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 at small expense; but the water coming from these is almost insignificant in comparison with that which occurs lower down.

In the course of a river issuing from mountains, there are occasionally found broad valleys from which the water escapes through narrow canyons. These have resulted from the erosion of soft rocks, or more often from the disturbance of the drainage due to the uplifting of a part of the earth's crust, or by the outpouring of lava, or the formation of basaltic dykes.

It is apparent that, by closing the outlets of some of these valleys, the processes of nature can be imitated in regulating the flow of the streams. The flood waters can be held behind the artificial barrier, such as that shown on Pl. XXIV, and let out through gates whenever needed for power or for watering agricultural lands. At first sight it appears to be an easy matter to accomplish this, and throughout the arid region there are reported to be innumerable localities suitable for water storage. An examination of these, however, leads to many disappointments, as there must be a combination of several features to insure the practicability of reservoir construction.

REQUIREMENTS FOR WATER STORAGE.

The requirements for successful water storage on any considerable scale are: an abundance of water to be stored, capacity in which to hold this, favorable situation for a dam, and suitable material for its construction, and also reasonable cost of labor, material, and land, if any is purchased for right of way or flooding.

The amount of water to be stored should in all cases be ascertained in advance by careful measurements made through a number of seasons at the point where the water is to be held. Disappointment and financial loss have resulted from assuming that there will undoubtedly be plenty of water, or by taking the statements of the "oldest inhabitants" to this effect. It is impossible to judge by the eye as to the volume of a flood. One which is particularly destructive and impressive in its apparent magnitude may, upon careful measurement, be found to have discharged an amount far less than anticipated. The intensity of the flood, or rapidity with which it moves, often gives an exaggerated idea of its volume.

Many serious blunders have been made because of lack of definite information concerning the water supply. Persons dwelling along the bank of a stream often entertain absurd notions concerning the quantity flowing at ordinary or high stages. They have no means of forming a correct conception of volume, and will confidently assert that there is enough water to irrigate a million acres, when, as a matter of fact, there may be sufficient for only ten thousand. The investor, and even the engineer visiting the locality, may become infected with this optimistic spirit, and consider useless any further delay or expenditure to ascertain the fluctuations of the stream. Being impatient to begin work, they will take the statements of the people, and base their plans upon these.

In a well-known instance of the construction of a large storage dam which was under consideration for ten years or more, no measurements of volume of water were made, but when the constructing engineers were employed they were assured that the stream at that time was at a low stage. It was then carrying 2000 second-feet. As a matter of fact, it was really in moderate flood, and the low-water flow, six months earlier or later, was less than one-tenth of this quantity. The structure was planned and built without further delay, as the engineers did not consider that they had any duties beyond putting up the desired structure; but when finished, disappointment and loss of investment resulted, it being then found that there was not enough water.

The actual capacity of a proposed reservoir site is also often found to be disappointing upon careful survey. In going into the mountains where the slopes are steep, the eye is misled as to slight inclinations of surface. Valleys which seem to be flat are often found, when a levelling instrument is used, to be decidedly inclined, and instead of a dam 100 feet high backing up the water three miles, as at first estimated, it is not unusual to

discover that the water will be ponded for a distance of only one mile. In short, many localities which upon the first search are thought to be desirable are later found to have less capacity than anticipated. It is essential, therefore, to follow the preliminary examination by mapping each proposed reservoir site.

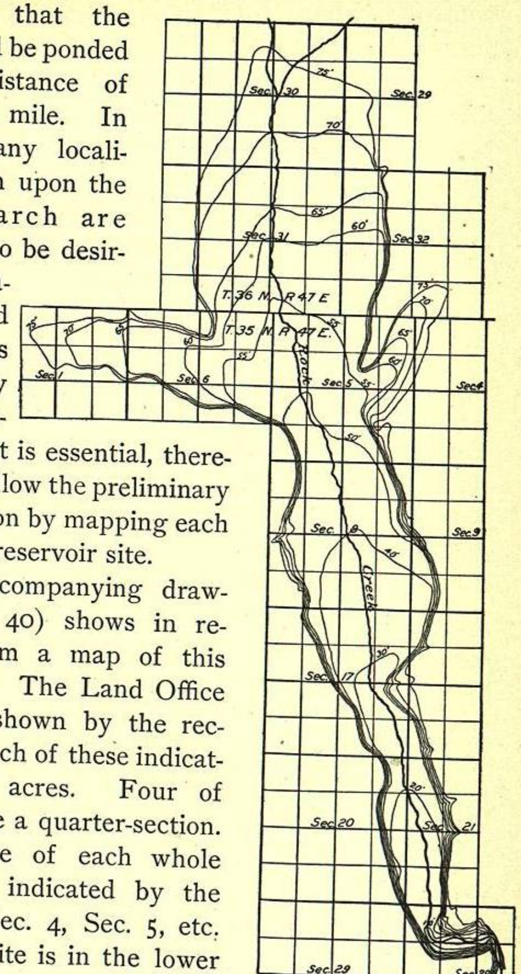
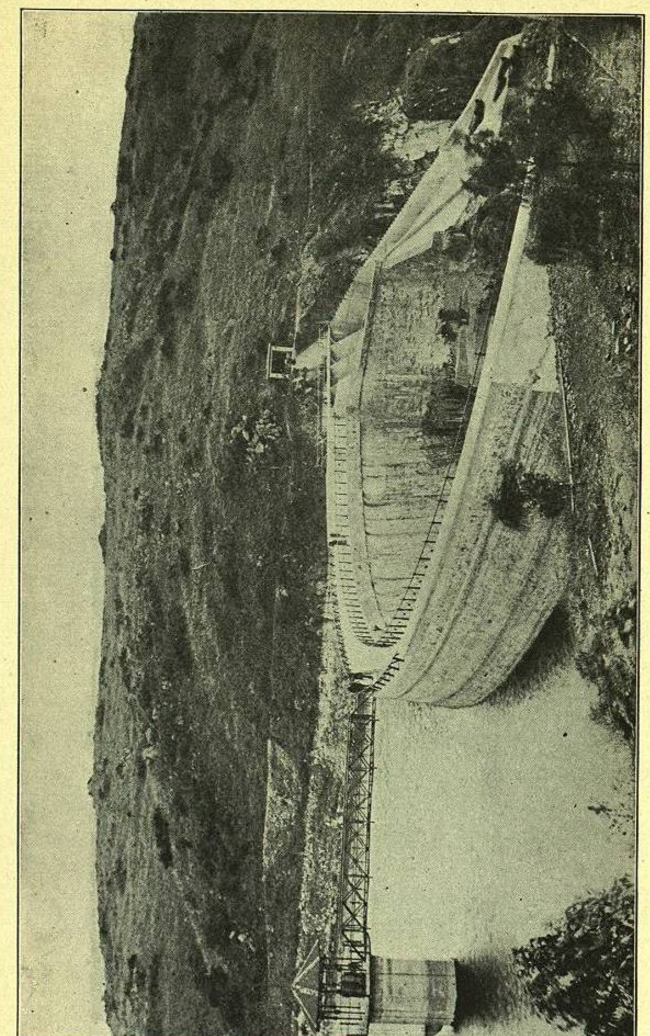


FIG. 40.—Map of a reservoir.

The accompanying drawing (Fig. 40) shows in reduced form a map of this character. The Land Office lines are shown by the rectangles, each of these indicating forty acres. Four of these make a quarter-section. The centre of each whole section is indicated by the symbols, Sec. 4, Sec. 5, etc. The dam site is in the lower right-hand corner of the drawing, where the contour lines come closely together, indicating a steep, narrow outlet. The first or lowest contour shows the location of all points 10 feet above the stream at the dam site. The next contour, marked 20 feet, gives points 20 feet above the bottom, or which form the shore when the reservoir is filled to a depth of 20 feet. The highest contour is 75 feet, and indicates the outline of the reservoir when filled to this depth. Where the contours run together the banks are steep, and where they are far apart the slope is gentle. From a map of this character it is possible to ascertain the area and capacity of the reservoir for all depths.

If there is plenty of water, and a place in which to hold it, the next question is the feasibility of building a dam. Every consideration demands that this structure should be made absolutely safe, and therefore the most substantial masonry is usually recommended. This must be founded upon bed rock and extended at each side into the solid walls of the canyon or gorge.

Where a river escapes from a valley through a narrow rocky cut, it might be and frequently is assumed that the water would keep this gorge washed clean and flow over bed rock, but this is rarely the case. At present, in the arid regions, the bottoms of nearly all the canyons are filled to a considerable depth with loose material. In the earlier ages the rivers, probably having more



SWEETWATER DAM, NEAR SAN DIEGO, CALIFORNIA.

water, cut down into solid rock, and later, receiving a less supply, became overloaded with gravel and boulders during flood time, and have left these scattered all along the course, even in the narrowest places. This deposit of gravel and boulders, some of them weighing tons, usually has a thickness of from 20 to 100 feet or more. The foundation of a masonry dam must extend beneath all of this loose material, and the greater part of the expense is often incurred on that portion of the structure which is out of sight beneath the surface.

The clearing out of the débris in order to place the foundation upon bed rock offers many difficulties, since the stream must be passed over or around the work, and the latter kept sufficiently dry for the quarrying and stone-laying to proceed. With a depth of 50 feet or more, the cost of controlling the water, especially if floods occur, may become so great as to be prohibitory to the enterprise. The bed rock itself may be weak or partly disintegrated, and all of this loose or seamy material must be taken out to insure a perfectly water-tight joint.

In carrying up the masonry structure from the bottom, a trench is cut into the side walls as far as open fissures or cracks extend, and care taken to make such a perfect joint between the dam and the rock that no leaks may occur. A small amount of water working its way under or around the dam will sooner or later wear out or dissolve a large hole and weaken the structure, if it does not destroy it.

Besides these fundamental requirements there are others, such as cost of cement, which is largely governed by the distance it must be hauled from the main line of railroad, facilities for obtaining labor, and the value of the land or other property taken for the reservoir and dam site. All of these items must be carefully considered in connection with the value of the water when stored. This latter item is dependent upon the kind of crops to be raised and similar considerations. When all of these matters have been taken into account, out of a dozen reservoir sites considered, there is usually only one or two which can be recommended for construction.

KEEPING RESERVOIRS CLEAN.

There is still another item which must be recognized in some parts of the country, and this is the cost of removing silt from the reservoir. The floods bring down great quantities of material washed from the hills, rolling down boulders, gravel, sand, and clay, all of which may be caught in the reservoir. The boulders and gravel do not travel far at a time, and are usually soon deposited; but sand and especially fine clayey particles are often carried out into the reservoir, tending to fill it. Some of this material will remain in suspension and be drawn off, some can be washed out

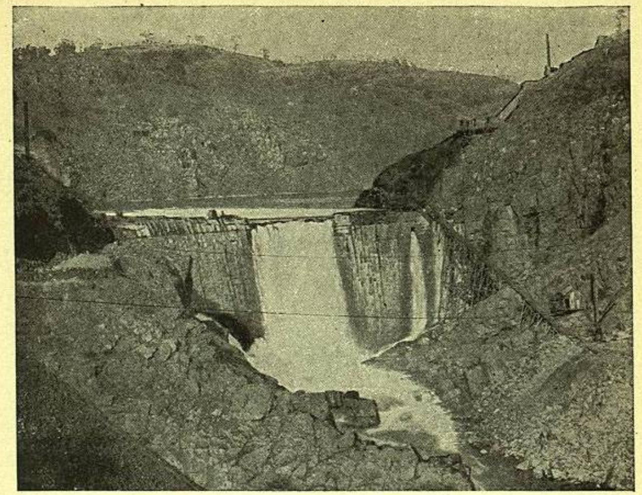
through or over the dam, while the remainder must be removed by hydraulic dredges or similar devices. The necessity for cleaning out a storage reservoir has not yet been demonstrated by actual filling of any in the United States, but this is a contingency worthy of consideration.

The difficulties which may arise from the accumulation of sediment in a reservoir have been a source of needless alarm to persons who have given slight attention to the matter. The work of removing silt has been exaggerated by persons who, for one reason or another, wish to bring about delay in the beginning of construction of storage works by the government. There is no question that in some cases the accumulation of silt will become a source of annoyance and expense, but not an insuperable obstacle. The condition is somewhat analogous to that in railroad construction. It might be argued in advance that a railroad could not possibly be operated more than ten years, because at the end of that time all of the wooden ties upon which the rails are laid would be rotten and unsafe, and the rails must be all taken up and relaid, with great expense and delay. Experience, however, has shown that, although railroad ties do decay, they can be replaced without disturbing traffic. In the same way it can be shown that the silt accumulating in a reservoir can be removed from time to time.

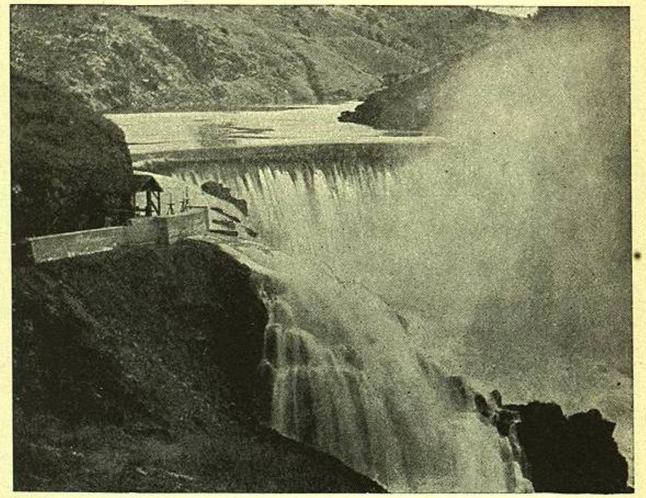
Most of the reservoirs in which silt is liable to accumulate are so situated that water is drawn from some point near the bottom, so that much of the silt, especially that near the dam, will be drawn out when water is taken for irrigation. The finer silt in the water in a large reservoir is kept in suspension almost indefinitely by wave motion and currents, the lighter particles floating for weeks, and even months. That portion of the sediment which has settled on the bottom is very easily disturbed; and when water is being drawn out of the reservoir, a stirring of the bottom by a dredge or other device will cause much of the material to rise and be carried off.

As the water in a reservoir is drawn down, exposing the mud banks, it is practicable to bring the incoming stream at the upper end around the top contour of the reservoir in suitably constructed ditches, and then turn the water down, washing out the mud banks either by the stream flowing across them or by confining the water in pipes and cutting out the accumulation of débris by hydraulic giants similar to those used in placer mining or in hydraulic construction, as shown on Pls. XXVIII and XXIX. An enormous amount of the light dirt can thus be moved at very small cost and run out through the lower gates of the reservoir.

Another way proposed for keeping reservoirs clean is by means of floating dredges, particularly those which pump up the mud by suction and



A. LAGRANGE DAM, NEARLY COMPLETED.



B. LAGRANGE DAM, WITH FLOOD PASSING OVER CREST AND SPILLWAYS.

deliver it into pipes conveying it to the shore. Such dredges can be operated by electric power generated by a small portion of the water drawn from the reservoir for use in irrigation. By such means, adapted to the local conditions, it is practicable to keep a reservoir clean just as other public works are kept in order. All great structures, whether for river and harbor improvement or for other purposes, require a certain amount of attention, and the fact that continual and intelligent care is needed for storage reservoirs cannot be used as an argument against their success.

MASONRY DAMS.

The oldest and most substantial structures for holding water are those built of masonry. The form of a dam of this character is shown in the accompanying figure (41), which is typical of a considerable number of works in the United States and in Europe. This is a section of the masonry dam in Tuolumne River, a short distance above La Grange, California. The dimensions are indicated, the thickness near the botton being 84 feet and the height nearly 120 feet. The stones composing the dam have been carefully set in cement, and those on the outer face have been cut to fit one another. A general view of this dam with the water pouring over it is shown on Pl. XXV. A plan is also given in Fig. 42, the direction of the water being indicated by the arrow.