expenditure in support of soil conservation amounts to R9 million.

(e) The large disparity between off-site damages and national conservation effort bears out what Trustrum (1984) noted for New Zealand. In most countries, carrying out soil conservation simply to maintain the soil in place, is not viable; some socio-economic benefit must be demonstrated. In this regard it is essential that policy makers consider both on-site and off-site benefits in order to develop a balanced soil conservation program.

(f) This will require greater efforts towards the identification and quantification of soil erosion and sediment delivery, as well as a thorough evaluation of the impact in economic terms.

ACKNOWLEDGEMENTS

The cost figures supplied by a number of colleagues are greatfully acknowledged. The paper is published with the permission of the Director-General of the Department of Water Affairs.

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