Sedimentation
Watersheds

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SOLVING SEDIMENTATION PROBLEMS IN AGRICULTURAL WATERSHEDS

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The damages caused by sedimentation and its many restricting effects upon our environment are tremendous. You are probably aware of some of the damages and limitations, but here are a few reminders:

1. More than 50 percent of our cultivated land is susceptible to serious erosion (15). Loss of topsoil may reduce the soil's fertility and its ability to maintain a good protective cover (Figure 1).

2. Removal of the absorbent topsoil usually exposes the less pervious subsoil, causing more storm runoff and aggravating downstream flood problems (10).

3. Sediment plugs channels and increases water-surface elevations, thus creating and/or intensifying floods (Figure 2).

A few years ago, Louis Gottschalk (5) reported that the current flood damage in the United States was more than $900 million annually, of which a sizeable portion is chargeable to sedimentation. In Johnstown, Pennsylvania, following the flood of March 17, 1936, it cost $3,870,000 to remove the sediment and debris from streets and cellars. Imagine what this cost would be today!

4. Deposition of infertile sediment damages crops and reduces the productivity of our normally fertile flood plains (5) (Figure 3).

5. Conservation projects rapidly lose their usefulness and efficiency unless sedimentation has been given adequate consideration in the planning.

6. Sediment in streams or lakes often obscures light needed for aquatic plant growth and smothers fish eggs (3).

7. Eroded material fills natural and artificial channels, waterways and harbors (14). Removal of this sediment is very costly.

8. Sediment deposits decrease the capacity in our major reservoirs by at least 1 million acre-feet each year (4). This reservoir volume is large enough for a water supply for a city of 5.5 million people (14). Such deposits in reservoirs also rob space needed for flood control and water power development.

9. Sediment hinders the function of irrigation and drainage ditches.

10. Sedimentation ruins river, lake and other recreation facilities (Figure 4).

11. Sediment ranks with domestic and industrial wastes as a major source of water pollution (14). It is estimated that the suspended-solids load carried into the nation's streams by surface runoff is at least 700 times the load caused by sewage discharges (11). Such volumes require water treatment costing about $70 per million gallons of water (11).

Because of the tremendous damage it causes and its many restricting effects, the sedimentation problem makes an impact in one way or another upon the environment of the majority of humanity and thus warrants action by soil and water conservationists. The powerful forces of sedimentation must be managed properly. This can be done effectively when the processes and the forces at work are understood.

Sedimentation--General

The term "sedimentation" encompasses the processes involved in erosion, transport and deposition of eroded materials. Water is involved in each of these components. The flow of water causes erosion. Water is also the transporting vehicle, and a decrease in the velocity of the flow mixture causes deposition of sediment. Water, then, is a key to the control of sedimentation. Since the components are interrelated, they must be studied as a unit for maximum conservation and remedial results.

Since all the processes of sedimentation occur in a watershed, it is a natural basic unit for studying the entire sedimentation system.

Sedimentation--System

Erosion

Erosion was the first process mentioned. It is the initial phase of the sedimentation system. "Normal" or geologic erosion and wind erosion will not be discussed. Attention will be limited to accelerated, water-induced erosion brought about by man (12).

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the Proceedings of the 22nd Annual Meeting,
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This accelerated erosion takes place mainly as sheet and upland gully erosion. Rill erosion is included with sheet erosion. Rills are caused by minor concentrations of runoff and are usually obliterated by normal field operations.

Much effort has been made to determine methods of measuring and predicting field soil loss. Wischmeier and Smith and others have done a marvelous job in analyzing the many years of erosion plot data. Their universal soil loss equation is extremely helpful in predicting field erosion and planning conservation methods to limit erosion (18). Rill erosion, however, is not included entirely and must be measured or estimated separately. Furthermore, although the amount of erosion expected from a plot or field of uniform slope, length, soil, etc., can be determined, we do not know how to calculate the field erosion when the runoff from one field crosses several fields and where there are changes in the slope within a field. Some research has begun on this aspect, but much more needs to be done.

Sediment production rates for small watersheds vary widely because of the great contrast in erosion factors among small areas. There is also a large variation in sediment yields between large and small areas. The annual sediment yield for the Mississippi basin is about 400 tons for each square mile of drainage (10). In contrast, Gottschalk and Brune (6) reported a rate of 127,000 tons per square mile per year from small, intensely cultivated watersheds in western Iowa.

John Wark (16) and a number of others[1] reported that the sediment yields in areas undergoing urban growth are 10 to 50 times greater than those in rural areas, the rate depending on the intensity of construction activities. The long period of bare soil exposure during construction of residential areas, commercial enterprises and highways is a major cause for the high rate of sediment production in such areas.

This is a problem that will intensify if the urban areas in the United States double in the next century, as predicted. Already, contractors in some areas must explain how they will handle the sedimentation problem before they are given permission to develop a large area. The problem is also aggravated by the fact that as much as 90 percent of the annual sediment

[1]From a paper by L. L. McDowell and E. H. Grissinger, "Pollutant Sources and Routing in the Watershed Programs," presented at the 21st Annual Meeting, SCSA, August 14-17, 1966, in Albuquerque, New Mexico.

Figure 1. Serious sheet and rill erosion.

Figure 3. Floodplain ruined by infertile sediment.

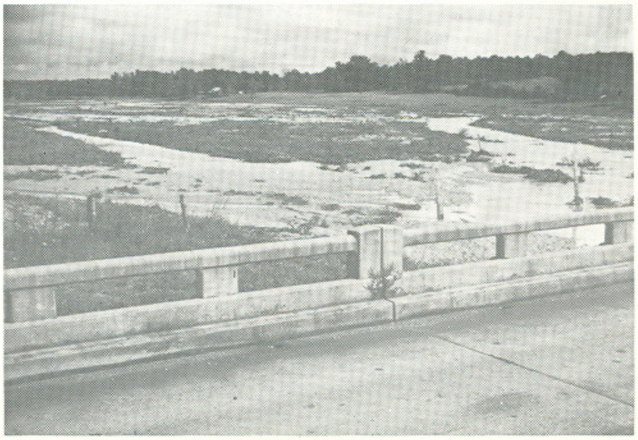

Figure 2. Sediment-plugged channel.

Figure 4. Recreation sites destroyed by sediment.

load is sometimes discharged during 10 percent or less of the time.

The problems of rill erosion, gully growth, urban land erosion and the erosive effect of water crossing a number of different fields or a field with several different slopes must be studied more extensively. The erosion part of the sedimentation cycle must be better managed. Control is possible. This is shown by the data in table 1[2], which summarizes some 1965 data from the Agricultural Research Service research watersheds near Treynor, Iowa. Here, runoff and sediment yield from the highly erosive soils of western Iowa have been reduced drastically by conservation measures. The Treynor watersheds received more than 21 inches of rain in less than 30 days during this past May and June. The level terrace system performed very well.

Ronald Renne[3], director of the Office of Water Resources Research, also has stated that conservation practices have a profound effect on sediment yield.

Transport

The second process of sedimentation is sediment transport, which is the movement of eroded material through space and time until it is deposited permanently. Sediment transport occurs in two ways, as suspended sediment and as bedload (10).

The type and size of material in transport are influenced largely by the sediment source. The finer materials usually come from sheet and rill erosion and the coarser materials from gully and channel erosion. Each is an important part of the overall system. Included with channel erosion are stream bank erosion, valley trenching, roadside erosion and floodplain scour.

The fine materials, such as clay and colloids, are generally distributed throughout the flow cross section. The silts are also distributed in this way in turbulent flow but normally increase in concentration with depth of flow. Coarser materials, such as sands, gravels and cobbles, usually move next to the bed as bedload; however, under conditions of turbulence and high velocity, they may also become suspended.

A large part of the material carried out of fields as sheet and rill erosion remains in the watershed as colluvial deposits. These deposits are usually located in areas where the land slope or transport capacity of flow has decreased suddenly. Sediment transport also includes the movement of sediment through nonincised channels, where much of the eroded material is deposited.

Watershed sediment trapping is increased by natural and manmade objects, such as fences, grassed waterways, bridges, trees in the channel, etc., which slow the flow of the water-sediment mixture. These lower the percentage of the total eroded material that leaves the eroded area. That is, watershed trapping lowers the sediment delivery ratio of an area.

The amount and type of bedload moving through a reach of stream vary with the flow and have an important bearing on the stability of channels. If the flow becomes overloaded with bed materials, deposition occurs. If the load is too small, however, the flow erodes the channel bed or walls in an effort to obtain a state of equilibrium between erosion and deposition.

Many channels have been straightened in an attempt to avoid excessive deposition in the channels themselves. This can, however, have an undesirable effect. In many cases this has caused the channels to degrade and really "chew up" the topography all the way to the headwaters. Also, such action usually causes a lowering of the water table. Examples of this are the Blue River in Nebraska and Willow Creek[4] and others in Iowa.

Channel degradation induced by conservation measures that reduce erosion more than

[2]From a paper by Keith E. Saxton and R. G. Spomer, "Conservation Effects on the Hydrology of Loessal Watersheds," presented at the 60th Annual Meeting of the ASAE and the Canadian Society of Agricultural Engineering, Saskatoon, Saskatchewan, June 27-30, 1967.

[3]From a paper by Roland R. Renne, "Research Guidelines to Sound Watershed Development," presented at the Irrigation and Drainage Specialty Conference, ASCE and ASAE, Billings, Montana, October 7, 1965.

[4]op. cit., footnote 1.

Table 1. Data summary for Treynor, Iowa watersheds, 1965.

	Field-contoured Corn	Grass	Level-terraced Corn
Drainage Area (acres)	82.6	107.0	150.0
Rainfall (inches)	44.4	44.3	44.9
Water Yield (inches)	13.65	9.22	13.07
Surface Runoff (inches)	10.69	4.61	2.52
Base Flow (inches)	2.96	4.61	10.55
Sediment Yield from Sheet Erosion (tons/acre)	44.4	1.2	1.0

runoff has been discussed by numerous authors including Roehl[5], Happ (7), Einstein (1), and Willis (17). One example is the channel degradation immediately downstream from Power Line Dam near Oxford, Mississippi. The channel degradation there was 7 feet in a 7-year period and is measurable for a distance of at least 2,000 feet.[6]

There are times, however, when the presence of sediment has a beneficial effect. For instance, sediment movement by water reduces the amount of energy available for further erosion.

Any condition that changes the sediment load or characteristics of flow will affect channel stability. Changes in channels below conservation works, such as terraces and dams, must be observed and studied.

Deposition

Deposition is the third process in the sedimentation cycle and is the counterpart of erosion. It occurs when the carrying capacity of the flow is reduced to such a point that transportation of the total load is no longer possible. When the flow velocity is reduced, the coarser sediments usually settle out first. This makes it a selective process and results in gradation of the deposits.

It is estimated that less than one-fourth of the eroded material from the United States reaches the oceans. The remaining material, about 3 billion tons each year, is deposited in the uplands, flood plains, channel systems and reservoirs (10).

Deposition of eroded material seriously damages our environment. Fertile soils, crops and pastures are often covered with the less productive material (Figure 5). Sediment in reservoirs and lakes occupies space needed for flood control, power, irrigation, domestic water supply and recreation. Stream channels are clogged and floods occur more often (Figure 6). Efficiency of irrigation canals and drainage ditches is reduced. Fishing and other recreational facilities are damaged. Homes, bridges and other floodplain developments are damaged (Figure 7). Groundwater levels are frequently raised and areas swamped. Swamping frequently occurs on streams of low gradient in watersheds with high sediment yields.

Several watershed organizations in the Northeast add flocculating agents to the runoff in an effort to induce deposition at selected locations. Studies on controlling deposition would be very rewarding.

Effects of Reservoirs

Reservoirs have a profound effect on sediment transport and deposition. Because they drastically reduce the carrying capacity of flow, most of the sediment is deposited in the reservoir basin. Small reservoirs below areas with large sediment yields rapidly lose their capacity.

These damages are usually accepted as unavoidable and relatively uncontrollable. How-

Figure 5. Corn destroyed by sediment.

Figure 6. Channel capacity reduced by sediment.

Figure 7. Home damaged by sediment.

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[5] "Sediment Delivery Ratios and the Effects of Structures on Downstream Contributions," by J. W. Roehl. Presented at the ARS-SCS Sedimentation Workshop, Panguitch, Utah, September 12, 1962.

[6] op. cit., footnote 1.

ever, storage capacities in the reservoirs and the valleys above and below the reservoirs are irreplaceable. Everything possible should be done to preserve them.

Most conservationists realize that a reservoir radically changes the river hydrograph downstream from the reservoir. The reservoir will trap most of the sediment, and the spillway will control the release of water. Seldom does much similarity remain between the old and the new river. Below the reservoir, the channel was originally sediment-lined and, in many cases, near a natural equilibrium condition. On the new river the sediment supply is reduced, and the capacity of the channel for transporting sediment is also changed by the reduction of flood flows and the increase in durations at lower flows. The sediment supply is usually reduced more than the carrying capacity, causing the channel to erode.

When the channel section has finally stabilized its profile, the sides may still not be completely stable. The banks, which usually contain finer material than the bed, may deteriorate because the supply of such fines to the stream flow has been reduced.

Discussion

A requisite for solving sedimentation problems is a full recognition and understanding of the nature of the problem. This requires a study of the field situation, along with knowledge of the fundamental sedimentation processes at work in creating the condition. Careful consideration must then be given to possible solutions and the effect that they will have on the sedimentation cycle and the watershed development.

The components of the sedimentation system are dependent upon each other. The sediment from upstream erosion travels in a certain place in a channel system and affects the channel stability, depending on the volume and the characteristics of the sediment. Deposition may or may not take place, also depending on the sediment characteristics and flow conditions.

Only a portion of the sedimentation system is completed during a given storm. Some eroded material is deposited, picked up during a later runoff period, moved farther, deposited again, and so on. Thus, the sedimentation system is dynamic and ever-changing. Researchers and conservationists must consider the effects of past and future sedimentation and conservation activities (8). One generation's concern for the land dictates the conditions that the next must face.

The installation of an individual conservation practice on any watershed must be evaluated, not only on how it handles a specific problem but also on its compatibility within the entire system. All aspects of conservation practices and total watershed use should be considered in this way. Hopefully, many of the goals will be complementary, but certainly this will not always be the case. The main objective must always be to prevent problems rather than to merely rectify them after they have been developed. The cause of every problem, however, must always be discovered and overcome.

Certain solutions within the small tributary watersheds will be very effective; but if similar projects are carried out on many such tributaries to a major stream, they may have significant effects far downstream. All the effects sought for may not prove to be beneficial.[7]

An equation can be developed for the sedimentation system of any watershed. The large basic input is usually sheet erosion, as reduced by its delivery ratio. Other types of erosion, as affected by their delivery ratios, add to the input quantity, as does a portion of the channel deposit which may have remained from a previous time. The total output consists of colluvial deposits, alluvial fans, bed and bank deposits and reservoir deposits; the remaining sediment yield is input into a yet larger system. For some aspects of the total system, only the net results of an action are pertinent.

Einstein (2), who is studying the problems associated with reservoirs on channels, concluded that the channel must be designed and the banks must be stabilized artificially. They may not always be necessary on smaller watersheds, but it should be considered. In certain cases, Einstein suggested, it may be necessary to add coarse material to stabilize the bed.

More consideration should be given to the upstream and downstream effects of reservoirs, and the design and location of principal spillways should be analyzed (Figure 8). Some problems of reservoir deposition can be solved if the spillway is placed in the upstream channel of the reservoir. Then, if enough versatility is provided in the principal spillway by using gates and other devices, more sediment can be bypassed, especially the large quantity of sediment that usually occurs during the early part of a storm. Sediment-water mixture can also

[7] "Flood Runoff in Relation to Future Soil and Water Conservation Research Needs," by Robert B. Hickok. Presented at the Senior Staff Conference, SWCRD, ARS, at Estes Park, Colorado, September 28, 1961.

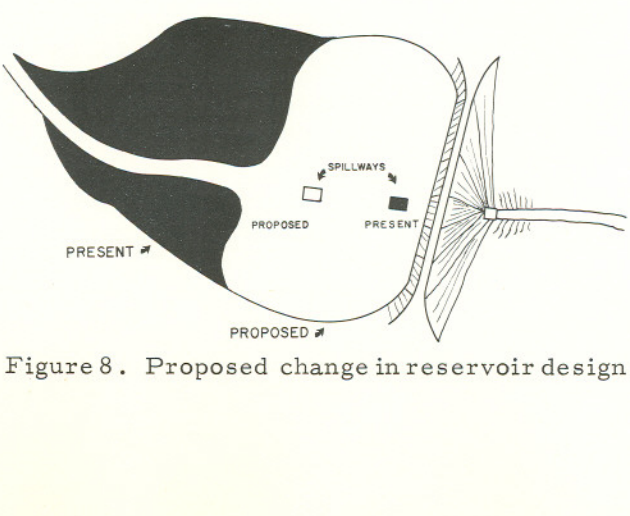

Figure 8. Proposed change in reservoir design.

be withdrawn whenever it is desirable. Some type of pressure-sensitive device can probably be developed to open the gates automatically when a large amount of sediment flows in the channel. Also, a more oval-shaped reservoir would be more effective for bypassing sediment. Our imagination and ingenuity should be used to the fullest to devise methods to alleviate the problems associated with reservoirs and other conservation measures.

The White House Report of November 1965, entitled "Restoring the Quality of our Environment," which was published by the Environmental Pollution Panel of the President's Science Advisory Committee (3), recommended that a base line measurement program be established to monitor the pollutants of man's environment. This will probably include reconnaissance sampling of the flow in many streams and rivers. In the future, excessive amounts of pollutants will probably be traced to their sources and the culprits taxed for the damage they cause. This could be an industry or a farmer. More rigid controls will surely be legislated if present regulations and self-control do not prove adequate. Conservationists should be ready for this time.

Conclusion and Summary

Sedimentation damages cost billions of dollars every year[8] and are a limiting and influencing factor in the environment of every man. Sediment has been described as the prime contaminator of our streams.[9] It has been estimated that the volume of the sediment pollutant equals 700 times the volume of the sewage pollutant (11).

Erosion, sediment transport and deposition--the components of sedimentation--are water oriented. They also are part of a system in time and space in which the components are interdependent. Therefore, the entire system should be studied as a unit to obtain the most complete understanding. A knowledge of the sedimentation processes is necessary for understanding the underlying causes of sedimentation problems and to formulate feasible control measures. Individual conservation practices should not only solve the problem at hand but should be in harmony with overall watershed program objectives.

Some sedimentation is desirable. Conservationists should learn to manage the forces involved in sedimentation so that they can control it and know how to consider it in its proper place in the total, maximum use of our environment.

Smerdon said recently in the Agriculture Science Review (13), "It is time that erosion was discussed more as a source of pollution. Research to reduce this pollution is imperative."

[8] op. cit., footnote 1.

[9] op. cit., footnote 1.

The comments made in the Office of Science and Technology report of February 1966, entitled "A Ten-year Program of Federal Water Resources Research" (9), are also very pertinent. Here they say, "The current widespread emphasis on pollution abatement and clean rivers highlights the need for methods of controlling erosion and the resulting sedimentation." Because of its importance in pollution abatement, that office recommended that the entire sedimentation research effort be doubled in the next 10 years.

Sedimentation affects many facets of our society. Conservationists are quite aware of its role and its effect on agriculture, but the effect of sedimentation on urban life and areas, manufacturing industries and recreation facilities must also be considered. It has a profound influence on where and how man lives, his work and his enjoyment of life. Conservationists must do more than just patch the wounds of sedimentation; they must build healthy watersheds that will resist deterioration by the forces of sedimentation.

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