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FIRST SESSION - STATEMENT OF SEDIMENTATION PROBLEMS

S. K. Love,* Presiding

RESERVOIR PROBLEMS WITH RESPECT TO SEDIMENTATION

by Thomas Maddock, Jr.**

The Bureau of Reclamation has constructed 77 storage reservoirs since its inception as a government service. Some of these dams are off channel storage and are subject to slightly different sedimentation problems than those built in stream channels. However, the experience gained in the operation of these reservoirs, either by the Bureau of Reclamation or by water users associations, has shown that deposits of sediment introduces certain problems that particularly relate to the life and water supply of the projects involved.

Reservoirs for irrigation storage can be roughly divided into two types, those providing seasonal storage and those providing hold-over storage. In the first type, storage is provided for the purpose of equalizing the flow of the stream during the year, while in the second, storage is provided to equalize the flow of the stream for a series of years.

Seasonal storage reservoirs are usually constructed in the early stages of the development of the utilization of a stream system or are constructed where the water supply is ample, in all years, for the irrigated areas involved. As the waters of a stream system approach full utilization, however, hold-over storage becomes necessary to provide water during periods of low discharge.

Multiple-purpose reservoirs are sometimes a combination of these two types of reservoirs, storage for flood control purposes being considered a short seasonal storage, while the conservation storage may be considered hold-over storage. Storage for water power may be a by-product of conservation storage. If not, storage for water power is usually seasonal storage.

Seasonal storage reservoirs have a small capacity in relation to the annual runoff, while those for hold-over storage have a large reservoir capacity in relation to the annual runoff of the stream, and furthermore a very large capacity in relation to the minimum annual discharge. Typical examples of these two types of reservoirs are shown in Table 1.

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TABLE 1. RELATION OF STORAGE CAPACITY TO ANNUAL RUNOFF

Reservoir	Capacity acre-ft.	Average annual runoff acre-ft.	Minimum annual runoff acre-ft.
Hold-over Storage			
Roosevelt	1,398,000	728,000	210,600
Elephant Butte	2,219,000	1,150,000	178,000
Lake Mead	27,930,000	12,987,000*	4,186,000
Pathfinder	1,040,000	1,258,000	485,400
Seasonal Storage			
Arrowrock	286,600	1,900,000	900,000
Cle Elum	435,700	646,000	
Buffalo Bill	456,600	907,200	536,000
Gibson	105,000	558,000	302,000
Pine View	44,200	191,900	27,400

*At Bright Angel.

In general, seasonal storage reservoirs are usually found in the northern tier of the Western States, while the hold-over reservoirs are found in the southern tier. Locations in between may have either type of reservoir. This location has a marked effect on the rate of sediment accumulation in reservoirs, since the sediment carried by streams in the Southern States is much higher, in general, than the rates in the Northern States, particularly in those streams in the Pacific Northwest and those draining mountain areas where the source of runoff is melting snows. It is possible, however, that some sediment accumulations in reservoirs in the Missouri, Arkansas, and Red River Basins may be as high, relatively, as some of those in the South.

The effects of sediment deposits in reservoirs are two-fold: first, the capacity of the reservoir is reduced; and second, the evaporation losses are increased. These effects vary in importance with the type of reservoir.

Seasonal storage reservoirs, since they have small storage capacities in relation to the average annual stream discharge are usually short-lived unless the sediment load of the stream is small. An example is Lake McMillan on the Pecos River, where 50 percent of the reservoir capacity was lost in 20 years.

This loss of capacity is probably more important in seasonal reservoirs than in hold-over reservoirs because of the short intervals between reservoir overflows. From this standpoint, rapid reservoir filling means that the irrigated acreage dependent on storage is rapidly returned to dependency on a run of the river supply with a consequent shortage of water or a reduction in irrigated acreage.

Deposition of sediment in hold-over reservoirs is not so important from a short-term standpoint as it is in seasonal reservoirs because of their large capacity and the infrequent spills. However, from the long-term viewpoint, the results are the same, water shortage and reduction in irrigated acreage.

Elephant Butte Reservoir, after 27 years of operation, had accumulated sediment deposits of about 430,000 acre-feet, yet had spilled but once in this period. However, studies now being made show that the excess capacity has been exhausted and that reservoir overflow may be more frequent in the future, thus indicating a slow reduction in the available water supply. Conditions at Lake Mead are similar to those at Elephant Butte, but are, of course, on a much larger scale as far as volume of runoff and sediment are concerned.

The second effect of sediment accumulations in reservoirs, the increase in evaporation losses, is of two types. First, the increase in the area of exposed water surface for a given quantity in storage; and second, the increased transpiration losses from vegetation growing on sediment deposits at the heads of reservoirs.

Both types of evaporation losses are not usually significant in reservoirs for seasonal storage only, since the water supply is usually ample. In fact, a vegetative screen at the head of a seasonal storage reservoir may be highly beneficial because such screens reduce the amount

of sediment deposited in the reservoir itself. In hold-over reservoirs, however, and where water supplies are short, such losses are highly significant.

At Elephant Butte Reservoir, the water surface area exposed at 1,700,000 acre-feet, a not unusual operating level, had by 1940 increased by 1,200 acres with a probable water loss of about 7,500 acre-feet per year. At Roosevelt Reservoir, a deposition of 7,800 acre-feet between 1925 and 1935 caused an increase in the surface area, at 700,000 acre-feet of storage, of about 450 acres, equivalent to an annual evaporation loss of about 2,500 acre-feet per year.

Relative losses from increased surface exposure varies from reservoir to reservoir, depending on their shape, slope of the stream, reservoir operation and other factors. Losses from this source at Roosevelt Reservoir should be expected to be higher, for example, than at Elephant Butte.

Losses from increased transpiration from vegetation growing on sediment deposits at the head of reservoirs is very large and in warmer climates can become a great problem. The increased loss from transpiration by vegetation growing on sediment deposits above the reservoir formed by Parker Dam is estimated to be 400,000 acre-feet annually. The losses from the same source at Lake McMillan on the Pecos River were estimated in 1940 to be 23,800 acre-feet per year from areas below the high-water line of the reservoir and 42,200 acre-feet per year from river areas only slightly above the high-water line. Transpiration losses from vegetation growing in sediment deposits between the water surface and the high-water line of Elephant Butte Reservoir in 1936 amounted to 114,800 acre-feet, and from areas slightly above the high-water line amounted to 56,400 acre-feet. Today the area of sediment deposits covered with hydrophilic vegetation is greater than it was in 1936, thus increasing losses from this source.

In each of these cases, reservoir capacity was preserved by the presence of the vegetative screen. For example, the apparent rate of sediment accumulation in Elephant Butte Reservoir has dropped from about 18,000 acre-feet per year to 6,000 acre-feet per year; but it has done so at a terrific cost of water, probably somewhere in the neighborhood of 100,000 acre-feet per year.

Because the location of sediment deposits within reservoirs is important from many standpoints, the graph shown on Figure 1 was prepared. On this graph is shown the relative location of sediments deposited in Guernsey Reservoir on the North Platte, Elephant Butte Reservoir on the Rio Grande, and Roosevelt Reservoir on Salt River.

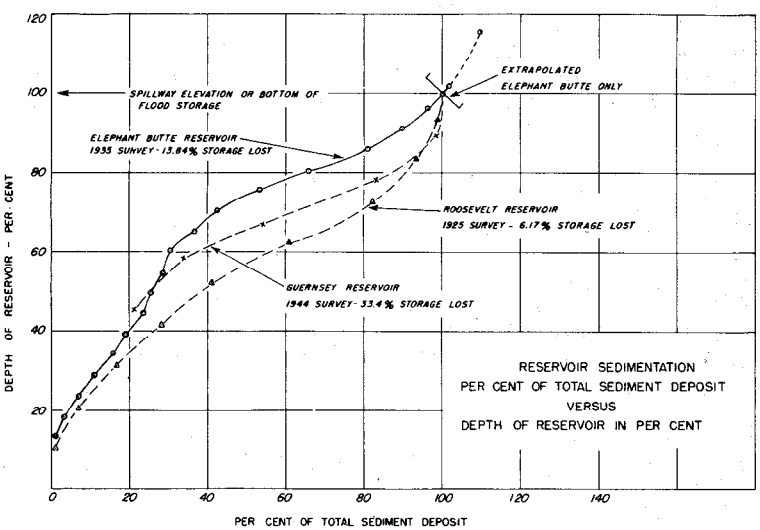

Figure 1. LOCATION OF SEDIMENT DEPOSITS IN WESTERN RESERVOIRS

Figure 1 shows that 50 percent of the sediment in Guernsey Reservoir is deposited in the upper 35 percent of the reservoir depth. Guernsey Reservoir is operated so that the reservoir pool is at, for all practical purposes, a constant elevation. In comparison with Guernsey Reservoir is Roosevelt Reservoir which, operating with wide variations in the pool elevation, has only 30 percent of its sediment deposited in the upper 35 percent of its depth, but half of the sediment deposits are above 58 percent of the reservoir depth.

In contrast to these two reservoirs is the deposit in Elephant Butte Reservoir where approximately 50 percent of the sediments are found in the upper 25 percent of the reservoir depth. Elephant Butte Reservoir has had considerable variation in its operating levels but not as great as those at Roosevelt Reservoir.

The relative differences in the location of these deposits is due to several factors, such as stream slope and quantity and particle size of sediment inflow, but the reason for the relatively high location of sediment deposited in Elephant Butte Reservoir can be attributed to the

growth of vegetation in the upper sections of the reservoir and to the relatively large amount of sediment being brought into the reservoir by the Rio Grande.

The important conclusion to be drawn from these studies is that in all cases so far studied in the West, over 50 percent of the sediment deposits lie in the upper half of the reservoir. Inasmuch as allocations for sediment storage in reservoirs are usually placed at the bottom, it seems advisable to question the construction of reservoirs with relatively large amounts of dead storage that will not be filled with sediment for many years.

Conversely, it has usually been considered that the upper levels of reservoirs, usually allocated to flood control in multiple-purpose projects, would be free from sediment deposits. Data so far collected show that in some cases this section of the reservoir may be subject to the greatest amounts of sediment deposition.

Usually in a discussion of reservoir sedimentation problems, the question is raised as to whether methods of reservoir operation can be adjusted to reduce the rate of sediment accumulation. There is evidence that, at least in some cases, it can be done. Data collected by the U. S. Engineer Office at Albuquerque and published as an "Interim Report on Sedimentation in Conchas Reservoir, South Canadian River, New Mexico," show that sediment concentrations as high as 5 percent by weight pass through the lowest outlet gates of the dam. However, during periods of no flood discharge into the reservoir, there was no appreciable movement of sediment out of the reservoir.

To take advantage of the movement through the reservoir, the following operating criteria were set up, to quote from the previously-mentioned report:

> "a. In the event of floods, the conduits will be opened as soon as the flood flow begins to enter the reservoir and maintained open as long as the discharge contains appreciable sediments. If the discharge runs clear after a short period, the conduits will be closed (unless the flood is expected to cause spillway discharge), and reopened periodically at about 6- to 12-hour intervals, pending arrival of the density current and a silty discharge, or until it becomes evident that such discharge will not occur.
>
> "b. During period of low or moderate flow, the conduits will be opened monthly and permitted to discharge as long as the release contains perceptible sediment."

It will be seen that the primary necessity for this type of reservoir operation is an ample water supply. Thus, this type of operation may be available to reservoirs operated for seasonal storage, but it cannot be used in reservoirs where water supplies are short and hold-over storage is necessary.

Measurements of the size of sediment particles passing through Conchas Dam showed that 97 percent were in the 5- to 20-micron range. Therefore, if material in this size is not an important part of the total sediment load of the stream, saving in reservoir space through evacuation of sediments will not be important.

The evacuation of sediment during periods of normal water release has been observed at Lake Mead and Elephant Butte Reservoir. No doubt, if enough were known about density currents, reservoir outlets could be designed so as to pass sediments through reservoirs during periods of normal reservoir releases.

Because the sediments deposited in existing reservoirs offer, when measured, the equivalent of an integrated record of several years of sediment movement by tributary streams, data from reservoir sedimentation surveys are used as basic data to determine sedimentation rates in proposed reservoirs.

That such data should be used with caution and properly evaluated is shown by the results of several re-surveys of Roosevelt Reservoir, given in Table 2.

TABLE 2. ROOSEVELT RESERVOIR SEDIMENTATION SUMMARY

Year	Sediment deposited (acre-ft.)	Increase
1905	0	0
1914	27,000	27,000
1916	62,000	35,000
1919	62,000	0
1925	101,000	39,000
1935	108,800	7,800

In this case, annual sediment increments range from 0 to 17,000 acre-feet, while the average rate is 3,630 acre-feet. There is no reason to believe that differences in this case are due to different degrees of accuracy in surveys, although the original reservoir survey may have been none too accurate.

Fluctuations in sediment accumulation in Roosevelt Reservoir seem to vary rather markedly with high runoff. The heavy deposition during 1915 to 1916 corresponded with very heavy runoff, the discharge during the period being the equivalent of almost 6 years of average runoff. The period 1917 to 1919, which shows no sediment deposition, was one of low runoff. Actually a considerable amount of sediment may have been deposited in the reservoir during this period, but the lowering of the water in the reservoir during this period allowed the consolidation of sediments to take place. Also, there was resorting of older deposits which tended, perhaps, to increase the density of the deposited sediments. The period 1925-1935, which also shows a low annual rate of sediment deposition, was also one of low flow, with low water levels that permitted compaction of sediment.

Very little is known about rates of compaction of sediments in reservoirs but this very important phase of the sedimentation problem is worthy of study. It seems possible that the apparent sedimentation rate for reservoirs with unfluctuating water levels may be higher than that for comparative reservoirs where water surface elevations vary widely, providing that in the first case there is no increasing deposition above the highest reservoir elevations.

As has been mentioned previously, the growth of vegetation at the head of reservoirs has a marked tendency to reduce the rate of sediment accumulation. Already noted is the fact that the apparent rate of sediment accumulation in Elephant Butte Reservoir has dropped from 18,000 acre-feet per year to 6,000 acre-feet per year.

Lake McMillan on the Pecos River, previously mentioned as a reservoir in which 50 percent of its capacity was lost in the first 20 years of operation, lost only about 6 percent of its capacity in the second 20 years of operation through the screening effect of vegetation growing on headwater sediment deposits.

Reservoirs located in cold climates do not seem to develop heavy growths of vegetation on their sediment deposits. However, it should be expected that such growth will take place in reservoirs constructed in Texas, Oklahoma, and Kansas, and perhaps in Nebraska.

The so-called "trap efficiency of reservoirs," that is,the proportion of inflowing sediments retained in a reservoir, has been the subject of much discussion. The experience of the Bureau of Reclamation has been that as long as there is appreciable storage in a reservoir, trap efficiencies are at least 90 percent. Studies of the operation of Imperial Dam show that at the time of closure in April 1938, there was 84,000 acre-feet of storage. Trap efficiency remained well above 90 percent until 1943, when the storage capacity had been reduced to 24,000 acre-feet, despite the fact that during this period the discharge of the Colorado River averaged about 16,000 cfs.

Once the trap efficiency began to fall below 90 percent, its rate of decline was rapid, so that by the end of 1944 the trap efficiency had fallen to about 60 percent and the storage capacity of the reservoir had been reduced to about 15,600 acre-feet.

I would like to make the observation that where successive surveys have been made on a given reservoir, there has been indicated a successive decrease in the rate of sediment accumulation. This has been due to the operation of a combination of the various factors noted previously. This statement is made not to minimize the importance of sediment accumulation in reservoirs,

which even at low rates is appallingly high, but to stress our lack of knowledge regarding the problem of reservoir sedimentation. This in itself should justify the need for resurveys of reservoirs to determine the loss of storage capacity and to evaluate the secondary effects of sediment deposits such as have been discussed.

The effect of loss of capacity in reservoirs used for irrigation has been brought to attention by many persons, particularly by J. C. Stevens and the discussion of his two papers in the publications of the American Society of Civil Engineers. The thought has been expressed, generally, that the West would revert to desert, for the most part, after the last potential reservoir had become filled with sediment.

What I would like to point out, in closing, is that reduction in acreage of irrigated areas will have to take place before the last reservoir site is utilized. We can expect full development of our Western streams before our present reservoirs are filled with sediment. Water will not be available to provide for the excessive losses that will take place in these reservoirs in later periods of their life and for evaporation from newly constructed reservoirs. We therefore must, to the extent possible, preserve what we now have.

DISCUSSION

GUNNAR M. BRUNE.* Mr. Maddock has covered very well reservoir problems in the West. I would like to mention only a few of the problems which we have encountered in the more humid Midwest.

First, as you know, evaporation is not such a serious problem in the Midwest. Therefore, the effect of transpiration by vegetation growing at the head of a reservoir is usually not important. In this region, willows, cattails, and other brush often grow naturally, even in the coldest climate, on delta deposits at the head of a reservoir. Such a screen is usually considered distinctly advantageous, since it reduces the velocity and carrying power of the water and causes it to deposit a part of its load before reaching the lake. At Pittsfield Reservoir, Pittsfield, Ill., the proposed flood and sediment control program calls for more efficient use of an already existing vegetative screen by blocking the stream channel with small dams and forcing the water to spread through the dense growth.

The other problem on which I would like to spend some time is the effect of World War II on rates of reservoir sedimentation, particularly in the Midwest. In the Midwestern States there are four reservoirs on which sedimentation surveys were made before the war, and which were resurveyed during or after the war. One of these, Pleasant Hill Reservoir, at Perrysville, Ohio, is a flood control reservoir with a permanent recreational pool 1/. One, Sharon Woods Reservoir, near Sharonville, Ohio, is strictly a recreational lake. The other, O'Shaughnessy Reservoir, near Columbus, Ohio 2/, and Lake Decatur, at Decatur, Ill. 3/, are water supply reservoirs.

The fact that two sedimentation surveys have been made on each of these reservoirs makes possible a study of trends in reservoir sedimentation. Such a study has already been made on Lake Decatur 3/. In the case of Pleasant Hill Reservoir, where the first survey was reconnaissance and the second detailed, the reconnaissance data were recomputed for comparison with the detailed survey data. All other sedimentation surveys considered were detailed surveys.

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1/ 2/ 3/ See "References" at close of comments.

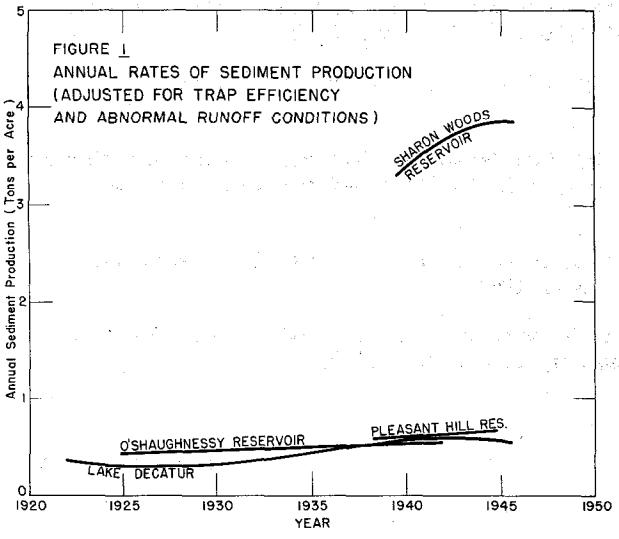
In order to make the data comparable, the measured annual sediment accumulation for the first and second periods at each reservoir has been converted from acre-feet to tons per acre of drainage area. At Lake Decatur a study of 21 sediment samples shows that the average specific weight of the sediment is 51.7 pounds per cubic foot. The specific weight of the sediment at the other reservoirs has been estimated, considering trap efficiency, fluctuation of water level, and other factors, as follows: Sharon Woods - 55 pounds, Pleasant Hill (first period of measurement) - 55 pounds, and O'Shaughnessy (first period of measurement) - 60 pounds. At Lake Decatur and Sharon Woods Reservoirs, fluctuation of the water level is relatively minor. At Pleasant Hill and O'Shaughnessy Reservoirs, however, it is important. This fluctuation has undoubtedly caused a compaction by drying of the sediment deposits. For this reason, higher specific weights were estimated for these reservoirs during the second period of measurement, namely 65 pounds per cubic foot for Pleasant Hill and 70 pounds for O'Shaughnessy Reservoir.

It was also necessary to convert sediment accumulation to sediment production, by making an allowance for sediment which has passed over the spillway or through outlets in the dam. At Lake Decatur, a study of turbidity records indicates a trap efficiency of 78 percent. For the other reservoirs, trap efficiency has been estimated, using the "design curve" developed by Brown 4/, and information as to the mode of operation of the reservoir, as follows: Pleasant Hill - 90 percent and Sharon Woods - 85 percent. At O'Shaughnessy Reservoir the trap efficiency is estimated to have decreased because of decreasing reservoir capacity from 65 percent during the first period of measurement to 60 percent during the second.

Finally, in this study some means had to be found to eliminate the effect of abnormal runoff. It is well known that there is practically no relationship between daily runoff and daily rate of sediment production. There is, however, a very definite relationship between annual runoff and annual rate of sediment production. Mr. Maddock has pointed out that annual sediment accumulation in Roosevelt Reservoir seems to vary markedly with runoff. Brown 5/ has shown that annual suspended sediment load varies with annual runoff to the 1.52 power on the Colorado River at Grand Canyon, Ariz., and to the 2.43 power on the Green River at Green River, Utah, with other streams ranging between these extremes. Preliminary data indicates that a slightly lower range of exponents may be expected in the Midwest, probably averaging about 1.8. This is the relationship which has been used in this study. It is recognized that at any particular reservoir a different relationship probably exists, but this is believed to be close to the average.

By this means it was possible to adjust the rate of sediment production from the amount that actually has been produced to the amount that would have been produced in each case if the runoff had been normal. Figure 1, therefore, represents annual rate of sediment production, converted from acre-feet to tons per acre of drainage area, adjusted for trap efficiency of the particular reservoir, and adjusted to normal runoff. The probable effect of compaction of sediment due to water level fluctuation and drying has also been taken into account in this figure.

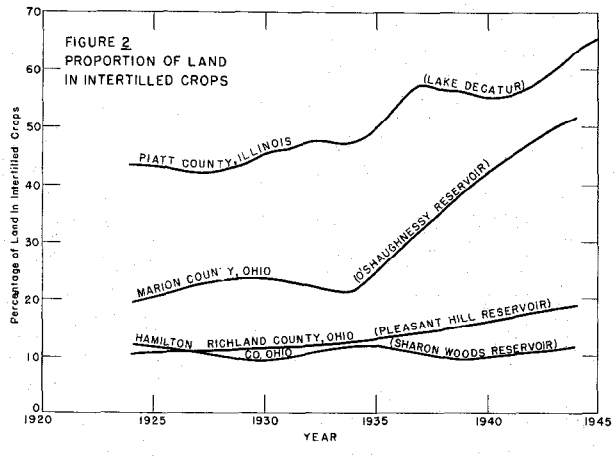
With the effect of these factors neutralized, what has been the trend in rates of reservoir sedimentation? As may be seen, all of the reservoirs have shown an increase in rate of sedimentation just before and during World War II.

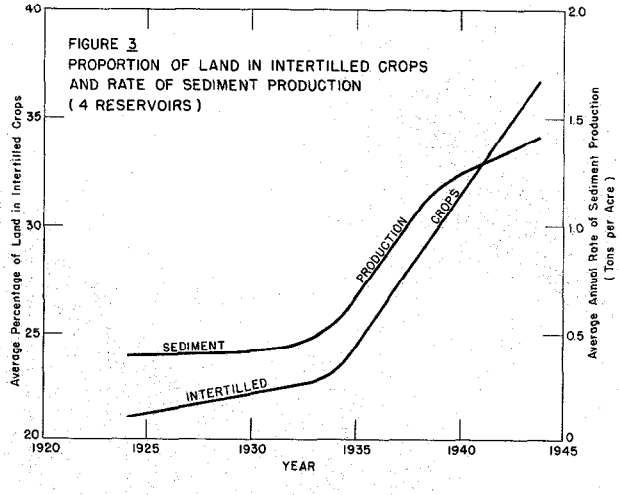


4/ 5/ See "References" at close of comments.

Figure 2 is intended to show the trend in cultivation of intertilled crops, such as corn and soybeans, in each of the four reservoir watersheds. These curves are based on county census figures, and may not be exactly representative of the reservoir watersheds. It is, therefore, dangerous to compare the rate of sediment production with proportion of land in intertilled crops for any one reservoir. However, it is worthy of note that in most of the watersheds there appears to have been a rather sharp increase in the amount of land in intertilled crops after 1934, caused chiefly by the increased demand for food before and during World War II, and increased production of soybeans.

In Figure 3 the average rate of sediment production for the four reservoirs and the average proportion of land in intertilled crops are compared. From 1934 to 1944 the average proportion of land put to intertilled crops





increased by 61 percent. During the same period the average rate of sediment production at these five reservoirs increased by almost three times, with the effect of abnormal runoff ruled out.

This does not mean that the intensity of cultivation to intertilled crops is the only factor, exclusive of runoff, influencing the rate of sediment production in this region. The indications are, however, that it has been the most important factor, except runoff, up to the present time. In the future, it is natural to expect that soil conserving measures such as contour cultivation, strip cropping, terracing, diversion ditches and dikes, grass waterways, streambank protection, and channel-stabilizing structures will greatly reduce rates of reservoir sedimentation in the Midwestern States. However, these measures cannot obtain their maximum effect unless the planting of intertilled crops is cut back to reasonable proportions, such as existed in 1934.

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VITO A. VANONI.* I would like to comment on the part of Mr. Maddock's paper dealing with density currents. A density current consists of the flow of the stream entering the reservoir and reservoir water that has been mixed into this stream where it enters the reservoir. This means that the flow in the density current is actually larger than the flow in the stream. If one proposes to pass the entire density current through the reservoir to prevent deposition of sediment, it is necessary to handles flows greater than the river flow. This would probably seldom, if ever, be practical, so that if material carried by density currents is to be passed, it will be necessary to store the flow temporarily to allow a settling time during which the concentration will be increased and the volume reduced. The fact that density current flows are greater than the stream flow is an added complication in using them to prevent reservoir sedimentation. I raise this point, not in any attempt to discourage the use of density currents, but as a point of information. I am not as pessimistic as Mr. Maddock regarding the use that may be made of density currents in the reservoir sedimentation problem. However, I feel that in order to make use of density currents, we must learn their characteristics and plan our operations to take all possible advantage of them.

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SEDIMENTATION PROBLEMS RELATED TO FLOODWAYS, NAVIGATION CHANNELS AND HARBORS

by Gail A. Hathaway*

It is the purpose of this paper to highlight a few of the major sedimentation problems that require prominent consideration in connection with river and harbor improvements. The presentation will consist principally of brief accounts of problems encountered by various Division and District Offices of the Corps of Engineers in their normal construction activities.

As used herein, the term "sedimentation problem" refers to either a deposition of sediment or the displacement of material by scour. A sedimentation problem is considered to exist either when deposition or scour of a detrimental nature is involved, or when it is desirable to control these processes for a useful purpose. The filling of reservoirs, navigable channels and floodways illustrates detrimental effects of sedimentation, whereas the rectification and stabilization of river channels by controlling scour and deposition of materials through the regulation of velocities and direction of currents is an example of the useful applications of these processes.

This paper will deal with sedimentation problems related to floodways, navigation channels and harbors. Problems pertaining to reservoirs are to be considered in detail in other papers on the program, and have, accordingly, been excluded from this discussion.

Sedimentation problems are encountered in the development and use of alluvial rivers from the headwaters to the mouth, extending generally to the river deltas or outer bars of coastal harbors. The most important of these problems usually relate to:

a. Obstruction of floodways and navigation channels by deposition of sediment.

b. Major changes in channel alignment resulting from deposition and scour in unstabilized channels.

c. Blocking of outlets of sewers, water intakes and drainage canals by sediment.

d. Destruction of river improvements, bridges and similar works as the result of scour and bed movements.

e. Readjustment of hydraulic conditions below newly constructed reservoirs, resulting from retrogression, deterioration of channel efficiencies caused by storage or diversion of normal flows and intermittent releases, changes in channel alignment, and similar factors.

Missouri River

The Missouri River is an excellent subject for study of sedimentation processes. Engineering problems of first order are encountered in bringing about proper stabilization of the river channel and floodway to prevent destruction of valuable farm lands and municipal property, and to permit profitable navigation. Prominent success has been realized to date in effecting these purposes, although there is, of course, much work yet to be accomplished.

The Missouri River has long been known as the "Big Muddy," for reasons readily apparent to those who have observed the river in flood stage. The unusual sedimentary characteristics of the river are reflected by estimates of silt discharge at Kansas City, which reached as high as 153 million tons for the flood month of June 1929. The average annual silt discharge at Kansas City has been estimated as 204 million tons. Advantage has been taken of the high sediment transporting capacity of the Big Muddy in forcing the river to excavate its own channel and fill in low areas.

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In the valley between Sioux City, Iowa, and the mouth of the Missouri River, the Corps of Engineers has undertaken stabilization of the Missouri River to provide a navigable channel of 9-foot depth and minimum width of 300 feet. Based on many years of experiment and experience on the river itself, an effective stabilization program has been developed whereby sediment deposition is incited where desired by installation of systems of permeable pile dikes, and bank scour is regulated by revetments. This program has advanced to the point where the river is "pegged down," and no longer free to meander at will. This stabilization program has provided a channel much more suitable than the original river for navigation, and has solved major problems which formerly resulted from the river shifting away from bridges, water intakes, etc., and destroying or threatening valuable farm lands and improvements in the valley.

It is expected that a future sedimentation problem of considerable importance to the Missouri River downstream from Sioux City will arise because of alterations in the Missouri's natural water and sediment discharge regimen by the construction of large main-stem reservoirs upstream from Sioux City. The exact nature and magnitude of this problem can only be speculated upon at present. However, it appears that sediment interception by the reservoirs may result in changes of such sugnificance that new techniques of river control may have to be developed.

Sedimentation presents important problems in connection with the continuous floodway to be provided between the authorized levees along both banks of the Missouri River from Sioux City, Iowa, downstream to the mouth. In the upper portion of this reach sediment deposition behind the river control structures (river stabilization program) is only well begun. In the downstream portion readjustment of the river to the new stabilized channel conditions is not yet completed, and considerable depths of sediment are laid down in overbank areas with each inundation of areas outside the channel proper. In still other areas, it appears that present equilibrium conditions may be upset by constriction of overbank flows to leveed floodways, with the resultant possibility of serious floodway scour. These sedimentation problems, particularly as they affect flood channel cross-sectional areas and roughness coefficients, are of considerable importance in the selection of levee alignments and design grades at the present time. They will continue to be of importance because of influence on levee heights, and also because tendencies toward sediment deposition or scour will influence, and be influenced by, the future culture and use of the floodway lands.

Among the more important tributary sedimentation problems in the Missouri River Basin are, on one extreme, those of rapid silting of drainage and flood channels, and, on the other extreme, those of erosion and scour incited by ill-advised channel straightening and "cutoff" programs originally installed by local agencies for improvement of drainage or for reduction in heights of floods. Channel silting is necessitating enormous expenditures for maintenance in several tributary streams. In some cases considerable good is being accomplished through such expedients as de-silting basins, but these practices must be expanded materially, and basic programs and practices to retain as much of the sediment as possible at its origin must be effectuated, if the channel silting problems are to be reduced to reasonable proportions. Similarly, the ill effects of cutoffs and imprudently straightened channels must be rectified, and future mistakes of this nature avoided in critical areas, if the general sedimentation problems of the basin are to be alleviated rather than aggravated.

Arkansas River

Sedimentation problems on the Arkansas River differ considerably in character and relative importance in various reaches between the mouth and the headwaters, generally becoming progressively more serious in an upstream direction.

The John Martin Reservoir on the upper Arkansas River in Colorado will be completed late this year. Allocation of storage is a particularly critical problem here and requires detailed consideration of the quantity and location of sediment deposits. Operational problems also exist to the extent that surveys must be made annually to determine storage loss by sedimentation.

Long before construction of the John Martin Dam was contemplated it was evident that the Pueblo (Colorado)-Syracuse (Kansas) reach of the Arkansas River was deteriorating. This was due, it is believed, to irrigation diversions that reduced the low-water flows in the river channel to return-irrigation-flows which were insufficient to maintain a hydraulically efficient channel. Flood flows were evidently sufficient to remove most of the tributary sediment contributions and to carry through this reach those sediments brought in by the main channel itself, but flood flows could not overcome the net effects of deterioration during low flows. This has, in effect, produced an aggrading channel with attendant impairment of drainage, reduced effectiveness of irrigation works and increased to some extent the flood hazard to points downstream.

Rio Grande

Sedimentation problems on the Rio Grande are more serious and perplexing than on any other stream in the Albuquerque District of the Corps of Engineers. The bed of the river is aggrading at a steady rate causing increased flood hazards through reductions in channel capacities, impairment of drainage, raising of the water table and reduction in the effectiveness of irrigation works. These factors combined have taken many fine farm lands out of cultivation and prevented or reduced productivity of many others. Aggradation has, of course, been a slow and gradual process.

The flood-control works tentatively proposed for the Middle Rio Grande will regulate floods without the degradation expected below the proposed dams. This expected degradation has been the subject of much study and comment. Some believe that with an outflow of 5,000 c.f.s. (selected as the desired maximum release for flood-control purposes), degradation will not offset tributary contributions. Another view is that 5,000 c.f.s. will affect degradation to an appreciable extent, but controlled releases, whatever their magnitude, must be sufficient to remove, at the very least, tributary sediment contributions; degradation can not otherwise occur and without degradation principal reclamation features of the project will not be realized.

Mississippi River

Many volumes would be necessary to treat in full all the sedimentation problems of any one of our principal waterways. Like others, Old Man River demands considerable attention from a standpoint of sedimentation problems; however, we will deal only briefly with one phase of the many problems worthy of mention - sedimentation within navigation pools in the Upper Mississippi.

Recognizing that canalization of the Upper Mississippi might cause accretions in the various navigation pools, a comprehensive investigation was undertaken to determine the silt-carrying capacity of the Mississippi and its tributaries. Field work was started in the early thirties, consisting of sediment sampling and of establishing survey ranges within the navigation pools and on backwater prisms of principal tributaries. During the past 25 years there have been additional sampling programs and additional ranges established, as well as re-surveys of original range profiles.

Analysis and interpretation of the results of these investigations involve study of the magnitude and duration of the stream flow of the main stem and of the tributaries, and study of data obtained from surveys as to the amount of deposition of scour in channel and in overbank storage volumes, together with correlation of data from sediment samples.

It would be inadvisable to attempt to present general and overall conclusions derived from these investigations. However, mention may be made of some specific tendencies.

a. Both scour and fill have occurred in the main channels.

b. Deposition has occurred in the channels and on the flood plains of the tributary streams.

c. The flood plain of the main stem has been raised by sediment deposition.

d. With certain exceptions, the storage capacities of navigation pools and of pools at the mouths of tributaries have been reduced.

One general conclusion may be reached - dredging in the main channel of the Mississippi River has been necessary for maintenance of navigation depths.

Debris Flows

In some drainage basins, the control of debris flows and heavy bedloads accompanying flash floods from precipitious mountain areas constitute serious problems. Many of the drainages in the Los Angeles District are located directly upstream of, or partly within, highly developed urban and semi-urban areas. Prevention of debris damage in such areas is of considerable economic importance. At the present time six small debris basins, whose only function is to trap debris, have been constructed in the Los Angeles area. Periodic removal of collected debris is required in order to maintain design capacities. The approved project for the Los Angeles County drainage area provides for construction by the Corps of Engineers of many additional debris basins.

As a result of extensive gold mining activities in the foothill and mountain sections of the Sierra Nevada during the last century large volumes of debris were produced which were carried downstream by flood waters and deposited either in stream channels near the foothill line or in the valley reaches of most of the streams in the Central Valley. Although mining activity has been greatly reduced in recent times, a serious debris problem exists in the foothill and valley streams because of the continued erosion by flood flows of old mining debris. Debris dams have been constructed on the North Fork of the American River and on the Yuba River. Since their construction, about 2,300,000 cubic yards of material have been excavated above these dams and no appreciable sedimentation has been observed below the dams. Additional debris dams have been authorized on Bear River and on the Middle Fork of the American River.

Although generally of less spectacular significance than described above, debris problems are encountered in connection with many local protection projects in the northeastern United States. The construction of small timber-crib check dams on small streams has proven profitable in many cases as a means of reducing costs of maintaining channel improvements or drainage facilities. These are usually located near the bluff lines or immediately above improved channel sections.

Harbors and Coastal Waterways

Numerous and varied sedimentation problems are encountered in connection with the development and maintenance of navigation channels and harbor installations. The magnitude and importance of these problems will be indicated by a few examples.

East Coast

New York Harbor. Sedimentation in certain channels in New York Harbor is sufficient to require yearly maintenance. The initial work on the South Channel, Raritan River, was completed in April 1942. Shoaling occurred rapidly thereafter, and in the fall of 1944 over 700,000 cubic yards of materials were dredged to restore the channel to project dimensions. Within two years the channel again shoaled to the extent of 704,000 cubic yards. The exact cause of the rapid shoaling is not known at this time. However, a preliminary examination has indicated that the following five factors, acting singly or in combination, must influence the condition:

a. Change of hydraulic cross-section of the South Channel of Raritan River;

b. Alignment of the South Channel;

c. Discharge of industrial waste and sewage disposal with resulting chemical precipitation;

d. Density currents due to tidal salt-water flow from the bay; and

e. Stream-bed load due to erosion of surrounding terrain.

A comprehensive survey has been recommended, including a possible model study, to determine means of controlling or eliminating this shoaling.

Delaware River. The Delaware River below Philadelphia, Pa., presents a major sedimentation problem. A continuous program of maintenance dredging is required in order to maintain navigation projects. The average yearly dredging, based on 1944-1946 records, is about 13,000,000 cubic yards. Corrective action has been limited to training works to increase velocities at points of heaviest shoaling. A program of comprehensive model studies is being planned to find a solution of the problem. The Delaware River is also the main source of the sediment that occurs in the tidal portions of the Schuylkill River and in Wilmington Harbor. In the case of the former, tidal currents from the Delaware furnish half of the sediment, the remaining sediment arising from operations of the coal industry. This pollution will ultimately be remedied by enforcement of State laws. Maintenance dredging has been accepted as the most practicable means of relieving the situation.

South Atlantic Coast Harbors

In harbors along the South Atlantic Coast the principal sedimentation problems of the Corps of Engineers have been those related to the maintenance of inner-harbor channels and basins at

Wilmington, N. Car., Charleston and Savannah, with similar but lesser problems at certain other installations. The sedimentation problem involves the flocculation and precipitation of finely divided sediment and chemicals in solution upon contact with salt water.

At Wilmington, Charleston and Savannah Harbors, annual costs of maintenance have greatly increased within the last few years, notably so at Savannah. A number of factors may have contributed to such increase, among them:

a. Decrease in vessel traffic due to war conditions, resulting in less stirring up of the deposited sediment into the water, with resulting reduced tendency for the sediment to be carried seaward out of the harbor.

b. Restoration of full project depths that had been allowed to deteriorate somewhat during earlier war years.

c. Increased unit costs of dredging.

The average annual dredging required for maintenance of navigation projects at Wilmington and Charleston is approximately 3,500,000 cubic yards for these two projects.

Savannah Harbor. Sedimentation in Savannah Harbor is attributed to the precipitation of Savannah River sediment by the action of salt water. Pollution of the harbor by industrial and domestic wastes may also affect the quantity of precipitated matter. The place and amount of deposits in the harbor vary with tidal conditions and river discharges. Full details of the work needed in connection with the Savannah Harbor sedimentation problem have not yet been worked out, but the following is a brief outline of what is considered necessary:

a. Determine the source of the shoaling material. If a large quantity comes from caving banks below Augusta, bank protection works may reduce the shoaling.

b. Determine whether the precipitation of sediment in the harbor is due to contact with the sea water alone or whether domestic and/or industrial pollution of the harbor waters affects the amount, and to what degree.

c. Determine the amounts, locations, and kind of sediment deposit in the several sections of the harbor for the principal flow conditions - mean, spring and neap tide, and high and low river flow.

With these data and the results of model studies, it is probable that benefits from the several plans of improvement studies can be evaluated with sufficient accuracy to determine which improvements are economically feasible and which should be constructed.

Gulf Coast

Mobile Bay. A few figures will illustrate another sizable navigation channel and harbor sedimentation problem. Maintenance dredging on Mobile Harbor for the eleven-year period, 1936 to 1946, averaged 4,000,000 cubic yards annually. The average annual maintenance dredging on the Warrior River and lower Tombigbee River, headwaters to Mobile Bay, for the same period is 2,300,000 cubic yards. The figures alone are significant of the undertaking necessary to maintain these installations.

Gulf Intercoastal Waterway. Shoaling in the Intercoastal Waterway, particularly at the Brazos and Colorado River Crossings, constitutes another problem. The opening of floodgates in the canal to permit passage of tows results in large intrusions of sediment in the waterway. Investigations and studies are underway so that remedial plans may be made to reduce sedimentation at these crossings.

West Coast

Mission Bay. The San Diego River was diverted from San Diego Bay to Mission Bay in 1876. Since that time, shoaling has been steady and pronounced in Mission Bay. Diversion of the San Diego River direct to the ocean is now authorized as part of a combined navigation-flood control project on Mission Bay and San Diego River.

Los Angeles Harbor. Sedimentation also constitutes a serious problem at other harbors on our Western Coast. The Los Angeles River annually deposits large quantities of sediment in

Long Beach outer harbor in the form of a delta at the mouth of the river. During the 1938 flood alone, over 6,000,000 cubic yards of material were brought down by the river. The San Gabriel River, which empties into San Pedro Bay, presents a similar problem but to a lesser extent. An initial dredging program at the mouth of the Los Angeles River, involving 5,200,000 cubic yards of material, was completed in 1946. With the further improvement of the Los Angeles-Long Beach Harbors, similar dredging at the mouth of the San Gabriel River may be required in the future.

San Pablo Bay. An unusual maintenance dredging problem of major importance exists in the San Pablo Bay and Mare Island Strait project. The conclusions arrived at from a study of the problem resulted in the continuation of normal maintenance dredging and the subsequent temporary adoption of agitation dredging. Agitation dredging as undertaken was based on the assumption that during periods of maximum ebb tides, currents would carry material into San Pablo Bay and deposit it in deep waters. This method has resulted in conflicting opinions as to whether it is satisfactory. A factor worthy of mention is an average deterioration of about 1,260,000 cubic yards in the Mare Island Strait Waterway each year. Maintenance is now undertaken by normal methods of hopper dredging. However, an expensive maintenance problem continues to exist.

Sacramento River. Continued deposition of natural and mining sediment in navigation channels of the Sacramento - San Joaquin Valley has required the dredging of about 700,000 cubic yards of material annually from the Sacramento River Channel, about 450,000 cubic yards annually from the Suisun Bay Channel and about 400,000 cubic yards annually from the Deep Water Channel to Stockton, in order to maintain authorized depths in these projects.

Columbia River Basin. To the present time, United States funds in an estimated amount of $12,000,000 have been expended for maintenance dredging on authorized river and harbor projects in western Washington. In addition, considerable sums have been contributed by local interests for work by the Government, and a great amount of continuous maintenance by private capital has been necessary. The silting of harbor navigation channels and tributary streams as far upstream as the tidewater effect is an ever present problem, the most satisfactory solution for which has been maintenance dredging.

Beach Erosion

In connection with harbor work, the Corps of Engineers is charged with investigations and studies of beaches with a view to devising means of preventing erosion. As beaches are deposits of sediment (sand, gravel and shell), beach erosion studies necessarily involve the study of sedimentation. Not infrequently the problem of erosion of a beach is closely connected with the deposition of sediment in a nearby harbor. A well-known illustration of such a condition is Santa Barbara Harbor, California, an artificial harbor which was created by local interests by the construction of a breakwater. The breakwater caused the deposition of sediment which was being moved along the coast under the influence of littoral currents. As the adjacent beaches are dependent for their existence on the continuing supply of this material, interference with its supply to the beaches caused them to be depleted of sand. At the same time the harbor was being shoaled. The beach erosion and harbor shoaling situations are now being alleviated by pumping on the beach material hydraulically dredged from the harbor.

Similarly, shore structures for other purposes than improvements for navigation have created beach erosion problems. In investigating beach problems it is important, therefore, to determine the source of supply of the beach deposits. It can then be ascertained whether the supply is being interrupted by natural or artificial means and what the most effective remedial measures might be. In cases where sediments are being introduced into the ocean by streams, the study of beach problems may require investigation of rainfall and runoff of tributary drainage areas. In such situations flood-control projects may have an effect on beaches by modifying the rate of supply of sediment.

Conclusion

This paper indicates a few of the major sedimentation problems in connection with river and harbor projects. The engineering profession is challenged to produce solutions to these problems - solutions that are sound and feasible from both an engineering and an economic standpoint. The intelligent development and management of our rivers and waterways is essential to the protection and improvement of our productive farm land and our large cities and industrial centers.

Acknowledgements

In response to a request for information concerning sedimentation problems in rivers, floodways and harbors, the Division and District Engineers of the Corps of Engineers contributed statements covering their particular problems. The principal portion of the text of this paper has been extracted from these contributions, and in many cases the information contained herein is verbatim. Complete reports on a particular subject were made available in some instances. It is quite impossible to cover the field in seven-league-boot style and at the same time do justice to all the sedimentation problems contained in the many deserving reports that have been made available for use. It is desired to thank the many contributors who furnished material for this paper and to point out that credit is vested in those individuals whose cooperation has made it possible.

DISCUSSION

ELLIOTT FLAXMAN.* Mr. Hathaway's paper stresses the general problems of channel sedimentation or scour in the major drainage basins of the Midwest and Southwest. It seems appropriate to point up the relationship of sediment sizes to channel changes which must be dealt with on streams which are generally smaller than those discussed by Mr. Hathaway.

On streams of the Northwest and Northeast with which the writer is familiar, the movement of gravels, although for short distances year by year, constitute a threat to channel improvements, capacities and adjacent banks. Sporadic efforts at bank revetment on the Walla Walla River, for example, have not prevented and have perhaps aided the development of fresh areas of erosion downstream. It has been found that a coarse bed load moving in streams through a flood plain reach must be stabilized in order to prevent loss in channel efficiency, loss of riparian lands and aggradation through accretions from the banks. Local impairment of floodways noted in the Upper Susquehanna of New York State and in the far West have been caused by excavation of channels from tributaries across fans and flood plains to the major drainage. In the Upper Susquehanna, glacial gravels normally delivered to the streams in small quantities are carried through former areas of deposition and into the principal stream where lower grades prevent dissipation of the accumulated material. A similar situation occurs in the Russian River Basin in California where artificial changes have impaired the drainage efficiency of a tributary channel. The conservationist and engineer should determine the effect of artificial changes of a river system and what may be done to reduce the volume of debris which may create a hazard due to those changes.

The problem of maintaining a stable, excavated channel through alluvial material consisting of fine to coarse sand has arisen in the development of work plans for flood control projects of the Department of Agriculture in the Santa Ynez River Basin of California and the Boise River Basin in Idaho. Severe gully development in tributary drainage basins has caused a large volume of sand to be deposited on highly developed, gently sloping fans and flood plains. An excavated channel of approximately 1 percent grade across the fan of East Cebada Canyon in the lower Santa Ynez River requires removal of sand yearly. In recent years this has been largely due to accretions from the unconsolidated banks of sand deposited since the beginning of accelerated gully development. Low, variable rainfall and droughty soils prevent establishment of vegatative controls and it is the opinion of engineers that construction of a concrete lined channel is the only permanent answer to the problem.

Mr. Hathaway's statement that six debris basins have been constructed in the Los Angeles District presumably refers only to those of the Army Engineers. In addition, the Los Angeles County Flood Control District has constructed about 20 debris basins at the mouths of San Gabriel and Santa Monica Mountain tributaries.

The statements on harbor sedimentation suggest that the development of costly maintenance operations in proposed harbor areas may be foreseen by comparison of capacity, shape and position of the harbor to a hypothetical reservoir on the same stream. A small harbor at the mouth of a large stream has a low capacity-inflow ratio and will quickly lose its capacity in a manner comparable to a small reservoir on the same stream although much fine material may be swept out to

* Sedimentation Specialist, Water Conservation Division, Regional Office, Soil Conservation Service, Portland, Oreg. (discussion not read at Conference).

sea. Flocculation by the action of salt water in the harbor areas induces deposition, as Mr. Hathaway points out. Slack water areas at the mouths of rivers and in artificial harbors also furnish ready deposition areas for bed load carried by the streams.

CARL B. BROWN. Harbor sedimentation is a problem of large economic significance. A study made several years ago by the Soil Conservation Service on Baltimore Harbor indicated an annual inflow of about 600,000 cubic feet, with an annual dredging cost, pre-war, of $150,000. The sediment is coming almost entirely from soil erosion on the upland drainage area. That represents an annual cost of about 50 cents per acre of drainage area contributing the sediment and dredged annually from the harbor by the Corps of Engineers.

GERARD H. MATTHES.* The object of this discussion is to invite attention to the need of revising current definitions of "sediment" by including therein the solids which normally are transported in solution. As stated by Mr. Hathaway, sedimentary deposits of considerable magnitude result from the flocculation of clays in suspension, and from the precipitation of solids in solution. Their removal by dredging from harbors and coastal waterways runs into great costs annually. These chemical processes are forms of sedimentation and merit recognition as such.

It has been customary to restrict the term "sediment" to designate only fragmental mineral debris transported by water, which settles out by gravity, a concept which takes cognizance of strictly physical processes only. It ignores the fact that solids transported in solution enter into and constitute a part of every fragmentary sediment deposit; it ignores also the deposition of solids by chemical precipitation. Manifest inconsistencies have resulted from this customary interpretation of the term "sediment" - inconsistencies which seem all the more inexplicable when one realizes that Webster's International Dictionary recognizes that sedimentary deposits may result from either physical or chemical processes. Excerpts quoted from this dictionary are appended to this discussion.

To elucidate, consider the case of a river bar in process of formation. Particles of gravel, sand, silt and clay - i.e., fragmental mineral debris - find lodgement and build up the bulk of the body of the bar. But each particle, down to the most minute, has a film of river water adhering to it, water which contains solids in solution. There results a bar structure containing chemical constituents, some of which may drain out or be replaced again as river stages fall and rise, but the residue of which, in the final consolidation or drying out of the bar, crystallizes out and coats the fragmental particles. To cite a well-known case, rivers whose waters leach tannic acid from the roots of swamp vegetation, contain tannates which coat sand grains and gravel so thoroughly as to render their sand and gravel wholly unfit for use as concrete aggregates. Another illustration is afforded by our Western streams, especially those of the arid regions which carry a heavy dissolved load - in some instances heavier than their suspended load - where efflorescence and incrustations along river banks, on bars, and even on the river bed proper where dry, are common sights. Here, again, the chemical constituents are detrimental to concrete and also to vegetation, as is well known.

Consider, next, the case of the bar first discussed, after a lapse of geological time, when it has become consolidated into sandstone. Analyses of its texture and chemical composition disclose the presence of some of the solids that prevailed erstwhile in solution in the river water that built the bar; and not unlikely also, some of these chemical constituents played a part in the cementing processes that bound the sand grains together to form the sandstone. Worthy of note is the fact that to geologists and engineers, sandstone is known as a <u>sedimentary formation</u>.

Transferring our thoughts next to the chemical sedimentation processes in harbors and estuaries mentioned by Mr. Hathaway, flocculation caused by sea water is found to take place on a vast scale, so vast in fact that deposits in our South Atlantic and Gulf Coast ports which require removal by dredging are reckoned in terms of millions of cubic yards annually. Nor does all that is removed by dredging constitute the total deposited by chemical action, for a large part is swept out to sea by the ebb-tide currents.

Flocculation is an electro-chemical process of base-exchange analogous to that which takes

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place in the reconditioning of zeolites used in water softening. Briefly described, the clays that result from the decomposition of limestones, dolomites and granitic rocks of the Appalachian Mountains, are hydrous silicates of aluminum having a calcium-magnesium base. The presence of iron oxides gives these clays their bright red color and accounts for the red color of the river waters descending from these mountains. The clay particles, in the course of their journey down the river in suspension, have no tendency to flocculate or deposit. They are kept in a state of complete dispersion due to all being charged with the same electrical potential. Contact with the salt water of the ocean causes the strong sodium in the latter's composition to become dominant in the chemical reactions that ensue. It takes the place of the calcium and magnesium while these latter combine with the chlorine of the salt water - a so-called base exchange. There results a hydrous silicate of aluminum with a sodium base, whose particles at once form nuclei which settle out. In simple language, what at first was a calcium clay now has turned to a sodium clay. The red color fades to a yellowish-gray and eventually to a bluish-gray. The deposits so formed partake at first of the nature of a sludge, which still permits a sounding lead to penetrate and touch bottom, but which offers considerable resistance to the passage of hulls and propellers of ships. If permitted to accumulate and lie undisturbed, compaction takes place and a stiff dark blue clay eventually results, known to engineers and geologists as marine clay. Deposits of this kind are abundant in stratified rocks as far back as the earliest, and are recognized as sedimentary formations.

Sludges result also from the chemical reactions of sewage and industrial effluents upon contact with salt water, as mentioned by Mr. Hathaway. Although not recognized as geological formations, these sludges nevertheless, after attaining a certain degree of compaction, may well some day become regarded as sedimentary formations.

In order to dispel any misgivings as regards the propriety of including flocculated and chemically precipitated matter in the definition of sediment, the following excerpts from Webster's International Dictionary, second edition, are here quoted verbatim. Pertinent statements have been underlined by the writer.

Sediment. - Latin sedimentum, a settling, from sedere, to sit.

1. The matter which settles to the bottom from a liquid; settlings; lees; dregs.

2. Geologic material, or a mass of it, deposited as by water. To deposit as sediment.

Sedimentary.

1. Of, pertaining to, or containing, sediment, as sedimentary deposits.

2. Formed by or from deposits of sediment, as sedimentary rocks.

Sedimentary rock.- Geologic rock formed of sediment, mechanical, chemical, or organic; especially:

1. Clastic rocks, as conglomerate, sandstone, and shale, formed of fragments of other rock transported from their sources and deposited in water.

2. Rocks formed by precipitation from solution, as rock salt and gypsum, or from secretions of organisms, as most limestone.

Sedimentation.- The act or process of depositing sediment; also, the deposition, especially by mechanical means, of matter suspended in a liquid, as the sedimentation of a water supply.

Flocculate.- To aggregate into small lumps; - said of soils, sediments, etc.

Lee or Lees. - That which settles at the bottom, as of a cask of liquor, especially wine during fermentation and aging; sediment; dregs.

Dreg. - Corrupt or defiling matter contained in a liquid, or precipitated from it; feculence; lees; grounds; sediment.

J. W. DIXON.* I wonder if I could make a couple of general remarks about Mr. Hathaway's statement, which I think cover some of the most challenging points that face all of us in sedimentation work. He pointed out, I presume correctly, that the irrigation diversions in the Upper Arkansas have caused a change of regimen in that stream, and mentioned the fact that in certain respects that had caused increases in the flood damage. That is a problem that the Bureau of Reclamation must face, and we are endeavoring to face it intelligently. Similarly I think other agencies, such as the Corps of Engineers in their channel work, must face realistically the problem which regulating works are causing in the rise of flood plains. The third point that I want to bring out is degradation or aggradation of river channels below big dams. We in the Bureau have had some experience along that line on the Colorado River and elsewhere. I think that Mr. Hathaway pointed out that on the Missouri we are anticipating such an effect from the proposed dams. I don't think any of us knows exactly what that effect will be, but in the progress in the development of major streams, or even of minor ones, we engineers who are confronted with the designs, plans and layouts of structures must take full account in our plans of the effects which we think they will have. Unfortunately, some of those effects will not be good.

RALPH F. RHODES.** The problem of sedimentation in the Savannah River, Georgia, is typical of that in many of the rivers of the South Atlantic Coast. The basin has an area of 10,600 square miles and is divided into the Appalachian Region and the Atlantic Plain, the former being subdivided generally into Appalachian Mountains and the Piedmont Upland. On the southerly side of the Piedmont Upland, which has an area of about 7,200 square miles, lies the Fall Line, and south of this, 3,200 square miles of Coastal Plain, part of which, at least, is made up of the Coastal Terraces. The river rises in the Appalachian Mountain area and flows through the Piedmont Upland and the Coastal Plain to its mouth in the Atlantic Ocean.

In the Mountain and Upland areas, the soils are derived from the granite rocks or from hornblende rocks and are light or heavy, according to the proportions of sand or clay in them. These soils are generally red, especially those derived from the hornblende rocks. The soils of the Coastal Plain, being derived from limestones, clays, and sands, are calcareous, argillaceous, or sandy soils predominating.

The largest rivers of the Coastal Plain of Georgia are what may be called through-flowing streams,i.e., they rise above the fall line and flow across or through the Coastal Plain. Above the fall line, they have general slopes up to 50 feet to the mile, while below the fall line the slopes are about 0.5 foot to the mile. They differ from the smaller streams in the quality of their waters which are more or less turbid and stained red or reddish-yellow by fine particles from the red clay of the Central Upland. These rivers are older, geologically speaking, than the Coastal Plain rivers, as the latter were not formed until after the development of the Coastal Terraces.

The streams rising within the Coastal Plain are much clearer than the through-flowing streams. Although the water is clear, it frequently contains, in suspension, very finely divided particles of decayed vegetable matter which color it with shades of brown.

The through-flowing streams have the larger drainage areas, and their sources are in the mountains where there is heavy rainfall. The average and maximum river discharges are, therefore, larger than the Coastal Plain streams.

As the through-flowing streams pass through the Mountain and Upland areas, they accumulate a load of eroded soil, depositing the heavier sand particles in the channel wherever there is an opportunity, such as in reservoirs, but carrying most of the finely divided clays on towards the lower rivers. When these rivers pass the fall line, their slopes flatten and they become meandering streams, caving their banks, and thus producing a load of sand which moves along the bed and a finely divided and suspended load of clay which is added to that already in suspension from above the fall line. The lower reaches of the through-flowing streams are, therefore, very different from the Coastal Plain streams, as the latter contain very little material in bed load movement and very little solid matter in suspension.

The mouths of the Coastal streams, where they emerge from the youngest geological terraces andenter the ocean, are single channels and are characterized by being deep gorges and by having pronounced ocean bars in the ocean and across their mouths. On the other hand, the lower portions of a through-flowing stream are characterized by a delta formation through which the river

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discharges into the ocean through a number of relatively shallow mouths, between which are marsh islands of various sizes. This delta formation and the islands were probably formed gradually by the deposit of sand and silt brought from the upper reaches of the river. The nearer the mouth of the river, the finer the sand and the larger the percentage of silt. The deposit of the sand within the channel was due to the reduction in current velocities by the tide waters, and the silt was precipitated by the action of sea water. The deltas are, therefore, a mixture of sand and silt.

The hydraulics of the tides in the mouth of a tidal river offer a wide field of research to obtain basic data for the use of engineers in designing channels which will be self-maintaining and stable in somewhat the same respects as the mouths of the Coastal Plain rivers. A complete investigation of such problems includes that of the sand moving as bed load and the larger problem of the silt which is deposited by the precipitating action of salt water.

An important step in an investigation of this kind may be the accurate analysis of the transported material to determine its composition. The next step may be finding where it comes from. If the original material is found principally in caving banks of the upper river, the remedy, as far as eliminating the silt is concerned, may be revetting the caving banks. It is possible that some of the silt may be mud from the marshes and some of the sand may be from the along-shore drift which is brought to the inside channels by the flood tide.

The precipitating agent or agents should be determined, together with the conditions under which they are most active. It is not sufficient to say that the precipitating agent is sea water. With an exact knowledge of the precipitating agents and how they act on the loaded fresh water, we will know how any industrial waste which may be dumped into a stream affects silt precipitation. The pollution of our streams by industrial and domestic waste is a matter which is now receiving some deserved public attention, and the determination of how such pollution affects the deposit of silt in navigable waterways may be a large factor in formulating policies and regulations governing disposal of wastes.

The importance of this matter of silt deposit in navigable channels is indicated by the cost of their maintenance for navigation. Such costs for four harbors on the Atlantic and one on the Gulf of Mexico are given in Table 1. In addition to the cost of removing this deposit, ships are delayed because now and for some time in the past dredging plants for the prompt removal of these deposits have not been available, and navigation has suffered accordingly.

TABLE 1. COST OF MAINTENANCE
ATLANTIC AND GULF PORTS ON SILT-BEARING RIVERS

Location	1941	1942	1943	1944	1945
Delaware River, Philadelphia to Sea	$1,231,000	$2,183,000	$4,263,000	$2,951,000	$3,273,000
Schuylkill River, Pa.	171,000	96,000	270,000	540,000	575,000
Wilmington Harbor, N. Car.	238,000	49,500	226,000	216,000	123,000
Savannah Harbor, Ga.	455,000	449,000	532,000	665,000	843,000
Mobile Harbor, Ala.	401,000	127,000	277,000	320,000	384,000

The above remarks do not cover all phases of the investigations and studies which should be made to solve the problems of sedimentation in rivers. They draw a general picture, however, which shows the wide field to be investigated and the importance of the problems connected therewith. It is understood that the Corps of Engineers is considering initiating some investigations and studies looking to the solution of the problems referred to above, and it is believed that the money and effort which may be expended along these lines will pay large dividends in the solution of problems of channel improvements and maintenance in the mouths of rivers flowing into tide water.

SEDIMENTATION PROBLEMS OF THE LAND

by E. N. Munns*

In the botanical world, a weed is a plant out of place. In the world of water, sediment is also a weed -- soil out of place. Soil in place is like a gorgeous rose, the pride of our gardens; soil out of place is like the dandelion, a public nuisance. Occasionally some botanist works with a weed. He propagates it, fertilizes it, cultivates it; sometimes he comes up with a new petunia, something of value. Some of us have done the same thing with sediment. We have encouraged it, fertilized it, leveled it. And when we have worked over it, fussed over it, and spent money on it, sediment becomes a valuable petunia in the form of a beach, an airport, a real-estate subdivision, an island. However to most of us, sediment is still a public nuisance. And because sediment is the weed of our water world, we must treat it as a weed lest it crowd out our valuable plants. Like good gardners, we must prevent, reduce, or control this weed.

Soil out of place is primarily a land problem, for it is a product of the land. It is the primary product of land abuse. Lacking protective plant cover, soil is torn from its rightful place by water, carried by water, and deposited by water. When in its lightest form and at its minimum, sediment may be only the "murk" in the cloudy water of a spring or merely the discoloration in a rivulet. At its maximum, soil on the move may resemble a concrete mix which contains but little water but floats great boulders on its surface like so many corks. When displaced soil comes to rest, it may be anything: mud flats, sand bars, deltas or debris cones. Wherever displaced soil may be found as suspended material, bed load, or sediment, it indicates mistreatment of land, mismanagement of our farms and ranches, fields and orchards, range land and forest.

Soil out of place is usually considered a problem of the bottoms. It is also a problem in the uplands. Here one will find its origin. The site from which this debris came is claw-marked by the thousands of gullies on our hill lands, by raw cuts in the peaceful banks along our waterways, by arroyos and ravines in our mountains, plains, and deserts. Its upland source is also marked by infertile fields, depleted range, declining agriculture, and by rural slums which invariably are a concomitant of impoverished land. Yet these ugly sores which some dare to say are normal, have only recently been developed on land that has laid quietly under the sky for thousands of years before man seriously abused the earth's surface.

Soil out of place threatens our national existence. It threatens us in the upland areas--the point of origin. It threatens us at its resting places in the bottoms. History tells us that deteriorating soil, no less than deposited soil, has brought proud and august nations to disaster. We are told that Mesopotamia once supported some 30 million people on 10 million acres of land. Today, its 5 million acres of tillable land barely sustain its 5 million citizens, many of whom have been reduced to a state of beggary. Even in our own West, a civilization of high order once flourished; today we trace faint lines on areal photographs that mark the route of extinct irrigation canals. This civilization too has all but disappeared because of soil out of place. Will history repeat itself? That question must be kept constantly before us.

Soil out of place has adversely affected irrigation. The effectiveness of irrigation ditches is maintained at a high level just so long as the transported soil material remains in suspension from the time it enters the system until it reaches the land. When fine silt reaches the land, such material may be a source of fertilizer, even as the waters of the Nile bring valuable headwater silt to the irrigated lower valley. The colloidal material so carried may also be beneficial in sealing unlined canals and ditches against water losses. On the farm, this material may or may not be damaging, depending on whether or not it may have a tendency also to seal the soil against the percolation of irrigation water. As yet such damages by suspended silt to American irrigation are relatively small.

Great damage however is caused to irrigation by the heavier sediments which are directly deposited in the ditches and canals. Where clear water is taken from a reservoir, this problem is largely absent, but when direct stream diversion is involved, troubles begin. Many irrigation

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enterprises, particularly the smaller ones, have been in difficulty year after year because with declining summer flows, sediment deposits at the dam have shifted position and so prevented water from entering the canals. In the light of present-day interest in great public works, there is an inclination among public agencies to forget the small developments. We, as public servants, cannot afford to take lightly the troubles of the small irrigation enterprises for these units make up 45 percent of all land under ditch and are 96 percent of all enterprises.

Troublesome as such sedimentation may be at the diversion dam, it is as nothing compared to the damage caused by the larger materials which enter the ditches and canals. I have been told that some of the main canals in the Boise Valley irrigation system have been occasionally so filled with erosion debris that sufficient water could with difficulty get through the ditch. In 1939 the average annual damage caused by sedimentation of canals and ditches in this valley was estimated at around $350,000. Rough calculations in the Boise Basin indicate that the irrigation farmer suffers an annual damage of one dollar an acre a year because of sediment. Translated into other terms, it costs him one dollar an acre a year to have someone so abuse the plant cover on his watershed as to cause the soil to get out of place. At Minersville, Utah, the main irrigation canal was filled with debris from upstream sources six times in a single season. The failure to get water through the ditch system that year cost the community some $60,000 in crop failures, and, in addition, irrigation assessments were increased 500 percent. With the right kind of soil cover, these losses could largely have been prevented. Other small irrigation enterprises have been brought to the brink of disaster by sedimentation resulting from watershed abuse.

Other problems affecting irrigation arise from soil out of place. We shall here be content only to mention the Rio Grande, probably the nation's most severely injured major river and certainly so where irrigation is concerned. The Rio Grande is only thus casually treated here because its conditions are widely known and because undoubtedly others will refer to them many, many times. The Rio Grande Valley is America's national monument to the destructive power of man-induced accelerated erosion and of its resulting sedimentation.

Soil out of place has ruined thousands of acres of farm land. Large areas of once rich and fertile bottom land in eastern States have been buried under heavy deposits of infertile soil materials. Extensive areas of Western valley lands have likewise been destroyed by the deposition of debris torn from slopes and channels.

The Soil Survey Report for Elbert County, Georgia, states: "Some of the areas mapped as meadow were originally good areas of congaree silt loam or congaree fine sandy loam, over which a mixed covering of sandy material has been deposited following the clearing of adjacent hillsides. The bottom land of Mill Shoal Creek about a mile from the county line is typical of this condition. It was reported that all the bottom was cultivated and the soil was congaree fine sandy loam 12 years ago. At present the bottom land is a sandy wash with poor drainage and is covered with alders and willows."

Repeated flooding in Utah in recent years has been responsible for the loss of rich agricultural land through deposition. Such deposition of sand, gravel and boulders on fertile valley lands appears always to be associated with the summer floods that originate on mistreated mountain watersheds. In 1945, a mud and debris flow from the abused portion of one small watershed of only 10,000 acres produced damages of over $100,000, a considerable portion of which was due to the deposition of sediments alone.

In the mountain areas of the West, it is not uncommon to find heavy deposition of infertile materials on meadow lands following abuse of watershed slopes. Many valuable grazing lands have thus been converted to willow and alder thickets as a result of a single storm. These recent deposits, sometimes ten or more feet deep, can be readily identified by the sharp contrast between the original dark humic soil below and the lighter colored raw mineral soil on top.

Most of us don't like spinach, especially with sand in it. Livestock don't like sand in their diet either. Yet many pastures and grasslands are each year given a coating of earth material which virtually ruins the land until new growth appears, or until after rains have washed the soil off the plants.

Deposition in both minor and major stream channels has also played a major role in destroying or reducing the productiveness of bottom lands. In channels of gentle slope we repeatedly find depositions so great as practically to fill stream channels almost to the level of the adjacent bottoms. Both east and west, north and south, our modern culturally-induced accelerated erosion has resulted in bed loads so heavy that many streams finally have become tired and dropped

their load in their tracks. The evidence of this is written in nearly every section by the lessened free-way under bridges, by clogged road culverts, in the higher stages of floods, and in the swamping of adjacent lands as the water table rises. Classical examples of these can be found in the Driftless Area of Wisconsin, in the hill section of northern Mississippi, and in the Rio Grande. I am told that the railroad embankment at San Marcial on the Rio Grande has been raised 36 feet since 1929.

The aggradation of channels is responsible for greatly accentuating flood damages. With clogged channels, flood waters that normally would do little damage spread out on each side of the channel, overflowing periodically lands that were flooded only occasionally. And with such frequent overflowing comes also the concomitant damage, that of overbank deposition of infertile soil material upon the flood plain. Such channel aggradation is not stable; it has the tendency to migrate upstream as shoaling progressively causes deposition. Thus the ill effects are spread.

The flood of March 1936 in the Connecticut River Valley completely destroyed some 300 acres of farm land in Vermont, a State which cannot well afford such a loss. In addition, nearly the same acreage was lost due to the excessively heavy deposition of infertile sand and gravel. In addition, over 1,700 acres were covered with from 6 to 8 inches of gravel; these were reclaimed with great difficulty. Some 2,200 acres were covered with shallower deposit of infertile material and most of these could be reclaimed. In all, some 4,500 acres of land were adversely affected by sediments in this one flood. And this is an area where channel degradation is a more dominant process than in most flood plains of the United States.

Sediments also tend to accumulate wherever small tributary streams enter into main valleys. Such sediments when of heavy material often result in the development of fans which grow to such an extent as to cause the main stream to change its course. In one flood, a fan of great dimensions resulting from a forest fire, pushed the Salmon River in Idaho against the opposite bank where a new cycle of bank erosion was induced. Sediments debouching from one tributary drainage in the Boise River Valley have been reported to be responsible for pushing the river two miles across its valley.

Delta formation and channel filling present other problems. Of these, perhaps the most important is swamping. As the channels are filled, ground water rises. In some valleys, the water tables have risen until in places they are just at the surface. Ponding becomes frequent. In such cases it is not long before valuable bottom lands become mediocre hay land and finally are surrendered to willows and alders. Rising water tables have in some areas resulted in the killing of considerable areas of commercial timber and the formation of swamps. Such swamping can be illustrated beautifully in the middle Rio Grande. Cooperrider and Hendricks state that, "Of the 85,000 acres that had been rendered unfit for farming, about 80,000 were given up on account of waterlogging, which resulted from the silting up of the main river channel and a corresponding rise of old canals and ditches to levels far above those of bordering lands."

The direct damages by sedimentation in channels are due first to increased flooding, increased deposition on the flood plains, and finally rising water tables which drown out cultivation. One aspect of damage of this nature frequently overlooked is that with the loss of valley lands, people are forced onto poorer soils on the slopes. Although agriculture may be practiced on sloping land, more care in cultivation and more thought to farm practices must be given if the soil is to be held in place. But with impoverishment of bottom lands, the farmer turns to the sloping land and attempts to recoup his losses by tilling a greater area, and, unfortunately, usually by methods poorly adapted to the site. The result is an acceleration of erosion, the products of which are dumped unceremoniously onto the valley lands only to augment the problem.

Another aspect of damage from swamping is the increasing danger from malaria. Throughout much of the country, cultivation has greatly reduced the area of mosquito breeding grounds. Swamping as a direct result of soil out of place has increased the malaria hazard in many parts of the country, and in certain areas is currently causing great concern.

Land drainage is a big problem in the United States, far bigger than most of us realize. At present, there are about 40,000 organized drainage enterprises in 38 States, involving 87,000,000 acres. But it is startling to realize that of these, 24,600,000 acres of presently cultivated land need rehabilitation of existing outlet drainage improvements before maximum production can be obtained from them. Outside of organized drainage districts are 98,000,000 acres of wet, swamp, and overflowed lands, of which 20,000,000 acres could be placed in profitable production at reasonable cost. Sedimentation is the great threat to the drainage improvements of these lands. The exact figures are not known, but many million acres of the total are in need of rehabilitation because of sedimentation. Practically all the lands needing rehabilitation are in

their present state because of soil out of place.

In Mississippi, approximately 3,000,000 acres are in organized drainage districts. About 1,900,000 acres are cultivated and otherwise improved but because of sedimentation are in need of extensive restorative measures. A report on drainage districts in Mississippi states: "The most difficult drainage problems are in areas lying along the eastern edge of the delta adjacent to the foothills. Enormous quantities of silt carried by the hill streams are deposited at the places where the streams emerge from the hills and enter the delta. Under natural conditions alluvial fans rising as much as 20 feet or more above the levels of the surrounding delta lands were formed at these places. These alluvial formations retarded the velocity of the hill streams and acted to spread flood waters in several directions over delta farms. In attempting to prevent flooding many districts excavated drainage channels through the alluvial accumulations and constructed guide levees to divert flood waters into main streams and rivers. Many of these improvements operated only for a short period, soon becoming destroyed by heavy silt deposits rendering the drainage works partially or wholly ineffective . . . In some districts, drainage conditions are much more unsatisfactory than before ditches were excavated . . . Usually at distances of about 3 to 5 miles from the hills, delta channels fill with sand, silt, and debris so completely that the level of the deposited material rises above the general land surface."

The report describes a highly cultivated area drained by a newly dug channel in 1928. Ten years later the lower half of the channel had become completely filled with sediment and the deposition over the adjacent fields during this period accumulated to depths of as much as 10 feet.

This was bottom land. What of the uplands? Drainage improvements in the tributary drainage area of the Yazoo River watershed required an original investment of over $2,000,000. In 1941 it was estimated that it would cost $2,850,000 to rehabilitate these works. At present day prices, restoration would in all probability be near the original cost. Rehabilitation alone will not change the conditions which cause deterioration of the channels unless the projects are constantly maintained, and so long as malpractice on the land continues, maintenance costs due to sediments will be high. Experience has shown, however, that agricultural returns during periods of low prices will not allow for adequate maintenance. A woeful aspect is that poor drainage conditions have reduced the income of the area by about $1,000,000 annually. Lands that should have produced an estimated net income of about $13.30 per acre annually were in 1942 producing only $5.70 per acre. Land abuse that results in sedimentation is costly to the farmer and to the public.

Other areas show somewhat similar physical and economic results of sedimentation of drainage channels. An examination of the Wabash River drainage basin revealed that 4 million acres of drained lands or 20 percent of the entire watershed are affected by the sedimentation of drainage ways. Much of the damage is caused by the deposition of silt, sand, and gravel which comes from the not too steep slopes adjacent to the waterways and from sheet erosion of cropped hill fields. Average annual maintenance cost was estimated at $2,100,000, of which about $525,000 is due to sedimentation. This represents an annual outlay of 13 percent of original cost of the entire drainage project.

There is another phase of this problem that bears mention. Displacing soil by erosion and its transit as bed load cannot be given much emphasis at this stage of the conference. Yet because moving bed loads are a source of damage often unevaluated, a damage seldom considered by engineers, perhaps including some sedimentationists, but affects a great segment of our people, it merits notice. Bed loads, the products of accelerated erosion brought about by carelessness and abuse, directly and adversely affect fish life in many of our inland waters. Bed loads resulting from improperly constructed roads, raw road slopes, raw cut banks and fills, have destroyed the nests and eggs of our sport fish. Bed loads from the constantly ravelling sands and gravels from upland gullies on agricultural lands, unhealing sores on overgrazed ranges, open wounds on deforested hills, bury or destroy the food on which sport fish live so that even the legal-sized, liver-fed planted trout starve to death. Or if the fish do not starve, the shoaling of the channels raises the temperature of the water to such a point that the fish disappear. Many streams, once worth from $500 to $1000 per mile for fishing, have been ruined for that purpose by carrying soil out of place. It has been estimated that up to as high as 90 percent of all the legal-sized fish planted in inland waters are killed by sediments.

Soil out of place in our channels also deleteriously affect other forms of wild life. Beaver for example are forced to move, the moose that feeds on aquatic vegetation must migrate to better pastures, and wild fowl that once found food in abundance in shallow ponds and lakes, now finds sand bars and gravel beds lying naked in the sun.

We all must recognize that sediments are soils out of place. We must recognize all the damages they do or are capable of doing. Wholly apart from this, however, all of us should realize that we are partially to blame. Many practices are followed by the engineering profession that lead to added bed load and to damaging sedimentation. Let us recount a few of them just to indicate that the engineering profession can of itself do much to help matters.

In many construction activities, no care is taken to insure that the displaced soil stays put. Foundations, streets, sewer systems, aqueducts, pipe lines, tunnels, dams and other types of public and private construction jobs are undertaken without any effort on the part of those who prepare the contracts or do the work to make sure that soil is kept out of stream channels. We in the public service should be alert at all time to keep the public's water free from soil.

Transmountain diversions are in the public eye. Engineers have taken water from one drainage system for use in another. They have not worried too much about the downstream slope where they spill the water. Instead, at the mouth of the tunnel or at the divide, they have turned water loose. A slope or a stream channel is the product of thousands of years of adjustment. The slope can, with its cover, handle a small quantity of surface run-off; it cannot handle the continuous outflow from a diversion. A channel has become accustomed to a certain volume of water; it is not capable of handling a continuous volume many times its normal capacity. The result of releasing diverted water at a high elevation to permit the water to seek its own level has been disastrous. Slopes and channels have been gouged out. A new cycle of erosion has been started. The deposits below have caused damage and suffering, and will continue to cause damage until the channel is stabilized.

Cities desilt water taken directly from surface sources. Often this soil material is dumped back into the river.

Road building in rough areas, especially mountain areas, is all too often done without regard for the spoil material. We have many times seen this dumped unceremoniously over the bank to slough off into the nearest brook.

Engineers who lay out logging and other types of roads do not take cognizance of the kinds of soils involved, the stability of slopes, the need for avoiding meadows, the need for keeping soil wastes out of the creeks. In some areas, large quantities of sediments are thus produced to add to our job. We who are interested in the deposition of material that affects the use and productivity of agricultural lands, are concerned over the apparent lack of consideration which many engineers show to the sedimentation problem except at the place where the sediment lies. Unfortunately the need for the education of engineers as to sediment production - a major problem from our standpoint - is not a subject for discussion. But is it not time that the engineers interested in sedimentation and the preservation of the water resource call the attention of their construction brethren to the need for keeping soil in place?

This conference on sedimentation is badly needed. It is needed not only to make us realize that soil out of place is costing the nation much good hard cash, but also that it does actually threaten much of our economic and social life. To the man on the street, a reservoir with an expected life of 100 years is a permanent institution, yet there are those among us who have seen in our brief span of years the usefulness of water projects gravely threatened by sedimentation. We here are not the man on the street. We represent the public and have a responsibility to our public, a responsibility that transcends the life of a man, a responsibility that can only be met by safeguarding the life of the nation.

Many of us have heard, if we have not seen in print, statements by eminent engineers and others that when one dam is filled with sediment and no longer useful, man will build another and another. Many of us have also heard that many of our resources are unlimited. We may have heard some say that the range cannot be destroyed; the forests are inexhaustible; our oil will last forever; our iron ore and our copper mines will never play out; that when this or that resource is gone we will find substitutes. Some of us however do not believe in the thesis that substitutes will replace our natural resources.

A reservoir site is also a natural resource. Nature has provided man with relatively few really sound and feasible reservoir sites. They should be preserved until such time as man can develop a substitute -- if he can. We must remember that topography and geology are such in many drainage basins as to make reservoir construction a doubtful venture. We can dredge channels, we can make harbors, we can rehabilitate ditches, we can drain swampy land; we cannot, however, generally empty reservoirs of their sediments. Let is not therefore waste our reservoir sites. Let us preserve them as long as possible for a future public. Let us take every step

possible when a reservoir is projected or built to make sure that the soil on the watershed is kept in place. Let us also make sure that the public understands the problem we face.

In my judgment, the possibilities of markedly decreasing sediments through work on the land deserve far greater attention by water engineers and geologists than yet has been given. If the engineers who are responsible for great public works would publicly recognize the sediment problem and would be vociferous in their demands that the land managing public agencies bring about reductions in land abuse and misuse on the watersheds, the problems associated with soil out of place would be greatly minimized. Some lands now badly eroding or capable of seriously eroding may be worth much more to the public if in some form of nonuse that will prevent or reduce sediments than if used. Lands low in productivity or value, but high sediment producers, should be closed to all forms of damaging use.

That we must do something - and soon - about the displaced soil that already has been deposited we all recognize. We also know that the moving bed loads now already moving downward in the channels will soon come to rest and thereby intensify existing troubles. We ought to know that unless the land is cared for, even greater loads will descend upon us. It is up to the engineers to make sure that the land managing agencies recognize their responsibilities in so managing, operating or using land that the weed in our water world may be eradicated. And if the land managing agencies cannot achieve that reduction in sediment that will safeguard our public works, then the public will have to be called upon to establish those controls which will prevent the land occupiers and users from further injuring public investments. Engineers should lead the way.

Here in brief review we can only catch brief glimpses of the problem of living with our weed - soil out of place. This weed is now beginning to over-run our garden. Very little can be said in its favor. Instead it is damaging not only the works man is building to control and harness water for his beneficial use, but is damaging the land and the practices by which man provides himself with food and clothing. Soil out of place hurts the irrigationist, the city dweller who pays more for poorer quality water, the industrialist who uses power, the owner whose land is covered with debris. It drives agriculture from valuable bottom lands. It decreases crop production and increases costs. It spreads a weakening disease especially among those whose living standards are gradually lowered to substandard levels. It destroys recreation, and fish and other forms of wild life. It is most damaging to the public who in the long run must pay the bills.

The problem facing all of us, no matter what our special interest, no matter whether we be engineers or agriculturists, geologists or foresters -- the problem is what are we going to do about it? If we cannot eradicate it, how can we control it?

The answer is simple. The method of doing it complex. The cost enormous. The time element long. The only sage and sure method by which damaging sedimentation can be prevented is to reverse the processes that create it. Keep the soil in place. How to do it will take all the skills, ingenuity, and imagination that all of us - no matter what our background or experience - can bring to bear. That is our job.

DISCUSSION

JOHN N. SPENCER.* As usual, Mr. Munns has rung the gong. There is little I can say about his paper which would improve what has previously been said. Obviously, on our Western irrigation projects we have a serious problem, especially so if we are to believe what Mr. Munns has said. Personally, I am a believer because I have lived in the West, I have observed the situation on the land, and I know the seriousness of the problem.

Assuming the situation which Ed Munns describes as actually existing, then, unless something is done immediately, the Western irrigator is bound to suffer.

Congress has authorized the Bureau of Reclamation to construct irrigation projects. This agency has now under construction, or authorized, about two billion dollars worth of projects. When that program is completed there will be water storage reservoirs on practically every major watershed in the West. Up to the present time the Government has invested about 400 million dollars in irrigation installations. From that investment the nation is receiving about 525 million dollars in annual crop returns. About 81 thousand families are living on the lands irrigated

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by Bureau of Reclamation projects, and almost five million people are directly dependent upon these projects for a livelihood.

Assuming continuation of this mammoth construction program, we can look forward to the day when about four times as many acres will be irrigated, when the crop production will be four times as great, and when four times as many people will be dependent upon these irrigation installations. Are we going to sit by and wait until 30 millions of people must close shop and become "Mesopotamian type of beggars" because of our failure to regard the facts as set forth by Mr. Munns? I believe the answer should be an emphatic "No," and I wish to propose a plan of action.

In our planning and in the subsequent action let us divide the watersheds of the West into two parts -- the water supply area and the water use area. For the purpose of this discussion, the water supply area will be defined as that segment of the watershed from which is derived initial supplies of water to be utilized by irrigators, industries, and municipalities located in the water use area. The water use area includes the land to be irrigated and the cities and industries dependent upon an adequate supply of potable water. The water use area will include water storage facilities, canals, diversions, laterals, drains, the city water supply systems and hydroelectric power plants.

Our knowledge of the relationship between the two segments of the watershed may not be complete; however, it is complete enough that by utilizing the vast resources of knowledge in the hands of Federal agencies and local groups we can take the first positive steps toward protection of our greatest resources--land and water. Under this proposal, first priority in the water supply area would be given to the production of high quality water for consumption in the water use area. Initial steps should be taken immediately, based on minor tributaries, to determine the degree of lower priority use permissible in each contributing water supply area. These studies will show the nature and degree of grazing, timber and recreational use permissible without jeopardizing the quality of water and the resulting loss of values in the water use area. The data so secured should be made available to all interests in the water use area, who, I believe, when fully informed of the watershed problem can be depended upon to take whatever action is necessary to conserve the water resources and insure the permanent well-being of the people.

HAROLD B. ELMENDORF.* Mr. Munns has shown us the tremendous range of problems caused by sediment. All phases of agriculture seem to be threatened. Some problems are so serious that unless solved they will cause the abandonment of large acreages of farm land in another generation or two. He has pointed out that watershed lands are the source of the trouble and that we must look there for permanent relief. I can't add anything to Mr. Munns' excellent picture of this widespread threat.

However, I would like to point up his remarks by going into more detail concerning one stream system that we are all interested in. He mentioned the Rio Grande as one example of a deplorable state of affairs because of sedimentation. Answers may be found for each problem separately, but no overall solution seems possible as long as sediment keeps coming down from the watershed lands. The Rio Grande project extends from east of El Paso, Texas, to north of Las Cruces, with 155,000 acres almost entirely dependent on storage of flood waters in Elephant Butte Reservoir. The Middle Rio Grande Conservancy District extends from Socorro to north of Albuquerque, N. Mex., with around 70,000 acres of irrigated land. These two projects contain more than 90 percent of theapproximately 250,000 acres of irrigated land in the Rio Grande Basin in New Mexico. Three of the more serious problems of these irrigated areas are directly attributable to sediment:

1. Aggradation of the Rio Grande channel through the middle valley has clogged the outlets of existing drains and resulted in a rising water table. Unless checked this will eventually destroy the project. In one seven-year period the rise in water levels, averaged through the middle valley, was 0.1 foot a year.

2. Elephant Butte Reservoir has lost nearly 20 percent of its original capacity in thirty-two years of operation. If the past rate of depletion continues, in another 45 years Elephant Butte and Caballo Reservoirs will not have sufficient capacity to supply irrigation needs through even the second year of a three-year dry spell such as we have experienced twice since 1915. Buareu of Reclamation personnel who are now surveying Elephant Butte believe that deposition in

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the reservoir has been much less since 1935 than it was in the first twenty years of operation. This only means that the problem has been trasferred upstream and that the sediment load is lodging in the Socorro Valley rather than passing into the reservoir.

3. The large concentration of salt cedars and other phreatophytes above the head of Elephant Butte Reservoir is taking a heavy toll of water, estimated by the Bureau of Reclamation as being more than 100,000 acre-feet annually, that is sorely needed in the Rio Grande Basin.

Suppose we look at some of the solutions which have been suggested. Management of the Elephant Butte Irrigation District, which operates the New Mexico portion of the Rio Grande project, shrugs off its loss of reservoir capacity with the belief that when it becomes serious they can raise the dam and restore the lost capacity. But will the Middle Rio Grande Conservancy District and particularly the people in the vicinity of Socorro, with the knowledge of what has happened at the head of the present reservoir, allow the reservoir levels to be raised?

One suggested way to stop the robbery of water on its way to Elephant Butte is to dredge a channel through the large sediment deposits at the head of the lake. True, this might convey the flood waters through the salt cedars with a minimum of loss, but what about the sediment load in the future? Evidently, the salt cedars have been keeping much of the sediment out of the reservoir, but when flood waters are concentrated in an open channel this screening effect will be lost. It seems reasonable to expect the reservoir depletion to rise sharply if that is done.

Virtually everyone agrees that large reservoirs must be built in the Rio Grande and its chief tributaries to protect the middle valley from floods and sedimentation. The proposed reservoirs will provide room to store the sediment that is now coming down the streams for fifty to seventy years. Then sediment will begin to encroach on the capacity reserved for other purposes and usefulness of these structures will steadily decline. What do we do then? Simply build more reservoirs and start over?

Even the proposed large reservoirs, necessary as they seem to be, may cause new problems in some places. Granted that the release of relatively clear water should result in degradation of the river channel, at least for some distance below the dams. But where can this sediment go? Either it will be deposited in the lower part of the valley or it will be carried into Elephant Butte. Will either of these eventualities please the people who will be affected by them?

So we see that as long as sediment continues to be produced on the uplands, solution of sediment problems in the main river valley are only temporary and often will merely trade new problems for old. As Mr. Munns emphasized, the only permanent solution is to check the sediment at its source, on the watershed lands.

RANBIR SINGH SHRIKANT.* I am here as a trainee and don't have much experience in sedimentation problems. However, I can say, as has been repeatedly pointed out, the problem created by sediment transported by water cannot be too highly emphasized.

As in the western United States, we in India have been faced by problems created by sediment. Our area under irrigation is about 70 million acres, which is nearly equal to the area under irrigation in the rest of the world put together.

I was personally connected for three years with the maintenance of some canals in the Punjab. Our rivers mostly flow through alluvial plains and carry enormous quantities of sediment in summer. The sediment has a tendency to deposit in our canals and distributories and thus decrease the capacity of the channels and upset the balance in the distribution system. Much research hasbeen done by various Indian engineers in this field and the names of Kennedy and Lacey stand prominent among them. Generally speaking, the attempt of our engineers has been:

1. To draw into the canal only as much sediment as can be carried by it without deposition or scour, and

2. Distribute the sediment load into various laterals according to their sediment carrying capacities.

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I noticed quite an interesting phenomenon on the inundation canals which take off from river Indus. There is no dam in the river for diverting water into these canals. Use is made of creeks of the river which have flatter slopes and higher water levels. Due to change in the meander of the river, the mouths of these creeks sometimes used to get closed by sediment deposition, although the full length of channel downstream was still allright. We were able to keep the creek flowing by constructing suitable spurs at proper places.

To me it appears that the immediate problem before the irrigation engineer is not how to stop the sediment from reaching the streams, because, even if the water reaching the stream is quite clear, it will pick up its sediment load from stream's bed. Maybe we should devote still greater energy to perfect our knowledge of sediment transportation so that we can accurately design works to select and carry the desired quantities of sediment in different channels and reservoirs.