Watershed management

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Water management has increasingly been realized to be an essential component of sustainable water development. While no-one argues with the desirability of proper watershed management, achieving it has not been an easy task. It requires concurrent accomplishment of many tasks, among which are strict control of land-use practices, afforestation and forest management, and implementation of appropriate soil and water conservation practices. Two main impacts of inadequate watershed management are discussed. These are increased reservoir sedimentation which reduces storage capacity which may in turn render water projects uneconomic, and changing patterns of stream flow. It is argued that watershed management should not be viewed exclusively from the narrow perspective of benefits to water projects alone. It should be considered essential for soil and water conservation and forest management, which in the long run will enhance the prospect of self-reliance of nations in terms of food, fibre and energy.

Even though watershed management has become an increasingly important aspect of water resources development in recent years in both developed and developing countries, it should be noted that its importance has been realized for at least some 2 500 years. For example, Plato (428–348 BC) has graphically noted the impact of land-use changes on river discharges (Biswas, 1970). In his book *Critias*, Plato discusses the conditions of Athens some 9 000 years before his time:

> Furthermore it (the land of Attica in ancient times) enjoyed the fructifying rainfall sent year by year from Zeus; and this was not lost to it by flowing off into the sea, as nowadays because of denuded nature of the land. The land (then) had great depth of soil and gathered the water into itself and stored it up in the soil we now use for pottery clay, as though it were a sort of natural water-jar; it drew down into the natural hollow the water which it had absorbed from the high ground and so afforded in all districts of the country liberal sources of springs and rivers; and surviving evidence of the truth of this statement is afforded by all the extant shrines, built in spaces where springs did formally exist.

The importance of watershed management, however, has become especially relevant in recent years because of the increasing realization that the long-term sustainability of water projects is an essential requisite for human welfare. Large- and medium-scale water development projects are invariably capital-intensive, and economically they can be considered to be efficient only if the benefits accruing from such projects can be assured over their designed life periods. There is now considerable evidence from projects from many different parts of the world that the life spans of some reservoirs will be less than expected due to more than anticipated rates of sedimentation, which may occur due to changing land-use patterns or serious underestimation of sedimentation rates.

Watershed management

Watershed management, in its broadest sense, can be considered to be an attempt to ensure that hydrological, soil and biotic regimes, on the basis of which water development projects have been planned, can be maintained or even enhanced; under no circumstances must they be allowed to deteriorate.

It is now well-known that changing land-use patterns affect water and soil regimes of any watershed.

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These changes, if properly planned, could be beneficial. However, in nearly all watersheds of developing countries, the changes are due to unplanned and *ad hoc* activities. Individual activities that affect land-use practices are generally small and incremental. However, when all the individual activities over an entire watershed during a specific time period are considered, their overall aggregated impacts could be substantial. Based on recent experiences, such aggregated impacts, unfortunately, tend to be deleterious in terms of watershed management.

The root cause of these changes is undoubtedly continual increase in human and animal populations. With rising human and animal populations, more and more land is required for shelter, food production, forage requirements and fuelwood. Since in most areas, good agricultural and pastoral land are already being utilized, people are forced to use marginal land, often in upper catchment areas having steep slopes. Forest is cleared so that the land can be used for agricultural or pastoral purposes.

Against a background of rising human and livestock populations, and the combined effects of agricultural encroachment and deforestation, land-use patterns of most watersheds have undergone serious changes in recent years and are likely to be subjected to more changes in coming decades. These changes, for the most part, are unplanned. The extent of this increased pressure can be easily demonstrated by considering the case of the Sudan, where over the period 1957–77, the human population increased more than six-fold, the number of cattle twenty-one fold, camels sixteen-fold, sheep twelve-fold and goats eight-fold (Biswas *et al*, 1987). Given such rapid increases in populations, it may not be possible to develop and implement watershed management policies which could be sustainable over a long term.

Much international attention has been focused in recent years on the present status of environmental degradation in the upland areas of various watersheds in countries like Nepal, India, Thailand, China or Ethiopia. What is, however, much less realized is that the environmental degradation of such areas is a primary symptom of a disease, but not the disease itself. The disease in this case is the economic condition of the rural poor, who are forced to exploit the environment for their very survival. It is evident that no enduring solution to such an environment problem is conceivable without relieving the pressures that are forcing the local population from a sustainable to an unsustainable relationship with their natural environment. Until the pressing need of the rural poor living in the watersheds is alleviated, the practice will continue, unless a very forceful policy of exclusion of humans and livestock from land can be implemented, which might satisfy the needs of sustainability of land, but certainly not of the people.

Currently, two main implications of improper or inadequate watershed management that are receiving increasing attention are sedimentation in reservoirs and changing patterns of streamflow. Reservoir sedimentation, by reducing storage capacity, is seriously damaging economics and long-term sustainability of many water projects. Streamflow patterns could change due to deforestation. While increasing sedimentation in many reservoirs all over the world is no longer a debatable fact, hydrologic and environmental scientists are not unanimous in their views on the extent and nature of streamflow changes due to changing land-use patterns.

Reservoir sedimentation

Undoubtedly the most serious and widespread impact of watershed management, so far as water projects are concerned, is in terms of reservoir sedimentation. While the problem is global in nature, the magnitude of the problem often varies from country to country, and even from site to site within the same country.

All rivers carry sediments, but their concentrations vary from one river to another. Table 1 indicates the sediment yields of some of the important rivers of the world. The table shows the magnitude of surface runoff per unit area, sediment yields in tons/km^2 of catchment area, and sediment concentration in ppm. It can be seen that sediment yields range from a high of 40 500 ppm for the Haihe in China to a low of 34 ppm for the Zaire River.

Table 2 shows the total suspended solid and dissolved sediment loads for three African rivers (Martins, 1984). It shows that the suspended solid loads for all three rivers exceed the dissolved solid loads, thus indicating the dominance of mechanical erosion in these watersheds. For the Nile, suspended solids carried accounts for 83.4% of the total sediment load which is significantly higher than dissolved solids carried account for 83.4% of the total sedi- because of extensive wind erosion in the desert areas through which the Nile flows.

Three estimates are currently available on the aggregated amount of sediments carried to the oceans by the world's rivers. Strakhov (1967) estimated the total load to be 12.7 billion tons. Corresponding estimates by Milliman and Meade (1983) and Holeman (1968) are 13.5 and 18.3 billion tons respectively. In the absence of real data, it should be noted that these estimates are very rough: the real figure may be very different.

Table 1. Sediment yields of selected rivers.

River	Country	Catchment area ($km^2 \times 10^6$)	Runoff (cm)	Sediment (t/km^2)	Yield (ppm)
Haihe	China	0.05	4	1620	40500
Huang He	China	0.77	6	1403	22041
Chiang Jiang	China	1.94	46	246	531
Mekong	Viet Nam	0.79	59	203	340
Ganges/Brahmaputra	Bangladesh	1.48	66	1128	1720
Indus	Pakistan	0.97	25	454	1849
Tigris/Euphrates	Iraq	1.05	4	50	1152
Amur	USSR	1.85	18	28	160
Niger	Nigeria	1.21	16	33	208
Nile	Egypt	2.96	1	38	3700
Zaire	Zaire	3.82	33	11	34
Mississippi	USA	3.27	18	107	602
Amazon	Brazil	6.15	102	146	143
Orinoco	Venezuela	0.99	111	212	191

Source: Adapted from Milliman and Meade (1983); Mahmood.

Construction of dams and reservoirs invariably changes the river regime. As the river approaches a reservoir, its velocity starts to drop. This reduces the sediment transportation capacity of water, which in turn increases the rate of sedimentation. When a river enters the reservoir, because of very low velocity, sediment deposition rates become very high. Accordingly, sedimentation is a normal process in all reservoirs. What good watershed management can do is to reduce the rate of sedimentation, and thus prolong the useful life of the reservoirs. Table 3 shows the extent of sedimentation in various reservoirs in China over specific time periods.

After the sediment loads carried by a river are deposited in a reservoir, water released from it is generally clear. Thus, the construction of the Hoover dam has reduced the sediment discharge of the Colorado River at Yuma, Arizona, where it enters Mexico, from 135 million tons to only 0.1 million tons per year (Meade and Parker, 1985). Similarly, the River Nile used to carry 100–150 million tons of suspended matter at Aswan before the construction of the High Aswan Dam (Biswas, 1982), most of which is now deposited in the High Dam Lake.

Discharge of clear water from reservoirs, however, may create erosion problems downstream. For example, in the case of the Aswan Dam, bank and bed erosion downstream in the Nile has become a problem. Even more serious has been the erosion of the Nile Delta, some 1 000 km from the dam. Prior to the construction of the dam, the delta used to be built up during the flood season with the sediment carried by the river to the Mediterranean. This sedimentation compensated the erosion of the delta resulting from the ocean waves of the preceding winter. There was an equilibrium between sedimentation and erosion. With most of the sediments being trapped in the lake, sufficient sedimentation does not now occur in the delta, and this has resulted in serious coastal erosion in that area.

Forecasting reservoir sedimentation

Continued sedimentation over a period of years means that the storage capacity of any reservoir decreases with time. If the rate of sedimentation is equal to or less than the designed rate, cost-effectiveness of the project from the sedimentation point of view is not under question since the expected life of the reservoir would remain as planned or more. However, when the rate of sedimentation is higher than expected, the economic life

Table 2. Sediment rates of some African rivers.

River	Catchment area ($km^2 \times 10^6$)	Average discharge (km^3)	Dissolved solids $10^6t/year$	Dissolved solids $t/km^2/year$	Suspended solids $10^6t/year$	Suspended solids $t/km^2/year$	Total land $10^6t/year$	% by solution
Niger (mouth)	1.24	200	13.8	11.1	19.4	15.6	33.2	41.4
Zairo (mouth)	3.70	1330	43	11.6	44	11.9	87	49.4
Nile (Cairo)	2.96	89	21	7.2	122	42	143	14.6

Source: Martins (1984).

Table 3. Reservoir sedimentation in China.

Reservoir	River	Catchment area (km^2)	Storage (m^3 × 10^6)	Sedimentation m^3 × 10^6	Years	% of storage
Sanmenxia	Huang He	688421	9700	3391	7.5	35
Qingtongxia	Huang He	285000	627	527	5	84
Yanguoxia	Huang He	182800	220	150	4	68
Liujiaxia	Huang He	172000	5720	522	8	11
Danjiangkjou	Hanshui	95217	16000	625	15	4
Guanting	Yongdinghe	47600	2270	553	24	24
Hongshan	Laohe	24486	2560	440	15	17
Gangnan	Hutuohe	15900	1558	185	17	12
Xingquiao	Hongliuhe	1327	200	156	14	71

of a reservoir reduces, which means that the economic effectiveness of the project may become questionable. Unfortunately, for many reservoirs all over the world, the rate of sedimentation has been seriously underestimated for a variety of reasons.

First, sedimentation is a complex process, and the present state of knowledge for forecasting the rate of sedimentation leaves much to be desired. Much of the work is empirical in nature, and there is considerable doubt over its validity in different agro-ecological zones and under different socio-economic conditions.

While some of the early studies on sedimentation were carried out in India, many of the recent analyses are from Europe and North America. Analytical techniques developed on the basis of empirical work in the western countries are often not applicable in various Asian and African countries for many reasons.

It should be noted that there are important differences between temperate climates where most recent erosion and sedimentation studies have been carried out and tropical climates (Biswas, 1985), which makes technology and knowledge transfer from one to another a hazardous process. For example, rainfall and temperature distribution patterns in tropical climates accentuate the soil erosion problem. The yearly average rainfall between London in a temperate climate and Sokoto on the southern border of the Sahel does not differ appreciably: 568 mm and 668 mm, respectively. However, when distribution of rainfall throughout the year is considered, the two cases are very dissimilar. The rainfall pattern of London is characterized by a low but reasonably uniform monthly rate over the entire year. It varies from a maximum of 61 mm in October to a minimum of 35 mm in April. Similarly, rainfall retained in the soil is reasonably uniform. The situation is very different for Sokoto where the rainfall is intense during July to September, but virtually non-existent between October to April. The rainfall varies from a maximum of 239 mm in August to zero between November and March. Furthermore, Sokoto has a significantly lower rainfall retention rate in the soil when compared to London. Thus, even though the total average annual rainfall in Sokoto is actually 15% higher than in London, its distribution throughout the year is very uneven, making Sokoto very arid.

Rainfall has a direct impact on soil erosion all over the world, but the potential ability of tropical rainstorms in causing soil erosion is far higher than rain in temperate regions. This could be attributed to the high kinetic energy of the tropical rainstorms when compared to the gentler kinetic energy of rainfall in temperate regions. Kinetic energy of rainfall depends on the size of drops, intensity and wind velocity. While long-term detailed data on tropical rainfall are not available, it appears that a median drop size of well above 3 mm is not uncommon. Drop sizes as high as 4.9 mm have been observed. From these data, a preliminary observation could be that the drop-size distribution of rainstorms is much higher in the tropics than in temperate regions.

Kinetic energy of rainfall is an important consideration since kinetic energy and the impact of raindrops initiates loosening and detachment of soil particles, the first essential step for soil erosion. Once soil is loosened, the particles are washed away, thus contributing to serious soil erosion problems.

So far as intensity of rainfall is concerned, it appears that its erosive power significantly increases at about 35 mm h^{-1}, which can be considered to be a threshold for erosion. Since more rainstorms in the tropics equal or exceed the level of this erosive threshold, the erosive potential is higher in the tropics when compared to the temperate parts (Hudson, 1971).

Another climatic aspect further contributes to soil erosion. The rainfall and temperature distribution patterns in tropical climates, especially in those areas having pronounced dry and wet seasons, accentuates the soil erosion problem. During the long dry season, there is some loss of topsoil due to

Table 4. Sediment load at gauging stations of Huang He and its tributaries in its middle reaches.

River	Drainage area (km^2)	Maximum annual sediment load		Maximum 5-day sediment load	
		Year	Load (tons × 10^6)	Load (tons × 10^6)	% of total annual load
Huang He	497559	1967	2460	814	33.2
Weihe	106498	1964	1060	400	37.8
Wuding	30217	1959	440	185	42.2
Beiluo	25154	1966	216	137	63.6
Kuye	8645	1966	303	228	75.2
Huangfu	3199	1959	171	97	56.8

wind erosion. However, far more damage is done during the onset of the rainy season. The vegetative cover, at the end of the dry season, is already reduced and often at an absolute minimum. Thus when a heavy thunder shower occurs, the water does not infiltrate into the soil as it might in light steady rain, and year after year soil erosion takes place due to surface runoff.

Another important factor in the tropics for predicting sediment yields is the instantaneous river discharge, and not discharge averaged over a period of time. It is not uncommon to find that one major flood in a river carries more sediment than the sum of all non-flood events during that year. Table 4 shows the maximum five-day sediment loads observed in some Chinese rivers, which represent 33–75% of the maximum annual sediment load.

Second, reliable hydrological, meteorological, geological and land-use data for most watersheds in developing countries are not generally available. At best, such data may be available for limited periods and for localized areas. Under these conditions, it is a difficult task to predict accurately the rate of erosion and resulting sedimentation from the entire watershed.

Third, all irrigation projects significantly change the prevailing land-use patterns. Cropping intensities increase, cropping patterns are changed and fallow periods are reduced or even eliminated. These changes directly affect soil loss from the area. Table 5 indicates how the rates of runoff and soil loss change under different vegetative covers in India.

The magnitudes of runoff and soil loss from grasslands also depend very much on their conditions in terms of livestock grazing. Studies carried out at Deochanda, India, indicate that overgrazing not only reduces grass cover but also deteriorates topsoil by compaction and loosening of soil particles by animal hoofs. Soil losses and runoffs from overgrazed areas are significantly higher than ungrazed

Table 5. Runoff and soil loss under different conditions in India.

Location, soil type, slope, rainfall	Vegetative cover	Runoff as % of rainfall	Soil loss (t/ha)
Dehradun, silty clay loam, 9%, 1250 mm (3-year average)	Grass (*Cynodon dactylon*)	27.1	2.1
	Bare fallow	71.1	42.2
	Bare and ploughed fallow	59.6	155.9
	Natural grass	21.2	1.0
Vasad, alluvial soil, 2%, 791 mm	Natural fallow	2.1	2.0
	Grass (*D. annulatum*)	1.1	1.5
	Tobacco	26.0	2.3
Sholapur, medium black soil, 1.18%, 607 mm (9-year average)	Natural fallow	4.8	1.3
	Bare fallow	19.8	43.0
	Shallow cultivation	22.5	60.4
Manjri, deep black soil, 3%, 627 mm (5-year average)	Bare fallow (weeds removed by cutting)	23.9	54.3
	Cultivated fallow	25.0	87.5
	Shorghum (winter)	16.1	60.5
Dehradun, silty clay loam, 11%, 1117 mm (2-year average)	Grass (*Cymbopogon citratus*)	11.0	2.31
	Cultivated fallow	16.2	18.46
	Strawberry	26.6	23.07
	Pineapple	10.5	8.44
	Pomegranate	33.5	16.39

Source: Adapted from Singh (1985).

Table 6. Runoff and soil loss from grasslands at different levels of grazing, Deochanda, India.

Conditions	Runoff (%)	Soil loss (t/ha)
Natural pasture, no grazing	11	0.40
Proper grazing	19	0.79
Overgrazing	27	2.37

Source: Singh (1985).

natural pastures. Results of the Deochanda studies are shown in Table 6.

Because of the above-mentioned and other problems, forecasting reservoir sedimentation in developing countries has been a complex and difficult task under the best of circumstances. Table 7 shows the designed and observed sedimentation rates for eight major reservoirs in India. It indicates that for these reservoirs, the average observed annual sedimentation rate is twice the designed value. It further shows that the average annual rate of loss in storage capacity due to sedimentation is 0.6% of storage volume.

It should be noted that while concentrations of suspended sediments depend on river discharges, the relationship between them is not necessarily one to one. Figure 1 shows the seasonal variations of discharge and total suspended solids for the Niger River for 1980–81. It shows that the peak sediment concentration was attained well before the maximum river discharge (Martins, 1984). While sediment load is highest during the rainy season, it appears that large amounts of fine sediments are washed to the river as flow starts to increase during the onset of the rainy season. Peak floods may, however, carry substantially higher bed load. The second sediment peak in Figure 1 could be due to atmospheric dust deposition from the surrounding desert.

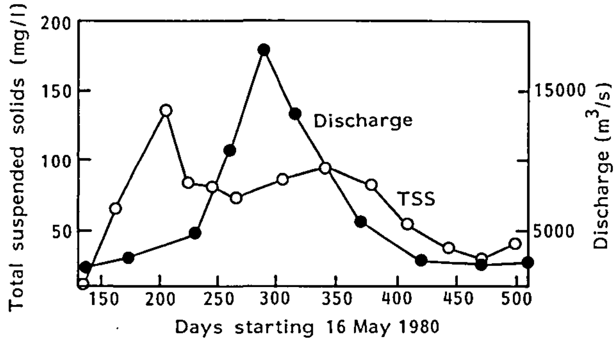

Figure 1. Seasonal variation of discharge and total suspended solids for the Niger River at Lokoja.
Source: Martins (1984).

Economic cost of sedimentation

The economic cost of sedimentation in rivers and reservoirs is quite substantial. While no reliable estimate is available, Mahmood (n.d.) suggests that on a global basis, reservoirs are losing storage capacity at the rate of 1% annually. Cumulatively it would mean a total annual water storage loss of 50 km^2, which Mahmood (n.d.) further estimates 'modestly' at $6 billion per year.

The 1% estimate in annual storage capacity loss of reservoirs is likely to be an over-estimate for larger reservoirs. Analysis of eight major Indian reservoirs shown in Table 7 indicates an average annual loss of 0.6%. Similarly analysis of 19 reservoirs in Central Europe, having storage capacities ranging from $1.5 \times 10^5 m^3$ to $23 \times 10^6 m^3$, indicated an annual storage depletion of 0.51% (Cyberski, 1973). According to Dendy *et al* (1973), storage losses in the USA due to sedimentation decrease with increase in reservoir capacities, and amount to about 0.16% for capacities higher than 10^9 m^3. In contrast, average annual storage loss for small reservoirs having a capacity less than 10 000 m^3 is 3.5%.

Table 7. Design and observed sedimentation rates for selected Indian reservoirs.

Reservoir	Year of impoundment	Storage capacity (million m^3)	Annual sedimentation rate (ha-m/100 km^2) Design	Observed[a]	Annual storage loss (% of volume)
Bhakra	1958	9 870	4.29	5.93 (1979)	0.35
Gandhinagar	1960	7 746	3.61	9.64 (1975–76)	0.29
Hirakud	1957	8 100	2.52	6.82 (1982)	0.68
Maithon	1955	1 357	9.05	12.38 (1979)	0.50
Mayurakshi	1955	616	3.75	16.48 (1969–70)	0.50
Nizamsagar	1956	456	2.38	6.37 (1967)	1.40
Panchet	1956	1 497	6.67	10.00 (1974)	0.65
Tungabhadra	1953	3 773	4.29	6.03 (1981)	0.45
Average			4.57	9.21	0.60

[a] Year of survey in brackets. Observed sedimentation rate is for the period between the year of impoundment and year of last survey for which data are available.

Sedimentation, especially in rivers, has another added economic cost in terms of dredging. It has been estimated that 376 × 10^6 m^3 of sediments are dredged every year from the water bodies of the USA at annual costs of more than $300 million (M.R. Biswas, 1979). In Bangladesh, its three major rivers – Ganges, Brahmaputra and Meghna – carry an annual sediment load of some 2.4 billion tons, and Bangladesh Inland Water Transport Authority has to carry out every year nearly 0.8 million m^3 of maintenance dredging and 2 million m^3 of capital dredging at substantial cost (Biswas, 1987).

Changes in streamflow pattern

Changing land-use patterns in a watershed affect streamflow. The magnitudes and durations of such variations depend on a variety of geo-hydrological, meteorological and agro-ecological factors. Because so many factors affect streamflow regimes, it is very difficult to determine the specific changes that may have occurred due to alterations in land-use practices in the watershed. Table 5 shows changes in runoff due to differing vegetative covers under experimental conditions in India.

Probably the most quoted example of changing streamflow patterns due to alterations in upper watershed vegetations is that of Bangladesh. Writers of popular articles like Eckholm (1976) and Myers (1986) have made it a 'conventional' wisdom that deforestation and land-use changes in the Himalayas in Nepal have contributed to higher flood runoffs and sediment loads during the monsoon season and lower dry-weather flow in rivers like the Ganges and Brahmaputra in Bangladesh. It has been further claimed that flooding in the Gangetic plain has systematically increased, both in terms of frequency and magnitude, during the past 50–100 years, and the devastating flood of 1988 in Bangladesh could be directly attributed to deforestations in the Nepalese Himalayas.

While this hypothesis has considerable public appeal and is quoted quite frequently in the present era of environmental consciousness, the following points are worth noting.

- There is very little reliable and replicable data which can prove or disprove the hypothesis categorically.
- Deforestation in Nepal was already well advanced by the middle of the eighteenth century, and in the Middle Mountains, which is the most densely populated region, all arable land had been converted by 1920–30. Little reduction in forest cover has occurred since 1930 (Ives, 1989).
- Geologically, the Himalayas is a young mountain range, and has some of the highest erosion rates of the world.
- Preliminary studies by Gilmour *et al* (1987) indicate that soil erosion and flooding are not necessarily due to deforestation, and are not likely to be significantly reduced by afforestation.
- High economic losses in recent years in the plains of Bangladesh can be attributed to a significant extent to rapid population growth, and a consequent high level of economic activity. Thus, floods of a given magnitude will create a much higher level of damage at present than, say, 25 years ago.

It is not possible at the present state of knowledge to make cause-and-effect linkages between deforestation in the Himalayas and increased flooding and high sediment loads in rivers in Bangladesh. Urgent scientific studies are needed to determine whether flooding in the plain has actually increased in recent years, and if it has increased, to what extent deforestation in the Himalayas has contributed to this impact.

Management practices

The main emphasis of watershed management at present has been to reduce sediment generation in the catchment area so that storage losses of reservoirs can be kept to an acceptable level. To this extent, the main management alternatives have been to increase forest cover in the upper catchment areas, develop and implement appropriate land-use policies and prevent overgrazing. In general, the results of such policies, even when they are carried out properly, take time to be visible. For example, if afforestation is practised, some improvement may be noted in about a decade or so.

One of the major difficulties of watershed management, which has not been addressed thus far, is to what should the cost of such practices be charged. The present tendency has been to charge the entire management cost to the water development project itself. This raises a fundamental question. Should afforestation costs be charged entirely to water projects, even though much of the deforestation damages may have occurred well before the project was designed? While benefits to water projects of afforestation are undeniable, society benefits from such practices in many other ways as well. If the entire cost of such afforestation is charged to a project, it may – in certain cases – no longer be economic and thus may never be built. The real question is what percentage of afforestation costs are attributed to a water project and on what basis? The debate on such vital issues has not yet even started.

A second difficulty is institutional implications. Water projects are within the jurisdiction of the Ministry of Water Resources, whereas forestry generally belongs to the Ministry of Agriculture or the Ministry of Environment. Very seldom has interministerial coordination been effective in any developing country to ensure rational watershed management practices are implemented during the early stages of the project. Because of the long time interval needed between the beginning of an afforestation process and some observable impacts, afforestation should be initiated during the planning phase of a project. One would, however, be hard pressed to identify even a single major water project where such practices were implemented systematically in the planning stage.

Check dams

Even when afforestation has been practised in the upper catchment, sediments will still be generated by natural processes and by accelerated agricultural activities due to the introduction of irrigation. One of the alternatives available for sediment and water control has been the use of check dams. Check dams are generally small and low dams which are built across gullies and streams to store flood runoff. The practice has successfully been used for many centuries in rural areas of several countries like India, China, Sri Lanka, Mexico and the USA. Basically check dams provide upstream storage of flood waters, which may be used subsequently for irrigation and livestock.

Check dams could range from relatively simple structures built with stones, gravels and clay to fairly elaborate and sophisticated rockfill dams with concrete spillways. Many of the early check dams were simple structures that were built across narrow valleys, having somewhat impervious rock or soil strata. These dams required very minor changes in the local topography, and accordingly could be constructed relatively quickly with low financial investment as well as limited labour input. These dams not only controlled the flow of water, but also sediments carried by flood waters. With the reduction in flow velocities by the presence of these dams, the rates of soil erosion are also reduced. Construction of a series of check dams on a gully or stream can significantly reduce the overall rate of soil erosion. Furthermore, as the flow velocities are reduced, sediment present in flood water is deposited behind such dams.

As the silt deposited on the river bed increases every year, after a period of time a very fertile area is available for cultivation, especially when the stored water disappears. Thus, check dams are structures which can not only harvest seasonal flood waters but also contribute to soil and moisture conservation.

While check dams have been used for centuries, their use in recent years for water and erosion control is receiving increasing attention in countries as diverse as China, Nepal, India and Ethiopia. In China, check dams have been very successfully used in many areas.

A good example of the use of check dams for water and erosion control can be found in the Jiuyuan Gully in Suide County, Shanxi Province, China. The Gully is a small tributary of the Wuding River, which in turn is a tributary of the Huang He (Yellow River). The length of the main channel of the Gully is 18 km and it has a catchment area of 70.1 km^2, of which 2 130 ha is used for agricultural production. Some 10 000 people live in this rural area and agriculture is the main source of livelihood (United Nations Environment Programme, 1983).

Water and erosion control was the most serious problem facing the Jiuyuangou Peoples' Commune in the Gully catchment area. The catchment has a high gully density of 5.34 km per km^2. Before a control programme was initiated, the rate of annual soil erosion from the catchment was estimated at 1.27×10^6 tonnes, which was equivalent to an average soil loss of 18 116 tonnes/km^2. Because of the high silt content of the water in the gully catchment, it could not be used efficiently for irrigation.

The Commune initiated a combined programme of contour farming and check dams. By 1974, 727 ha of land had been provided with contour farming. In addition, 311 small and medium check dams were constructed, which primarily acted as silt traps, and 30 small reservoirs were built to store a total of 1.18×10^6 m^3 of water for irrigation. The general plan of the Jiuyuan Gully catchment is shown in Figure 2.

The construction of this series of small- and medium-size check dams had a remarkable impact on the water use and erosion rates of the area. The irrigated area increased to 170 ha, which was eleven times the pre-construction period figure. The flood peak in the Gully was 90% less than before and the average annual soil loss decreased by 770 100 tonnes, which was a reduction of nearly 60%. This meant that the total agricultural production in the area increased by 2.3 times within a period of only two decades.

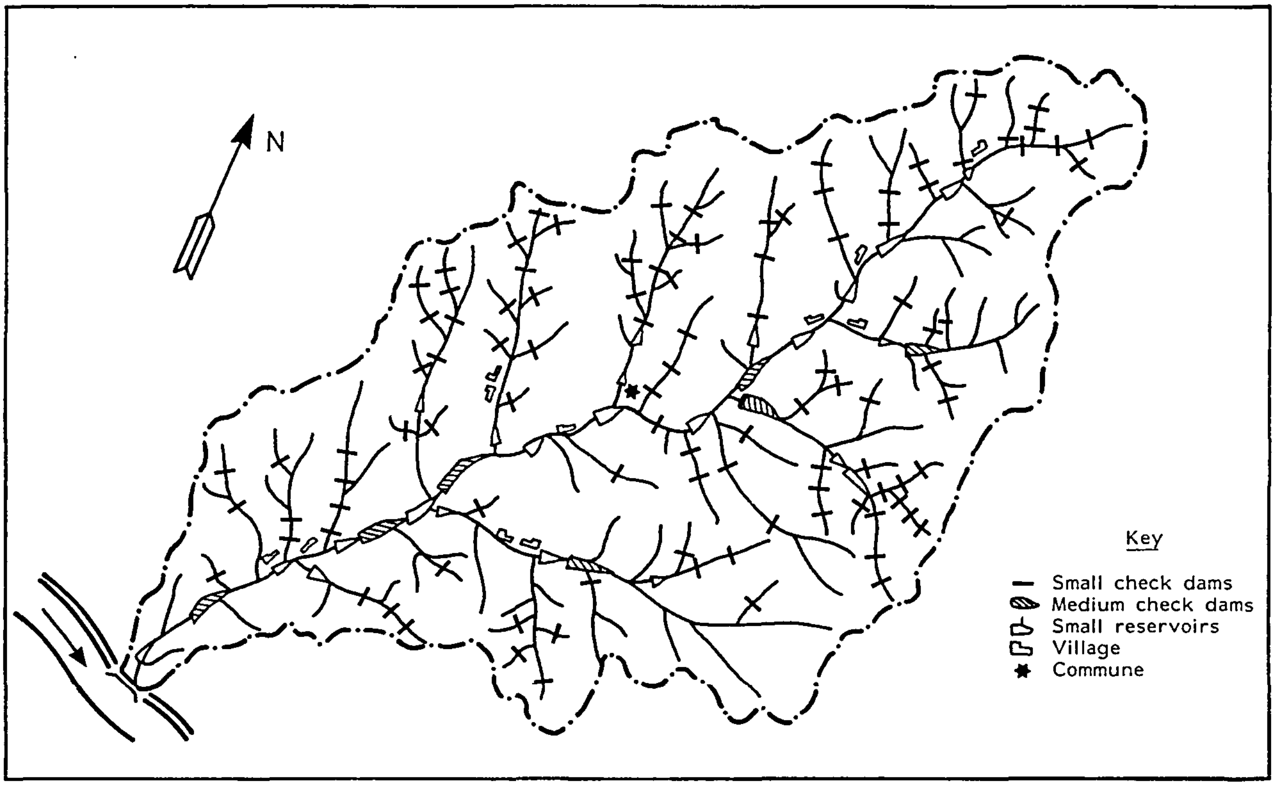

Figure 2. Use of check dams in the Jiuyuan Gully Catchment Area, China.

Because check dams are small and widely dispersed over rural areas in many arid countries, it is not possible to comment on their overall efficiency. Furthermore, the check dams are often constructed by local people, based on past experience and broad rules of thumb. Thus, there are numerous types of such dams, based on different 'design' parameters, located in an immense variety of site-specific topographical and other physical conditions. Their maintenance often differs from one location to another. In addition, not even a single country has made a national survey of these dams. Under these conditions, only some general comments can be made on their advantages and limitations.

Check dams, when they are properly designed, constructed and maintained, can be considered to be a very useful small-scale alternative for water and erosion control in rural areas of arid and semi-arid countries. They are easy to design, construct and maintain. Labour and capital requirements are minimal, certainly significantly less than other sophisticated hydraulic structures. This means individual households or small communities can afford to build these dams without external assistance. Foreign exchange is generally not necessary, which could be an important consideration for many debt-laden developing countries at present. These simple structures can be constructed within a very short period of time, compared to large dams where the gestation periods are often more than a decade. Large-scale centralized institutions are not necessary for their construction, operation and maintenance. Also a series of such dams in an area can be developed incrementally.

Check dams have many limitations as well. They provide unreliable and discontinuous supplies of water, which means communities must have access to other alternative sources of water. Because of their decentralized nature, they often suffer from poor quality of design, improper construction and inadequate maintenance. Frequent repairs are necessary, but these repairs can be carried out quickly and within a limited cost. Many check dams are very vulnerable in terms of water quality contamination, and they often act as the main foci of water-borne diseases, especially those transmitted by mosquitoes.

Concluding remarks

Watershed management has become an important consideration for sustainability of water development projects. While the desirability of good watershed management is not in doubt, achieving it is not an easy task. It would require simultaneous achievement of many tasks, among which are afforestation, strict control of land-use practices, and more emphasis on small-scale structures like check dams for better soil and water conservation. Land-use practices are generally very sensitive issues in most countries, at least politically, and thus to what extent it may be possible to develop and implement a rational land-use policy is always difficult to predict. Furthermore, since watersheds of medium and large-scale projects cover large areas, ensuring appropriate land-use practices over entire catchment areas may not be a feasible process.

It should also be noted that afforestation of degraded lands needs substantial capital investment in early years, with no direct financial return to the investors. Thus, in most developing countries the governments would have to play the main role in afforestation, and/or subsidize private efforts substantially. Many governments are unlikely to give it priority at present in terms of investment because of their current economic conditions as well as financial requirements for other competing activities.

However, for most countries, watershed management should not be viewed from the narrow perspective of benefits to water projects alone: it should be considered to be essential for soil and water conservation, which in the long run will enhance the prospect of self-reliance of nations in terms of food, fibre and energy. Viewed in this holistic perspective, watershed management has to be considered to be a priority activity.

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