Reduction of Mangla Reservoir Sedimentation by Watershed Management

By

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An extremely serious erosion problem exists in the catchment area of the Jhelum River above Mangla Dam. The major aspects of the problem are that valuable land resources are being destroyed and that the high sediment inflow to Mangla Reservoir will rapidly deplete its water storage capacity.

WAPDA has established a Watershed Management Project to study methods of reducing erosion and to establish pilot and demonstration areas. WAPDA also commissioned Hunting Technical Services of the U.K. to prepare a report appraising the problem, suggesting methods for relief, and evaluating the economics of erosion control.

The Problem.

The erosion problem in the Mangla draingae basin is described in Hunting's report and other literature and will be only briefly summarized here. The drainage area of about 13,000 sq. mi. varies from deep silt deposits in the south through gravel foothills, steep mountain ridges with much shale, to high granitic mountains in the north. Geologically, the main river and its tributaries are young and erosion is actively wearing down the basin.

The southern, right-bank area, which is drained by the Kanshi River, is made up primarily of deep deposits of wind blown silt or loess. Vegetative cover is generally sparse and farming practices are poor from the standpoint of erosion control. Precipition during the monsoon season can be very intense ranging up to several inches in an hour. All these factors combine to cause severe erosion in the form of gullying and sheet erosion (sheet erosion is erosion caused by overland flow before the water enters a definite channel).

1960 suspended sediment transport in the Khanshi was approximately 4.8 million tons—8% of the 58 million ton total at Mangla from 3.6% of the Mangla drainage area.

Further north on the right bank are steep foothills and fairly high mountains known as the Murree Hills. Much of this area is forested but

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the land is being used more and more for agriculture and grazing. Much of the rock is easily erodible shale which gives a characteristic red color to streams originating in this area. No sediment records are available. It is likely, however, that this area produces a disproportionately high sediment runoff.

The left bank drainage area lies in Azad and occupied Kashmir. The area is mountainous but has a considerable depth of soil mantle whose erosion is being accelerated by intensified agricultnre. The largest tributary from this area is the Punch River whieh in 1960 transported approximately 10.7 million tons of sediment—18% of the total at Mangla from 9.7% of the drainage area.

The Kunhar and Kishanganga (Neelum) Rivers enter the Jhelum near Muzaffarabad. Both these rivers drain high mountain valleys in which a large part of the runoff is from melting snow and glaciers. Land slides and avalanches are quite common in these valleys and probably produce much of the sediment. The Kunhar River in 1960 transported approximately 4.2 million tons sediment—7% of the total at Mangla from 6.6% of the drainage area.

The drainage area of the main stem Jhelum above Muraffarabad is mostly in occupied Kashmir. No comparable sediment records are available but it is probable that the rate of sediment production from this area is less than the average for the entire basin. Erosion is no donbt taking place but the river flows through a large lake in the Vale of Kashmir which probably acts as a sediment trap.

Binnie, Deacon and Gourley, Mangla Project consultants, have estimated the mean annual sediment load of the Jhelum at Mangla to be 63 million tons, of which 7 million tons are assumed to be bed load. This amounts to 5200 tons per square mile of drainage area per year. For comparison, the average sediment production of the Colorado River above Lake Mead is 1040 tons/sq. mi. and that of the Rio Grande above Elephant Butte Reservoir is 854 tons/sq. mi. *The only major U.S. river for which comparable sediment production could be found is the Salt River above Roosevelt Lake with 5100 tons/sq. mi.

A very significant consideration is whether sediment transport has been increased above geological rate by activities of man and how much. Presumably it may be possible to eliminate at least a portion of the sediment produced as a result of man's activities. According to revenue statistics, the population of the southern-most portion of the basin has increased significantly during the past 50-75 years. Most significant is the statement that this area concentrated on production of livestock with its associated grazing.

As a result of the conflict in Kashmir, the population density in Azad Kashmir has also increased significantly and agriculture is being

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**From Brune "Trap Efficiency of Reservoirs" Trans. AGU, June 1953.*

carried cut in very marginal areas, particularly on steep slopes. Sediment production of mountainous northern regions probably has not increased significantly over geologic conditions except in small areas. Little is known about conditions in occupied Kashmir, although it has been inferred that erosion in the area has increased mostly due to deforestation and unrestricted grazing.

Possibility of Sediment Reduction.

Past experience, particularly in the United States, indicates that a reduction in sediment transport can be accomplished through soil conservation techniques. It is impossible, however, to predict the extent of reduction of sediment transport with any sort of accuracy. It is certain that very extensive conservation activities are required before a significant decrease in sediment can be expected.

Soil conservation with respect to alleviation of river sediment transport can be classified into two broad fields. One is land management which seeks to reduce erosion by improvement in agricultural and other land-use practices. The other is the construction of erosion control works, flow detention works, and sediment trapping structures.

Improvements in land management are basic to any program to reduce sediment in the rivers above Mangla. Land use practices in the Mangla basin at present are generally very poor with respect to erosion control. Large areas are denuded by unrestricted grazing especially by goats. Demonstration areas prove that grass, shrubs, and trees will grow and survive if grazing is restricted and cutting is controlled. Vegetative cover under the best conditions appears to be rather thin and cannot be expected to completely eliminate erosion.

Tilled fields on sloping lands are usually terraced but the terraces are generally poorly levelled, bunds are too low, and adequate overflow c ntrol is not provided. Many fields are left fallow for various periods to store up moisture for eventual cropping. These fields are frequently plowed for weed control and present absolutely bare, loose soil for rain erosion. Terraces in the mountainous areas are often poorly made on extremely steep slopes. Failure of an upper terrace during heavy rain will usually cause successive failures of all the terraces below. The removal of natural vegetation in favour of tilling on the steep slopes in Kashmir has caused heavy erosion.

A serious problem in the forested areas is ground fire. Forest fires which involve burning of the trees themselves are rare but burning of the ground cover in the forests is very common. Trees themselves help to furnish structural stability to slopes but have little effect in controlling sheet erosion. Uncontrolled grazing in forests may have the same effect as burning.

Improvements to land management must be approached through education, sociology, and psychology. Farmers must be convinced of the benefits of improved practices, particularly the benefits which will accrue directly to the farmer himself. Legislation giving conservation agencies the power to manage communal grazing lands might be desirable.

The Mangla Watershed Management Project is active in the field of land management in pilot areas and has had commendable success. The Project wisely selected an area near Gujar Khan in which some pilot revegetation areas had been established some years before by the forest service. The neighbouring farmers were aware of the success of revegetation by controlled grazing and were willing to co-operate with project staff. The expense of improvement to land management should be relatively minor. Since it is primarily an education program, few materials are needed and costs are almost wholly limited to staff salaries and organizational expenditures.

The "engineering works" phase of the watershed conservation program seeks to repair damage already done. In this discussion, "engineering work" includes all treatment work physically carried out by the Project at the expense of the Project contrasted to these measure carried out by farmers and land owners at their own expense. Works which have been carried out include planting, construction of check dams, and construction of detention reservoirs.

That planting of grass, shrubs, and trees on unused land of the type prevailing here will reduce erosion is generally accepted. This treatment is relatively cheap and if well planned and maintained, has excellent prospects of success.

Gully erosion is well developed in many areas and more expensive remedial works must be undertaken to stop its advance. Once gullying is stopped, land management and maintenance of vegetative cover should maintain stability. The reduction of sedimentation by check dams is difficult to evaluate. The chief function of a check dam is to dissipate the energy of flowing water in a non-harmful way. Check dams can be effective in reducing and controlling erosion at the heads of gullys and also in controlled dissipation of energy in streams draining steep slopes. Check dams are not intended to trap or store sediment to keep it from getting into the reservoirs.

Control of erosion and reduction of sediment production must proceed downward through a drainage basin. If check dams are built to control erosion in gullys and rills, works must also frequently be built to control the stream and river channels. A sometimes unexpected consequence of upstream erosion control works is that the relatively sediment-free water appearing in the main channels has increased erosive power and bank cutting and bottom scouring begin. From the standpoint of the downstream reservoir. there is no improvement if the sediment from land erosion is replaced by sediment from channel erosion. Low, weir type structures can be built across stream beds to serve as control points to prevent general channel deepening and bank protection works such as spurs and revetments can be built to control horizontal cuttting. Channel control works are quite expensive. The need for and type of channel protection structures depends upon the bed material, the river gradient, and other factors so each sub-area must be considered individually.

A measure often proposed for the reduction of reservoir sedimentation is the construction of silt trapping dams upstream from the reservoir. Building a separate dam for the storage of sediment is seldom economical when compared to the cost of obtaining the same volume of incremental storage by making the main dam slightly higher.

Several small detention structures have been built in the Gujar Khan demonstration area. They can be justified for other purposes but serve to reduce downstream erosion only slightly by reducing flood peaks. Considerable experience with structures of this type in the United States has indicated that they have relatively little affect on major flood peaks. These structures are of great value, however, as a perennial source of water for human and animal consumption and when the pond eventually fills up with sediments, a high quality agricultural field will have been formed.

Anticipated Effect of Watershed Management

As far as WAPDA is concerned, the principal object of the Mangla Watershed Management Project is to reduce the rate of sediment inflow to Mangla Reservoir. The watershed management consultants (Hunting) have proposed that the completed program will have the effect on sediment inflow tabulated below :

Basin	Area	Sediment million tons/year Present	Future	Percent Reduction
Kunhar	940 mi.^{2}	3	2.5	17 %
Kishanganga	2849	7	6	14
Upper Jhelum	5530	22	20.5	7
Punch	1630	15	9	40
Lower Jhelum	1930	14	5	68
		61	43	30

The estimate presented above by Hunting Technical Services is based mostly on judgment because there is no analytic way be which a forecast of sediment reduction could be determined. It must be kept in mind that the above reductions apply only after the watershed management project has been completed which will be many years.

The above table indicates that complete management of the Punch (portion acceasible to Pakistan) and Lower Jhelum areas would account for 25% out of the 30% potential sediment reduction. In other words, improvement of these two basins would account for 83% of the possible reduction.

No data exist by which the proposed reductions can be proved or refuted. In the opinion of the writer they are not unraesonable and should be used as a basis for evaluating the project until better forecasts become available.

The effects of watershed management programs on sediment production have been determined elsewhere in the world, particularly in the United States. There is no inherent reason why measure used in similar areas elsewhere should not work in the Mangla Basin. It is suggested that the proposition that sediment production will be reduced by conservation practices be accepted.

Few quantitive data on the reduction of sediment production by conservation practices are available even in the United States. A paragraph from "The Flood Control Controversy" by Leopold and Maddock, Ronald Press, 1954 is quoted :

"The flood control reports of the Department (of Agriculture) do not present curves...showing the reduction in sediment production due to land treatment. The effect, however, is of a higher order of magnitude than that indicated for reduction of volume of runoff. Examples are given below of the estimated reduction, resulting from the upstream program, of sediment carried by rivers. For the Trinity basin, Texas, it is estimated that the sediment deposition in reservoirs would be reduced 40 to 60 percent by the program. For the Little Sioux basin, Iowa, farmland treatment is expected to reduce erosion 50 to 60 percent, and the complete program, including gully structures, is estimated to reduce the sediment discharge from gullies by 90 percent."

Chapter 10 of the above mentioned book has a considerable amount of pertinent information on the effectiveness and economics of land reclamation programs in the U.S. Most available data are for small drainage basins. Quoting "Water—Department of Agriculture yearbook—1955", Pg. 143, "A.........study in 1952 showed that measures to improve the watershed, and control erosion had effected a reduction in sediment yield of 33 percent from the watershed, which covers 1,666 square miles, above Lake Waco, near Waco, Texas". A chart on Pg. 207 of the same book indicates a reduction of mean annual suspended sediment concentration from about 350 ppm. to about 80 ppm., over a period of 22 years, in the Chattahoochee River at Atlanta, Georgia (D.A.—1450 sq. mi.) as a result of improved land management.

Economic Considerations.

The economic benefit of watershed management should be considered in two ways. One has to do with the ratio of financial return to financial expenditure. The other considers the fact that, unless watershed management is carried out, a national resource may be irrevocably lost. The economic considerations of the Mangla Watershed Management Project are further complicated by the fact that both land erosion and reservoir sedimentation are involved. It is almost impossible to aportion the benefits or costs of watershed management fairly between the two functions.

It is the general experience of U. S. watershed management projects that about 90% of the financial benefit of erosion control accrues to the land and only 10% to downstream benefits such as sedimentation reduction. There is no reason to believe that this ratio would be far different for the Mangla watershed.

The following table presents Hunting's estimate of the project economics on what is assumed to be an annual basis :

Output,	*Present.*	*Future.*	*Increment*
Agriculture	Rs. 488 Lakh.	Rs. 754 Lakh.	Rs. 266 Lakh.
Live stock	341	247	−94
Forestry	88	346	258
Reduced sedimentation		50	50
Reduced land loss		12	12
Total benefits =	917	1409	492
Costs.			
Agriculture and Livestock	Rs. 361 Lakh.	Rs. 429 Lakh.	Rs. 68 Lakh.
Forestry	13	52	39
Engineering (structures)		355	355
Population re-location		19	19
Administration		19	19
Total =	374	874	500

The cost-benefit ratio according to Hunting's table is about one-to-one. Incremental benefits to sediment reduction are estimated to be 11% of the total incremental benefits. This proportion corresponds to U. S. experience mentioned above.

The benefit under principal consideration in this discussion, reduction in sedimentation, has been determined from the estimated sedimentation rates and cost of storage in Mangla Reservoir. Hunting used Rs. 360 as the cost per acre-foot of Mangla storage. Recent revisions to the Mangla Project cost estimate indicate that the cost per acre-foot will be between Rs. 400 and Rs. 450. The proportionate increase in Hunting's estimate of reduced sedimentation benefits would be from Rs. 50 lakh to about Rs. 60 lakh. This change has a negligible effect on the overall cost benefit analysis.

Summary and Conclusions.

An extremely serious erosion problem exists in the catchment area of the Jhelum River above Mangla damsite. Agricultural and forest lands are being destroyed by erosion and the resulting, sediment transported in the river system will rapidly deplete the water storage capacity of Mangla Reservoir.

Certain areas within the Mangla catchment are subject to erosion rates far above the basin average. In most cases, these areas of severs erosion are areas where poor land management practices have caused a marked increase in erosion rates in the past century. It is physically possible to reducc erosion rates in these areas through proper land management practices and construction of erosion control works.

It is not possible to predict quantitatively the extent of sediment reduction which may be achieved. The benefits to the land as a result of a watershed management program can, however, be predicted with reasonable accuracy. The general experience elsewhere with programs of this type has been that about 90% of the benefit is to the land and agriculture and about 10% of the benefit is in reduction of downstream damages. The benefits estimated by Hunting Technical Services for the Mangla catchment are also in about the same proportion.

The cost-benefit ratio of a watershed management program was estimated by Hunting to be about one-to-one. The irretrievable loss of land resources and of reservoir storage potential must be considered in addition to the strictly financial aspect of the proposed watershed management project.