the area of the cross-section to a point where the water is forced to maintain its velocity and continue to carry the sediment.

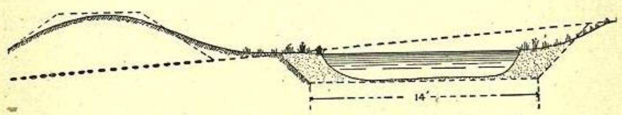


FIG. 39. — Cross-section of canal partly filled with sediment.

Some rivers, such as the Rio Grande, transport so large a volume of earth that the canals and ditches leading from the stream are quickly filled, and it is necessary to clean out the mud at short intervals. The view, Pl. XIII, *B*, shows one of these ditches with the mud piled high on each side, the result of the annual cleaning of the ditch. The cost of removing the sediment is often a large item in the operating expenses. For cleaning very large canals and for enlarging them, dredges have been used similar to that shown on Pl. XIV. These float along the canal as the material is dug out from the bottom and sides. By means of such a device a canal can be cleaned while in use, otherwise it is necessary to shut the water off and allow the bottom to become sufficiently dry for horses and men to work in it.

If, on the other hand, the grade of a canal is so steep as to erode the sides and bottom, some method must be taken to prevent this, for damage results in several ways. The erosion of the bot-

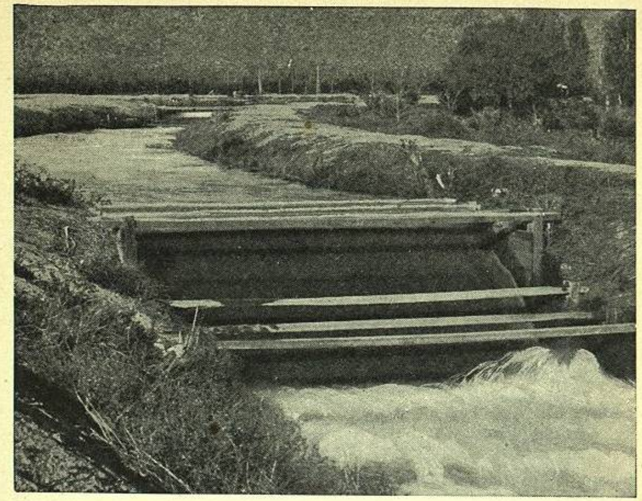
tom gradually reduces the level of the water in the ditch, and the material carried along is finally deposited at some place where it may choke the ditches or cover fertile land. The removal of fine material leaves the bed open and porous, the water escaping by percolation. The losses in this direction are prevented where the conditions are such that a small amount of silt is deposited and remains, filling or cementing the minute openings through which water would otherwise escape. The difficulties resulting from excessive grade of a canal are remedied by building what are known as "drops," two of these being shown on Pl. XXIII. They consist of suitable arrangements for the water to fall over low dams or weirs upon solid rock, or into a deep pool, where the force of the water will be expended without injury to the canal.

For very small ditches a great slope can be used, since the volume of water is not sufficient to move the large particles of sand and gravel; for example, on the farm lateral, carrying 1 or 2 second-feet, a fall of 50 feet or more to the mile may not be excessive, the velocity being retarded by the relatively great friction. On the other extreme, a large irrigation canal carrying 1000 second-feet may be in danger of injury if a grade of much over 6 inches to the mile is given it.

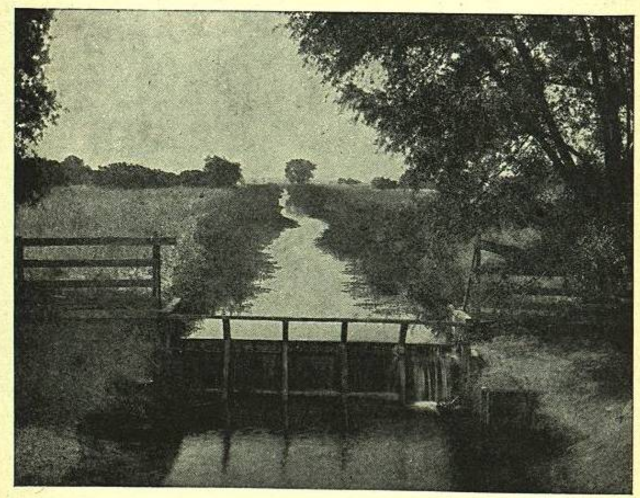
As a general rule it may be said that conduits of this character built in common earth should be so proportioned as to have an average velocity of a little less than 3 feet per second, or 2 miles per hour, when carrying their full capacity. It is necessary, therefore, to take into consideration the amount of water to be carried, and from this deduce the size and shape of the cross-section of the canal or ditch, in order to obtain its velocity.

Many of the older irrigation works laid out by crude devices, such as a large triangle and plumb-line, have been given an excessive grade through fear on the part of the builders of getting too little fall. Some of these are as much as 50 feet to the mile, giving a velocity of the water of 5 feet per second, washing the bed of the channel and leaving only a mass of cobbles. The seepage through this material, even if the water is flowing rapidly, has been known in one instance to be over 20 per cent of the total flow in a course of four miles.

Where the grade of a ditch is so small that the water is flowing very gently, the conditions are sometimes favorable to the growth of aquatic weeds or grasses. Under the bright sunlight the water is warmed, and the development of these plants sometimes reaches such an extent as to completely fill the ditch. The water must then be turned out and the plants cut and thrown out upon the bank. Sometimes, where it is not possible to shut off the water, the weeds are raked out, or even mowed under water. In any case a



A. DROP IN AN ARIZONA CANAL.



B. CHECK WEIR AND DROP.

considerable amount of time and labor must be given to keeping these gently flowing streams free from obstruction. For this reason it is desirable to give ditches such a fall that they will keep themselves clean and yet will not erode their bottoms. This is a difficult matter to estimate, since the velocity of the water varies greatly at different stages, and the soils encountered by the ditch may range from gravels to the finest clays or silts.

In very muddy waters many of the aquatic plants do not develop, so that there is frequently an advantage in this respect, in addition to the value of turbid waters in fertilizing the fields. If the silt can be retained in suspension, not dropped in the ditch to fill it up, and be carried out to the fields of the farmer, the fine material left here on the surface may have considerable value in enriching the soil. The muddy waters frequently carry a considerable amount of organic matter and nitrogen in form available for plant use. It has been estimated, from chemical analysis, that the mud deposited on irrigated lands of Salt River Valley, Arizona, is equivalent in richness to fertilizers valued at $8 per acre. That is to say, if the irrigators of this valley were forced to purchase and apply to their farms commercial fertilizer of equal strength, it would cost $8 per acre. As compared with clear water obtained from artesian wells, the muddy water possesses certain advantages. On the other hand, it frequently carries with it noxious seeds, and in extreme conditions may injure young vegetation by covering the leaves with slimy mud.

The greater part of the silt brought down by the rivers and carried out in the ditches occurs in times of flood, when there is ample supply of water, and when, by running the ditches full and at high velocity, the material can be carried through to the fields. Later in the year the waters usually become clear, unless the upper catchment basins have been denuded of their grasses and shubbery by overgrazing. In some localities the great bands of sheep, as shown on Pl. VI, *B*, have so completely eaten up the vegetation, and the ground has been so thoroughly pulverized by the small, sharp feet of the sheep, that every local rain brings down great quantities of soil, filling the ditches and keeping the water muddy.

The losses of water in canals through seepage and evaporation are frequently very great and have amounted to over one half the quantity received. The evaporation losses may be reduced slightly by increasing the velocity of the water, and thus shortening the time in transit. Seepage can be largely prevented, as above noted, by a cement lining, or by the deposition of the fine silt, which, when not in excess, is thus of great use and value.

CHAPTER V.

RESERVOIRS.

WHEREVER lakes, ponds, or large marshes occur on the head waters or along the course of a stream, fluctuations of the volume are to a large extent prevented. After a heavy rain the water, seeking the drainage lines, tends to flow off rapidly, but first fills the ponds; these overflow gradually, increasing the volume of the river, so that, instead of passing off as a violent flood of a few hours' duration, the storm results in the gradually increasing flow of a large volume of water in the river through days or even weeks.

The natural regulation of the flow can be further improved by placing obstructions at the outlets of these ponds, in order to hold the water when not needed in the river below. This has been done to a considerable extent for water-power development and for mining purposes. Natural lakes are, however, comparatively rare on the head waters of most streams useful in irrigation. Among the high mountains, especially under the peaks from which glaciers have issued, there are some ponds whose outlets can be closed