UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

SEDIMENT PROBLEMS ON IRRIGATION PROJECTS IN THE UNITED STATES

Hydraulic Laboratory Report No. Hyd-357

ENGINEERING LABORATORIES BRANCH
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DESIGN AND CONSTRUCTION DIVISION
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Sediment has been defined as: Fragmental material transported by, suspended in, or deposited by water or air, or accumulated in beds by other natural agents; any detrital accumulation such as loess. Sediment problems on irrigation projects, therefore, are any problems on these projects which involve the movement or disposition of soil material in or by water. In general, the sediment problems on irrigation projects fall into six classes, as follows: (1) filling of reservoirs, (2) scour or deposit in canals, (3) control of sediment entering canals, (4) enlargement of streams or drains, (5) aggrading streams, and (6) degradation of stream beds below dams. The purpose of this report is to discuss briefly these problems and the means of solving them, with particular reference to irrigation projects in the United States.

Filling of Reservoirs

Filling of reservoirs is probably the most important trouble on irrigation projects in the United States. The loss in this country alone due to filling of reservoirs was estimated by the United States Soil Conservation Service in 1947 as $50,000,000 per year. The principal reasons why this large loss does not stimulate more action to try to remove the cause is because most of the reservoirs are relatively young and are therefore only slightly filled with sediment, and the inconvenience at the present time due to the filling is relatively small. As the reservoirs become more and more filled, the loss will become more noticeable, and more and more attention will be given to preventing of it. Thus, although the loss of reservoir capacity proceeds at a comparatively uniform rate, the trouble caused will be felt at a rapidly mounting rate in the future.

There are several ways by which the rate of deposition of sediment in reservoirs may be reduced. Aside from the expense involved, the best method of keeping sediment out of reservoirs is the keeping of it in its original place on the watershed by soil conservation measures which reduce the rate of erosion of the land surface or in the stream channels of the drainage area. Under favorable conditions, much can be accomplished along these lines, but in many cases, the cost is prohibitive. In general, the best results can be obtained under conditions of low relief, scour resistant soil and sufficient rainfall to produce rapid growth of protective vegetation.

Scouring out of reservoirs is moderately effective in only a few cases. Conditions required for success are narrow, steep reservoirs filled with comparatively fine sediment which can be flushed with a relatively large flow of water when the reservoirs are practically empty.

Considerable attention has been given to the reduction of the rate of filling of reservoirs by discharging the sediment brought down to dams by density currents which carry sediment along the bottom of the reservoir beneath the clear water stored in it. Although some benefit may be secured by this method, sufficient knowledge regarding the action of density currents is not yet available to enable an accurate appraisal of the effectiveness of this method.

Persons inexperienced in the ways of sediment are apt to think of it filling a reservoir in the same way as water does, namely, fill the lower part of the basin first and then the higher levels, preserving a practically level surface of sediment in the reservoir as it fills. Such, however, is not the case, and the reservoir fills with the top of the deposited sediment having more or less of a slope.

This has both advantages and disadvantages, as compared with a level surface. If it filled in with a level surface, the sediment would first fill the reservoir below the level of the outlets where it would cause no trouble, as it would not reduce the effective capacity of the reservoir. Depositing on a slope produces some reduction of effective capacity at nearly all levels of the reservoir, beginning as soon as water is stored in the reservoir. The principal advantage of a sloping surface of filling is that a reservoir can hold a larger volume of sediment than it can of water. This advantage, however, is secured at the expense of filling of the channels and often of the valley with sediment upstream from the water in the reservoir to higher levels than the water being stored in the basin. This sometimes destroys the arability of considerable areas of land upstream from the reservoir and will in time destroy improvements which are some distance above reservoir level.

Since in any reservoir some slope of the stream will be necessary to carry the sediment from the upper to the lower end of the reservoir, when a reservoir is filled with sediment at the downstream end to the spillway level, it will be filled at the upper end of the reservoir to a higher level. Therefore, practically all reservoirs will eventually fill to above spillway level at the upstream end.

Because all reservoirs will fill up eventually, it is very important that accurate estimates be made before reservoirs are constructed of how rapidly they will be filled, in order that none are constructed that will fill too rapidly to justify their construction. To make these predictions, it is necessary to know, in addition to the storage capacity of the basin, (1) the amount of sediment brought down by the stream, (2) the density of the sediment which will be deposited in the basin, (3) the proportion of the sediment deposited above spillway level, and (4) the proportion of the inflowing sediment that is deposited in the basin.

The amount of sediment brought down to a reservoir can best be obtained by measuring the sediment flow over a series of years by frequent sampling. Considerable study has been given to the method and instrumentation for this sampling, and if carried out over a sufficiently long period, reasonably accurate predictions can be made, provided conditions in the watershed do not change.

The density of the sediment depends on the particle size composition of the material brought into the reservoir and the extent to which the deposited sediment is permitted to dry out. Little data are available on the proportion of sediment deposited above spillway level. This factor is commonly ignored, which is on the safe side when estimating a rate of filling. The advantages of the decreased rate of filling resulting from filling above spillway level will be offset to a large extent by the damages which result from it. Little quantitative data are available on the proportion of the sediment which is deposited in the basin or the "trap efficiency" as it is called. For large reservoirs, until they are nearly full, this efficiency is usually close to 100 percent. The trap efficiency increases with the size of the sediment and for sand sizes, is ordinarily close to 100 percent.

After a reservoir is put into service, periodic surveys are usually required to tell how fast it is filling up, in order to be able to keep at all times an accurate account of the water stored, as this knowledge is necessary for the most efficient use of the water. A great deal of survey work has been done, and the methods have been developed which are the result of extensive experience.

Scour and Deposit in Canals

Scour or deposit in irrigation canals is another important aspect of the sediment problems of irrigation systems of the United States. This is ordinarily spoken of as the "stable channel" problem.

A stable channel is a canal for carrying water which does not scour or fill with sediment to an undesirable extent. In general, unstable channels can be divided into three classes, (1) those where scour but not deposit occurs, (2) those in which deposit occurs but which do not scour, and (3) those in which both scour and deposit occur.

The first class of channels usually carry water with little or no sediment, and the scour depends on the tractive force or shear around the periphery of the channel. In the past, scour was commonly related to mean canal velocity, but it has long been known that when built in the same material, large canals could carry water at a higher velocity without scouring, than small ones. The problem of scour in canals has recently been the subject of an extensive study by the United States Bureau of Reclamation, and new methods of canal design to prevent scour, based upon tractive force or shear distribution, have been developed which, it is believed, constitute an improvement over the methods formerly in use.

The second class, canals in which deposit but not scour occurs, ordinarily are found where heavy sediment loads are transported in canals with banks and bed of material which are highly resistant to scour. The design of these canals is a problem in sediment transportation. Although considerable progress has been made in recent years in perfecting methods of computing the sediment carrying capacity of canals, this phase of the problem is not yet adequately solved.

The third class, canals which both scour and deposit, also usually carry heavy sediment loads but differ from Class 2 in that they are constructed in easily erodible material. In this case, the problem is to so choose the shape and slope of the channel that the heavy sediment load will be carried without scouring the banks. It is probable that the fine material carried in suspension in the water sometimes also enters this problem when it tends to make the bank more resistant to scour. This type of problem has been extensively dealt with in India, and methods of handling it have been developed which are reasonably successful. Unfortunately, the formulas developed frequently involve factors which have been learned by experience but which are not readily used by one lacking this experience.

The deposits of sediment in canals are in many cases a very troublesome and expensive feature of irrigation project operation. It is often the most costly item in project maintenance. Before the construction of Hoover Dam, one large project on the lower Colorado River paid over a million dollars a year to keep its canals cleaned out. Where heavy deposits occur, the securing of space to deposit the excavated sediment along the canals eventually becomes a problem.

Control of Sediment Supplied to Canals

When a canal of satisfactory shape and slope, capable of carrying the required sediment load cannot be obtained, it is necessary to reduce the amount of sediment which will be supplied to the canal. A great variety of devices have been developed to accomplish this purpose. The design problem in this case includes the selecting of the type of device best fitted for the conditions at hand.

One of the most widely used methods of reducing the sediment taken into irrigation canals is to locate the intake on the outside of a bend on the stream from which it diverts water, as extensive experience has shown that intakes so located take in less sediment than those placed in straight stretches or on the inside of the bends. Structures for reducing the sediment are frequently divided into two classes: (1) excluders, which are located just upstream from the canal head gates and prevent the sediment from entering the canal and (2) extractors, ejectors or eliminators which are usually located just downstream from the headworks and extract or eject the sediment from the canals after it has entered them. Deposits in canals usually are heaviest near their upper ends, and a common method of removing such deposits is to scour them out by allowing the water to escape from the canal through a sluice located some distance downstream from the headworks. This is sometimes done by continuously using part of the canal flow and in other cases by occasionally flushing out the deposited section, with the entire canal flow.

A great variety of devices have been used for excluders or extractors. This subject has been studied most extensively in India and Pakistan, but some work has been done in many countries. The following discussion is based on a study of the subject from all available literature rather than just in the United States. Practically all of the devices used involve one or more of nine types of action. These types of action are as follows: (1) the slot, (2) the step, (3) deflecting vanes, (4) drawing off of slower moving currents, (5) separation of top and bottom water, (6) the skimming weir, (7) grillage, (8) curved currents, and (9) settling basins. Of these types, Numbers 1, 5, 8, and 9 are most frequently used. In some cases, two or more of these actions are combined in a single installation.

The slot is a depressed trough or channel across the bottom of a canal into which the sediment drops as it passes down the canal, and from which it is washed out by a flow of water. The step is somewhat related to both the slot and the settling basin. In it the bottom of the canal is gradually depressed, forming a small basin, at the downstream end of which the bottom rises abruptly to the normal canal bottom level again. A gate is placed in the canal bank just upstream from the step through which the sediment which deposits in the basin can be flushed out.

Deflecting vanes are sometimes placed in channels to deflect the material rolling along the bed or carried in the water near the channel bottom, away from an opening through which the water for irrigation is drawn. Drawing off of the slower moving currents is a means of removing the sediment from irrigation water. The slower moving currents are usually at the bottom of the channel where most of the sediment is carried, and these currents are more easily deflected than the faster currents. A sluice in the side of the channel will therefore draw out more water from the slow moving bottom currents than the fast moving top ones, and the water drawn out will contain much more than the average concentration of sediment carried by the canal.

Since the concentration of sediment of sand or larger particle size is much greater near the bottom of a canal than near the surface, by placing a horizontal diaphragm across the canal some distance above the bottom and wasting the water which passes beneath the diaphragm, most of the coarse sediment can usually be taken out with this water.

So-called skimming weirs are often used to keep sediment laden water out of canals. They were supposed to skim off the top water which has a small load of sediment and allow it to pass into the canal, while the remainder of the water with its heavier sediment load goes on down the stream. They do not act this way, however, as the water passing over the weir comes both from the bottom as well as the top of the channel. They separate out only the particles which are too heavy to be lifted up over the weir by the currents which rise from the bottom and flow over the weir.

In streams which carry very coarse material such as cobbles or boulders, these are sometimes separated out by drawing the water from the bottom of the stream through a grillage of bars which separates out the cobbles and boulders and allows them to roll on down the stream.

The action of curved currents is the same as that involved in placing the canal intake at the outside of the bend, as previously mentioned.

Settling basins are enlargements of the channel in which the velocity and the turbulence is reduced, and the sediment settles to the bottom from whence it is flushed or pumped out. This type of basin will remove finer sediment than any of the others. Theoretically, as much sediment as desired can be removed from the water in a settling basin, but it is rarely practicable for irrigation to remove a high percentage of particles much smaller than sand (or below about 0.06 mm diameter) from the water. None of the other devices previously discussed will separate out material much finer than sand.

All of these devices require some water for their operation, but some require more than others. The types of device applicable are often somewhat limited by the amount of surplus water available.

In India and Pakistan, where sediment loads are high, the sediment is often distributed among the canal branches much as the water is, using devices somewhat similar to those mentioned above.

Hydraulic models have been extensively used to predict the action of excluders and extractors, and although the model theory for the sediment movement and deposition is not well established, they work surprisingly well.

Sediment in the irrigation canals may cause a great deal of trouble, but it can in some cases be a great benefit. Such sediment may improve the land on which it is placed, because it brings to it certain valuable materials which fertilize the soil, or improve the texture of the soil. In general, it may be said that the addition of sediment to the soil will improve its texture if it brings to the soil the particle sizes which the soil needs to obtain an optimum composition. Sediment may make the texture worse if it changes its composition in the opposite direction from that which would be best.

Enlargement of Streams Used as Drains or Supply Channels

One of the most troublesome problems on some irrigation projects in the United States is the enlargement of the streams used as drains to carry off the waste or seepage water from irrigation projects. These conditions are apt to happen in irrigated regions having considerable slope. Frequently, these streams have adjusted their size and slope to the small flows they carried before irrigation was introduced, and the addition of the extra flow of water from seepage or waste of an irrigation project causes them to scour out and deepen their beds. If the material through which they flow is easily eroded, large gulleys are formed, destroying valuable land and bridges along the stream. Much sediment may be carried downstream and deposited in reservoirs and canals of irrigation projects.

One sure remedy for this case is to build overfall dams at intervals along the stream, over which the water falls, thus reducing the gradient between the dams sufficiently so that scouring conditions are not produced. However, as these dams must be strong enough to withstand the occasional large flood which will occur in the stream, they are apt to be too expensive. Another way is to carry the waste flow in a separate canal with paved sides and bottom or with drop structures at intervals in which the energy can be dissipated without scouring the canals. Since these structures do not have to carry the flood flows, they can be much cheaper. In some cases, riprap on the banks and bed will accomplish the purpose, but often the stream slope is too steep for this method of protection.

As an example of this type of difficulty may be cited the case of Five Mile Creek on the Riverton Project in Wyoming. This stream has a slope of about 22 feet per mile and sometimes carries as much as 300 second feet of seepage and waste water. Figure 1 shows the nature of this creek in its original condition and Figure 2 shows a section of it which has greatly enlarged. Were it not for the fact that rock ledges are encountered in the banks and bed at intervals, much worse conditions would have resulted. Measurements show that about 2 million tons of soil per year are removed from the bed and banks of this stream. At times the rate of removal reaches as high as 20,000 tons per day. This stream discharges into Boysen Reservoir in which this sediment will deposit. Unfortunately, there is no known practicable way at reasonable expense of remedying this situation.

A somewhat similar case is on the Gering Drain on the North Platte Project in Nebraska. Here a small drain was constructed to carry off the waste and seepage water from the Gering Valley. The material through which the drain runs is easily eroded, and the slope of the valley was too steep, causing the drain to enlarge rapidly. Figure 3 shows the enlarged condition of this drain. The enlargement of the channel causes storm rainfall to run off very rapidly, accentuating still further the scour, causing the loss of numerous bridges and much valuable farm land. In a single flood the damage was estimated at $400,000.

A similar condition sometimes results when natural streams are used for supply channels. For example, water is brought into Sunshine Creek in Wyoming from another watershed and stored in a reservoir from which it is released when the supply to the irrigated land downstream is inadequate. The stream below the reservoir runs through easily erodible material and has a steep slope. The flows in the stream are now much larger than they were before, and the bed is deepening and widening, as shown in Figures 4 and 5. Trouble has been experienced in streams from the addition of water from other watersheds, even when the beds are composed of cobbles and boulders.

From the foregoing, it will be seen that in planning irrigation enterprises, it is important to anticipate the difficulties that will arise from these conditions and to avoid them as far as possible.

Aggrading Streams

The problem of aggrading streams can be illustrated by describing the situation in the Middle Rio Grande Valley in New Mexico. Here the bed of the river has been rising and is now above the street level of the business section of Albuquerque, a city of about 100,000 population and one of the fastest growing cities in the United States. This condition has resulted from four causes: (1) upstream from Albuquerque where the Rio Grande emerges from the mountains, a large volume of relatively clear water is diverted for irrigation, leaving less water to carry off the more heavily sediment laden water from the plains area further downstream; (2) the sediment movement from the plains area has been increased by overgrazing with resulting sheet erosion and gullying; (3) irrigation water is diverted from the river in the Middle Valley, and the sediment in this water is partially removed and returned to the stream; and (4) a number of low irrigation diversion dams have been constructed in the river, and experience has shown that under the conditions in this stream, such dams raise the river beds for long distances upstream. The result of this increase of sediment load combined with a reduction of the water available to carry it and the obstructing of the channels by dams is that this section of the river bed is rising at a rate of about 1 inch per year and is causing a rise of ground-water level in the irrigated areas that threatens to waterlog the land, as well as threatening the safety from floods of Albuquerque and the other towns along its course.

The remedy worked out for this case is combined flood control and sediment storage reservoirs on two of the most heavily sediment laden streams of the valley combined with extensive improvement of the stream channel. This work is estimated to cost about $45,000,000 and is a very expensive undertaking, but is absolutely necessary if this valley is to be prevented from gradual decline into ruin.

Degradation Below Dams

When a dam is constructed in a stream in which coarse sediment is moving with the flow of the water, if the dam stops the movement of this sediment, the water passing the dam picks up a new load of sediment from the bed downstream, thus causing a lowering or "degrading" of the bed. If the movable bed material is deep and of comparatively uniform size, the bed may be lowered considerably.

This action has been known for more than a half century, but only in about the last 20 years has it been widely recognized. If the dams are not designed for this lowering, they may be badly damaged, and in one case in India an important irrigation intake dam failed due to this action. In this country on the Pecos River in New

Mexico, the Fort Sumner Dam in New Mexico was so seriously threatened that an entirely new dam had to be built. Figure 6 shows the condition at the original dam; the bed of the river at the time of construction of this first dam being about at the level of the apron which is now about 9 feet above the river bed. Figure 7 shows the condition of the spillway at the opposite end from Figure 6 and also shows the apron high above the present bed level. The degradation may extend long distances downstream and cause trouble to structures there. Figure 8 shows a rock-fill weir on the Colorado River built to raise the water up to maintain diversion into an irrigation canal where degradation was caused by a dam 55 miles upstream.

Degradation takes place more rapidly on steep streams with fine noncoherent bed material. It may continue until a rock ledge downstream is uncovered which stops further lowering. The lowering of the bed level occurs first near the dam and gradually extends downstream. The water removes the finer bed material and leaves a sort of paving on the stream bed which cuts down the rate of movement. Although not yet observed, it is probable that large flood flows in the future will remove more or less of this paving and set up a new cycle of lowering. Approximate estimates can be made of the extent of the lowering which will occur, but the process is laborious and time-consuming.

Collection of Sediment Data

For the working out of the best solution of any case involving sediment, an accurate knowledge of both the quantity and particle size of the sediment is necessary. Since sediments composed of different size particles act very differently, it is necessary to know the size in every case if accurate predictions are to be made. In recent years considerable effort has been expended in the United States in devising apparatus and procedures for the accurate measurement of the sediment load in streams and for determining the size of the sediment particles involved. The collection of such data has been rapidly increasing, and is usually carried on in connection with the stream gaging program.

Conclusion

From the foregoing information, it will be seen that sediment problems on irrigation projects in the United States often are severe and the cause of such expense. In many cases good remedies for these difficulties have not been found, but by careful planning, they may sometimes be avoided and in most cases, the difficulties can be reduced by intelligent handling. In the future, more attention is likely to be given to these problems, as they tend to become more severe as time goes on, and most irrigation projects are comparatively young. The earliest projects in the United States generally used clear water, but recently streams carrying more sediment are being developed, on which sediment problems are more likely to be troublesome. Great benefits will result from well directed research in this field.

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The literature on sediment problems on irrigation projects is extremely extensive and widely scattered through the world's engineering publications. To give even a complete list of the most valuable papers would require several pages of references. The following references will enable anyone who wants to study this subject thoroughly to make a start in this direction. By reading the papers referred to in the references given, he will be referred to others and thus be able to study most of the best literature on the subject.

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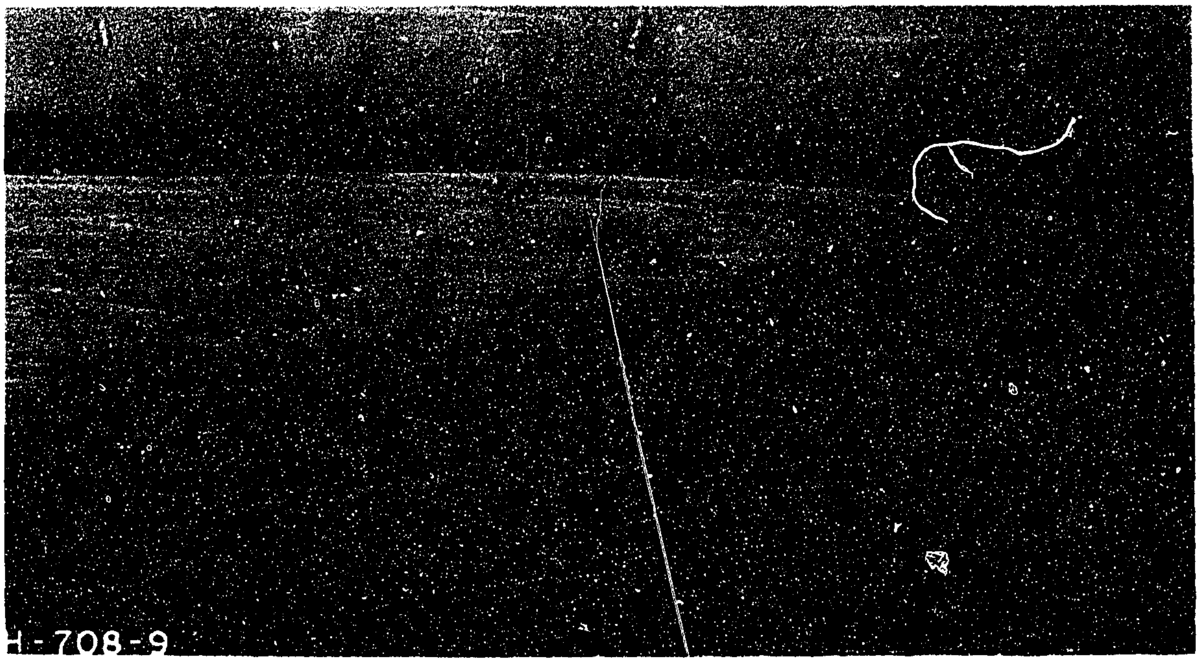
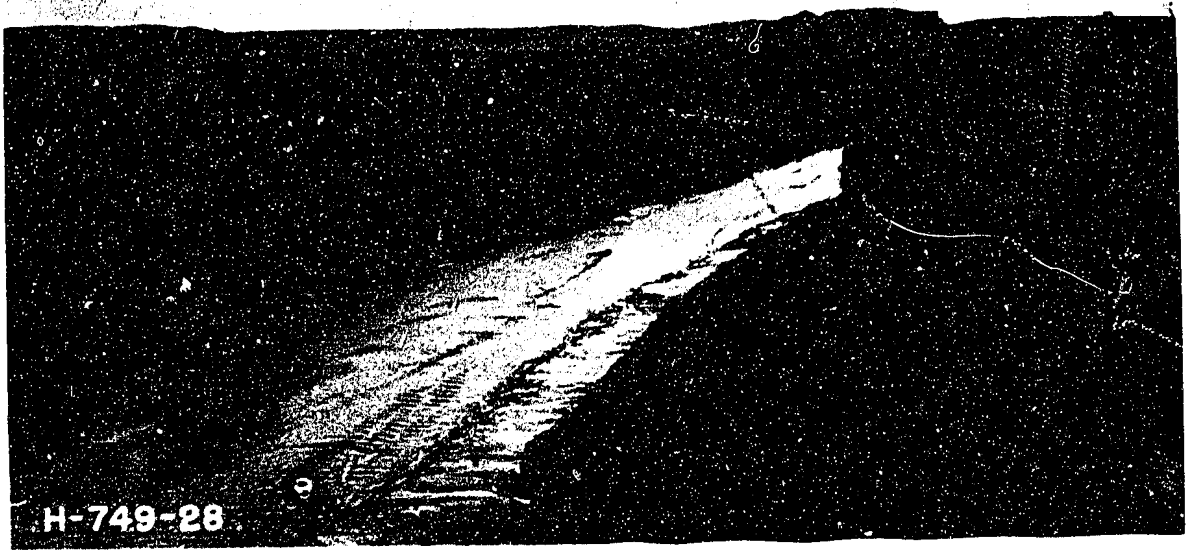
Original condition of Five Mile Creek, Wyoming.

FIGURE 1



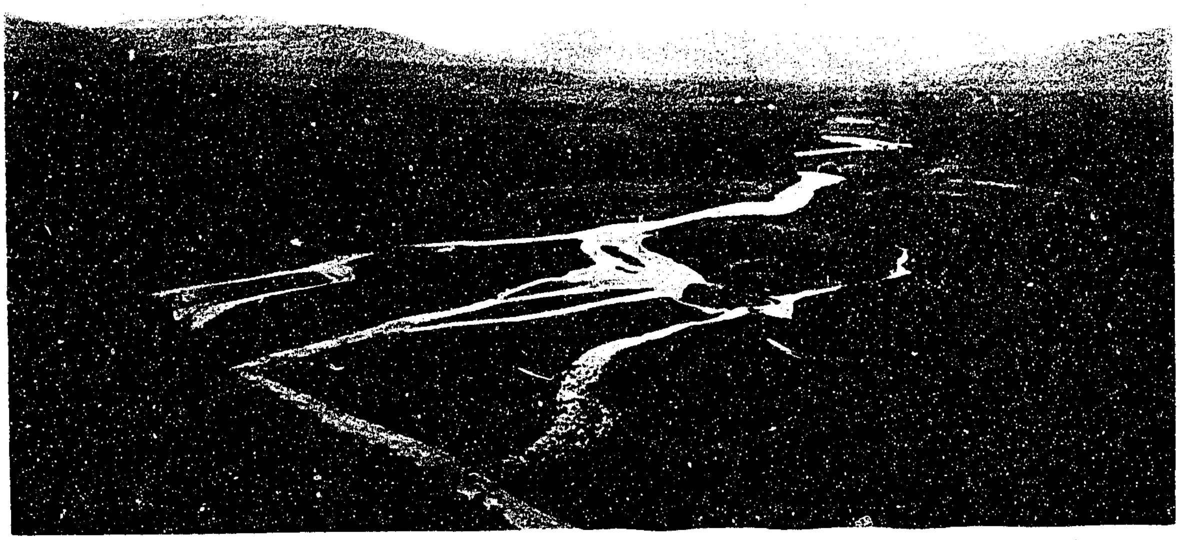
Present condition of part of Five Mile Creek, Wyoming.

FIGURE 2.



Enlarged condition of Gering Drain, Nebraska.

FIGURE 3.



Enlarged section of Sunshine Creek, Wyoming.

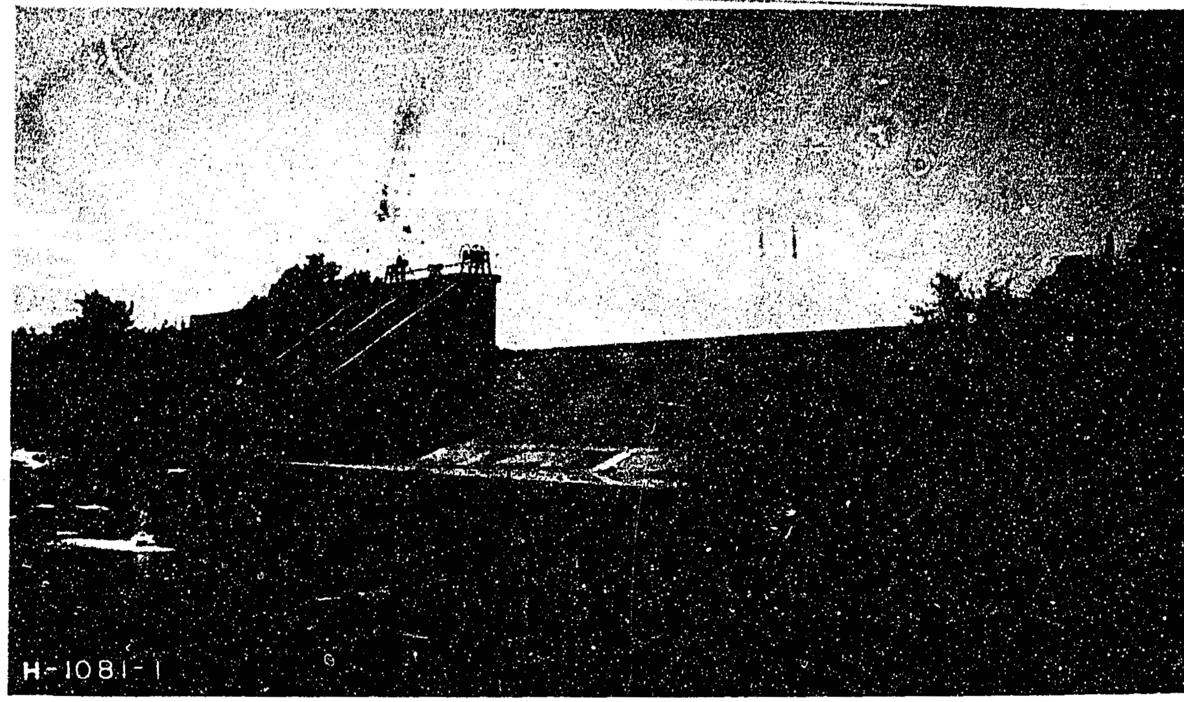
FIGURE 4.

High banks due to added flow in Sunshine Creek, Wyoming.

FIGURE 5.

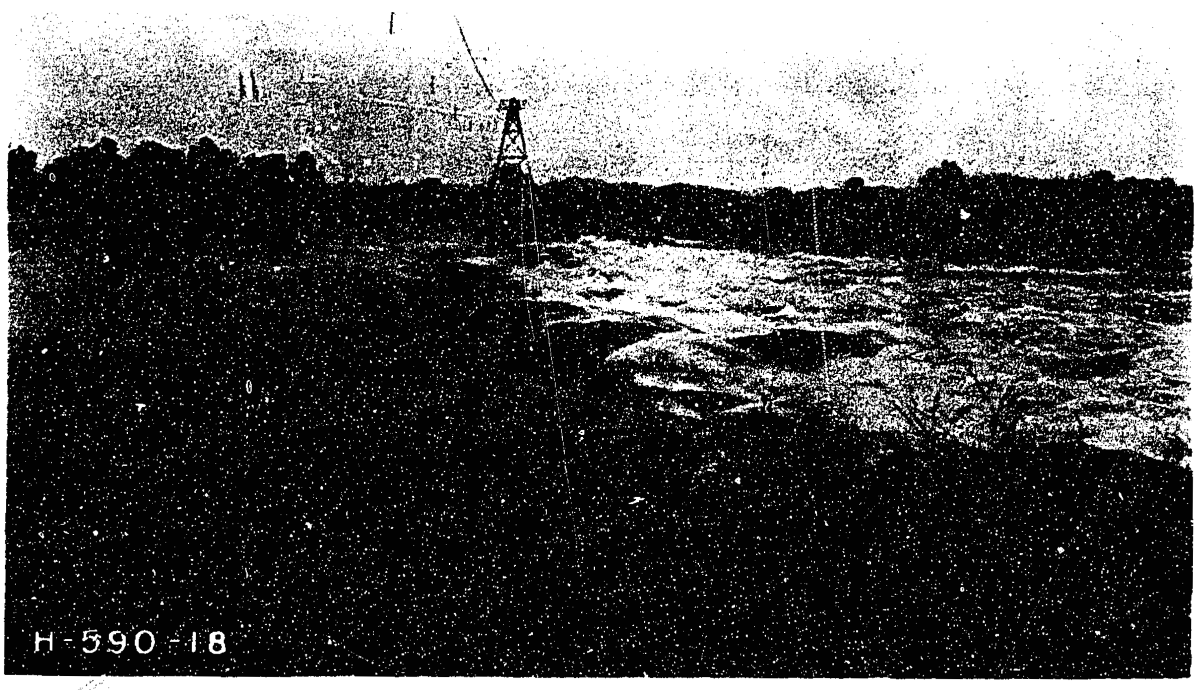
Degradation at left end of Ft. Sumner Dam, New Mexico

FIGURE 6.



Degradation at right end of Ft. Sumner Dam, New Mexico.

FIGURE 7



Weir on Colorado River made necessary by degradation caused by dam 55 miles upstream.

FIGURE 8.