

sion, and the square root of the cube been taken. Or in other words, the quantity equals $3\frac{1}{3}$ times the length into the three-half power of the height. In this statement the length taken is what is known as the effective length, and not the actual measurement, the measured crest being reduced by one-tenth of the depth of the water H for each end contraction.

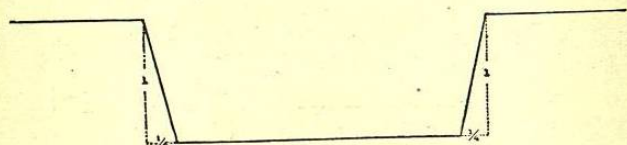
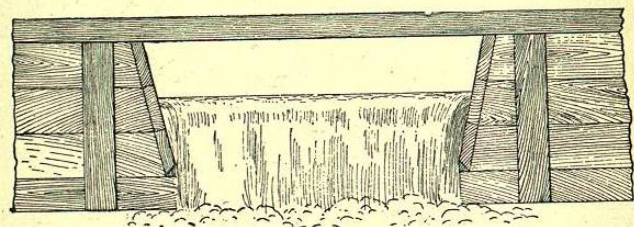
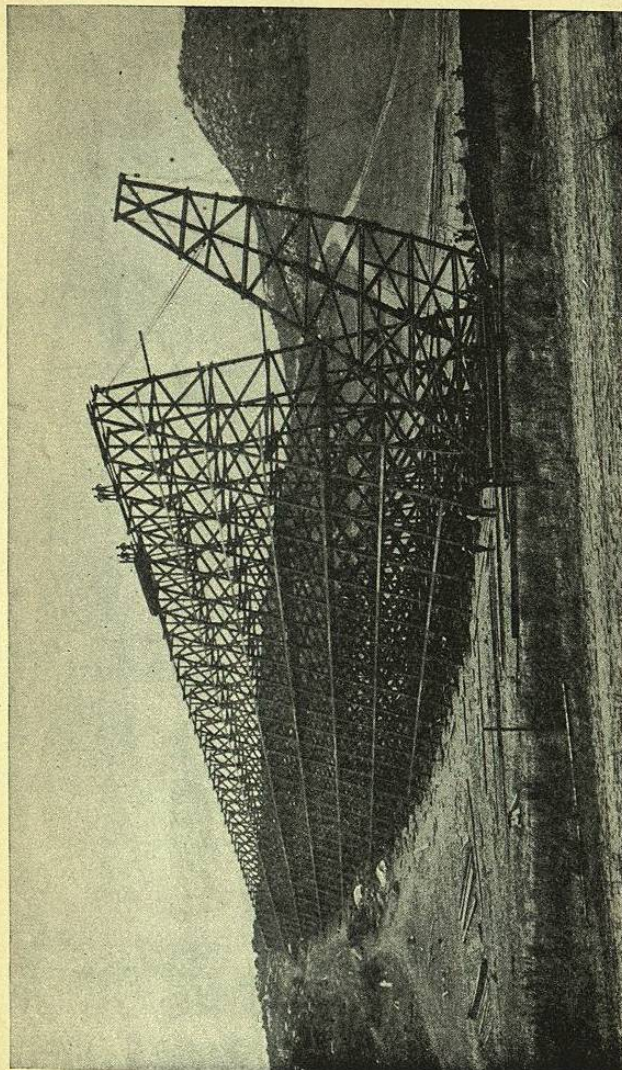


FIG. 34. — Trapezoidal or Cippoletti weir.

In order to obviate the necessity of making corrections for the end contractions of a weir, an Italian engineer, Cesare Cippoletti, devised a trapezoidal weir, or one with sloping edges, as shown in Fig. 34. The effective length in this case corresponds to the actual length of the crest of the weir, thus obviating the necessity of making an



RAISING THE TRESTLES FOR A LARGE FLUME.

allowance in the computation for the end contraction.

Weirs of this kind have been placed in irrigation ditches, and the height of water noted from time to time by means of the gage set back from the crest. It is possible at each reading of the height

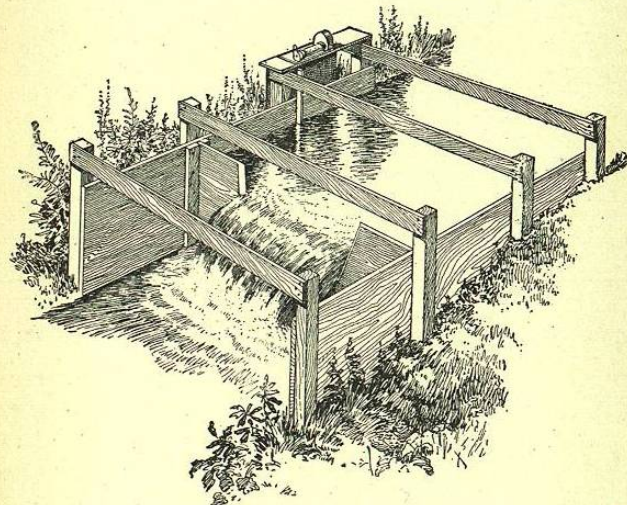


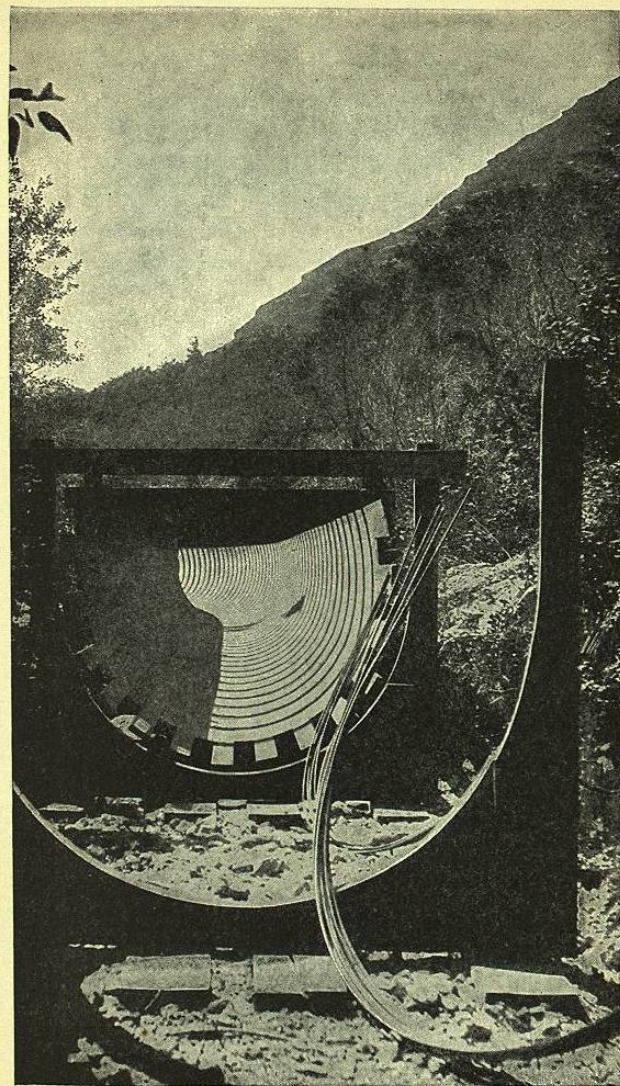
FIG. 35. — Trapezoidal weir with self-recording device.

of water to obtain by computation, or by a table constructed for the purpose, the amount flowing at that moment. As this quantity fluctuates, it is desirable to have some form of self-recording gage, so that the changes which have taken place can be known. An arrangement of this kind is shown in Fig. 35, where a trapezoidal or Cippoletti weir has

been placed at the end of a short flume and the small recording device arranged on the side of the flume. As the water rises or falls, a float attached to a pencil moves up or down, making a mark on a piece of paper placed upon a cylinder or dial and driven by clockwork. The irregular line traced by the pencil gives a complete record of the height of the water, and from this the corresponding quantities can be computed.

FLUMES AND WOODEN PIPES.

If the ground through which the ditch or canal is constructed were everywhere a gentle slope with well-rounded curves, it would be a comparatively easy matter to dig the necessary channel; but there are often small ravines coming into the main stream from each side, bringing water drained from the highland surrounding the valley. Some of these side channels are very deep and have steep sides, so that the ditch cannot be run around them or continued up one side and down the other. It often happens also that the water of these side channels is utilized by farmers, and must be kept separate from that in the ditch under consideration. Even if the water of the side drainage could otherwise be taken into the ditch, it is usually inexpedient to do so, because local storms often send down these channels great quantities of water, carrying sand, gravel, and boulders, and these deposited in the ditch would fill it up.



SEMICIRCULAR WOODEN FLUME.

In the construction of nearly every conduit of this character it becomes necessary to take water across a depression. This is generally done by means of a flume, or long box, usually rectangular in section. This is supported by a frame or trestle of timber, the lower part of which rests upon the ground. The vertical elevation of such a device is shown in the accompanying figure (36), which gives the general form of the trestle with its cross-bracing, also of the flume, which is shown with the water filling it nearly to the top.

Such flumes are often used across rocky ground where it is im-

practicable to dig a ditch. This is particularly the case near the head, where the water is often taken out from the river through a narrow, steep-walled canyon. Here the foundation for a flume is prepared along the rocky cliffs, supports being

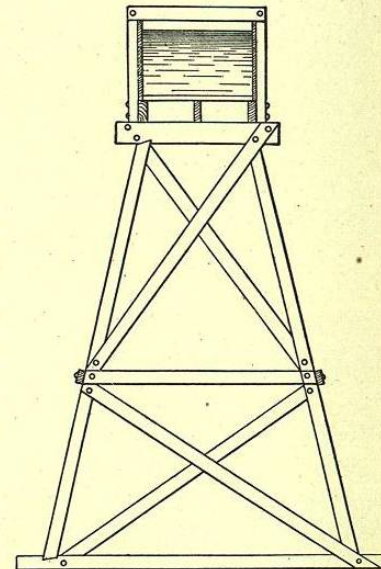
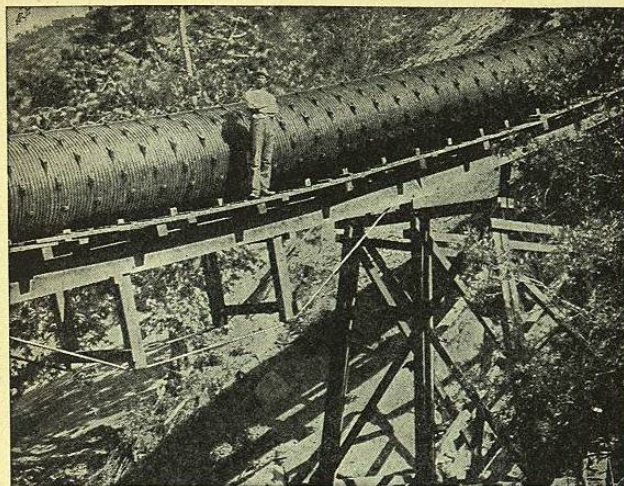


FIG. 36.—Vertical elevation of trestle and flume.

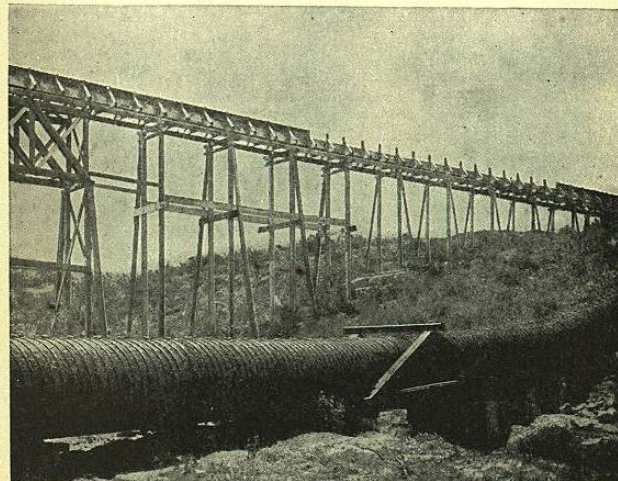
devised to suit the inequalities of the ground. Plate XVII, *A*, shows one of these flumes built along a rocky hillside.

In some cases, instead of a rectangular, box-like flume, a V-shaped section, shown in Fig. 48, on page 184, is built, economizing lumber and obtaining a greater velocity. Such flumes have been constructed mainly by lumber companies for transporting cordwood, railroad ties, planks, and boards from the mountains down to the lower lands, the water being used to some extent in irrigation. A better and more expensive type of flume is that having a semicircular section, such as shown in the accompanying view (Pl. XIX). These flumes are built of narrow planks or staves laid side by side, and held in place by iron bands run around under the flume and fastened by nuts and threads, by which the bands can be drawn up and the staves brought together, making a tight joint.

In crossing very deep depressions it is necessary to have a correspondingly high trestle, in order to carry the flume across on grade. Such high trestles are not only expensive, but are liable to destruction by storms, and in place of them have been built what are known as inverted siphons or wooden stave pipes. These pipes are built in a manner somewhat similar to the semicircular flume, being made of narrow plank carefully planed to a given dimension and held in place by circular iron bands or hoops. The ends of these hoops are



A. PIPE UNDER 160-FOOT HEAD, SANTA ANA CANAL, CALIFORNIA.



B. OLD FLUME AND REDWOOD PIPE REPLACING IT, REDLANDS CANAL, CALIFORNIA.

brought together by means of suitable screws, by which the hoops can be made smaller, drawing in the staves and compressing the joints. On the

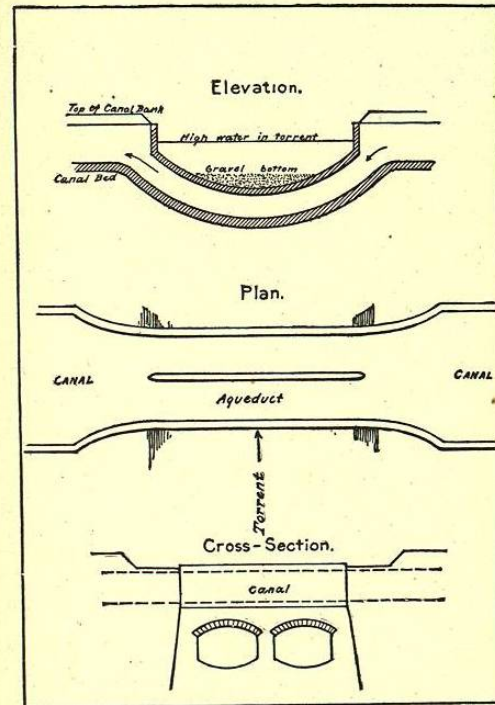


FIG. 37. — Siphon passage for canal.

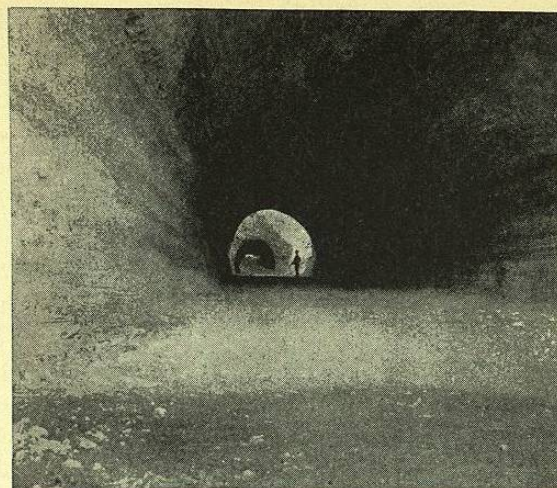
accompanying illustration (Pl. XX, *A*) one of these wooden pipes is shown supported on a low trestle, the ends of the iron bands appearing as projections

regularly arranged around the pipe. On Pl. XX, *B*, is shown an old wooden flume of the ordinary type, and in the foreground a redwood stave pipe replacing it. A similar wooden pipe is shown on Pl. LIII, and an open semicircular flume on Pl. XXII, *A*.

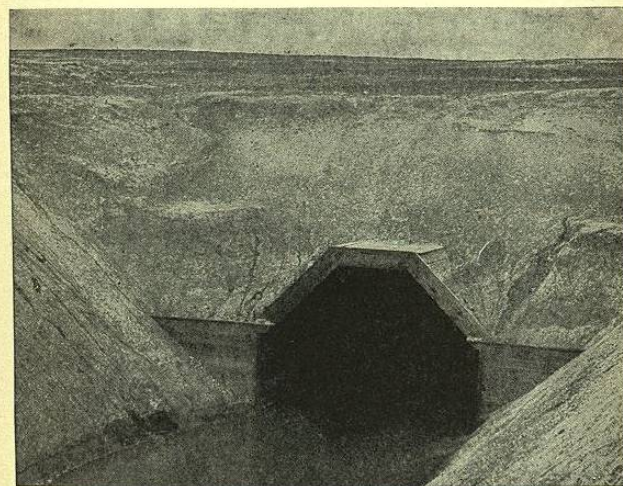
Inverted siphons, whether of wood or masonry, are used to carry a canal under a side channel instead of over it. Figure 37 shows a masonry structure built beneath the bed of a torrential stream. In the upper part of the figure is a longitudinal section, the course of the water in the stream channel being shown by the arrows. In the middle of the figure is the plan showing a dividing wall for supporting the masonry roof of the inverted siphon. At the bottom of the figure is a cross-section of the central part of the structure, showing the siphon passing under the stream through the two channels formed by the dividing wall.

TUNNELS.

Where the ground is so irregular that it is impracticable to build flumes, recourse must be had to tunnels. These are usually short, cutting through rocky spurs. An excellent example of work of this character is that along Bear River in Utah, near the head of the canal taking water from the canyon below Cache Valley, shown on Pl. LV. The rocky walls are so steep that it has been found necessary to excavate a canal partly in the walls



A. TUNNEL ON TURLOCK CANAL, CALIFORNIA.



B. TUNNEL IN EARTH ON CROCKER-HUFFMAN CANAL, CALIFORNIA.

and partly piercing projecting portions, making a substantial masonry structure.

Similar methods have been employed on the Turlock Canal in California, where a series of short tunnels alternate with open side-hill cutting as shown on Pl. XXI, *A*. Farther along the line of the canal it is sometimes necessary to make an underground passage to avoid a deep cut. Such a tunnel is illustrated at *B* on the same plate, this being on the Crocker-Huffman Canal, which takes water from Merced River, California. This skirts the base of the foothills on the south side of the river, and reaches the upland above the town of Merced.

These tunnels, when built through solid rock, do not require lining, but in many situations they must be supported by masonry or substantial brickwork, although in a few instances temporary wooden supports are preferred. In order to increase the velocity through the tunnel and thus reduce its area for a given volume of flow, a smooth concrete lining is usually provided for the bottom and sides.

LINING OF CANALS.

In portions of the United States where frosts do not occur to any considerable extent and where water has greatest value, experience has shown that it is desirable to line the ditches and canals with concrete or cement, thus reducing loss by percolation and making the channel so smooth that

the water moves rapidly even on slight grades. Often it is possible to trim the banks of the ditches to a uniform surface, and this is found to be sufficiently firm to serve as a foundation upon which to put a layer of cement mixed with sand and having a thickness of from $\frac{3}{4}$ of an inch to $1\frac{1}{2}$ inches. Where the bed and banks are not firm, it

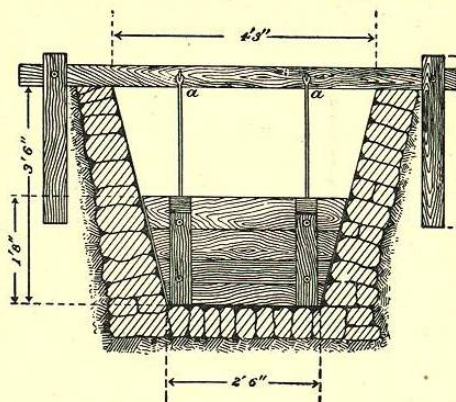


FIG. 38.—Section of cement-lined ditch with stop gate.

is necessary to pave or revet them with small stone, and then place upon this a coat of concrete made of small gravel and sand. The economy of water resulting from this careful construction has been found to be sufficiently large to justify a considerable outlay. The accompanying figure (38) shows a portion of a ditch lined with small stone covered with cement, and in this a stop gate for the purpose of regulating the flow. This gate is hung at the

points marked *a*, and can be swung up out of the way when not needed to check the water and raise it so that it will flow out into lateral distributing ditches or furrows.

The accompanying illustration (Pl. XXII, *B*) also gives a view of a portion of the Santa Ana Canal in Southern California as completed, with a lining of boulders roughly broken into shape and laid in cement mortar. The walls were first built against the sloping sides of the excavation, which was made in hard clay and natural cement gravel. These side slopes were generally 2 feet vertical to 1 horizontal. The bottom or invert was paved and the chinks were filled with coarse sand and spalls, with a layer of mortar roughly bedded on top. On this was laid the cement-plaster lining. The walls were laid with considerable care, giving a rough surface. They were from 16 to 20 inches thick on the bottom and from 8 to 10 inches thick on the top. In the view the width of the finished section is 12.5 feet on top and 7.5 feet deep at the centre.

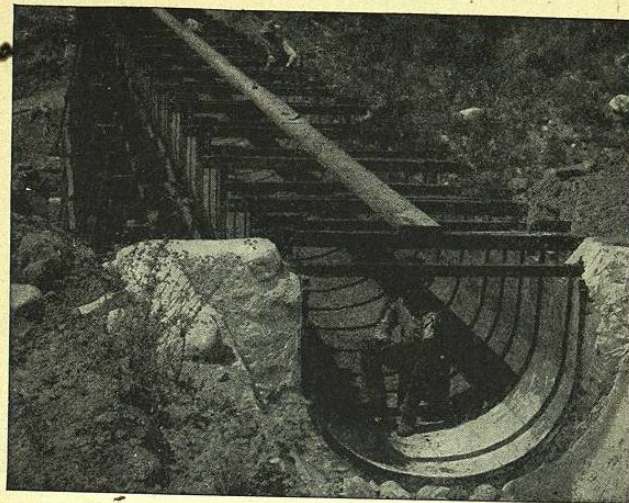
EROSION AND SEDIMENTATION IN CANALS.

Since the greater part of the water used in irrigation must for economy be conducted by gravity, it is necessary to consider carefully the slopes to be given the conduits. This is especially true where a broad valley is to be irrigated from a stream whose upper course is only a few feet above the general level of the land. If the grade

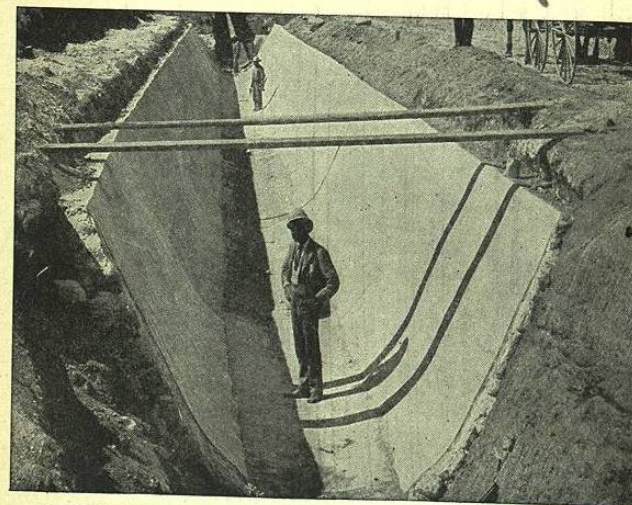
is steep, it will either be necessary to lengthen the canal or to take water only to the lower land, leaving the higher portions of the valley dry. If, on the other hand, a very gentle grade is given, the water will flow slowly, and a very wide canal must be built to carry the necessary volume.

Equally important as the consideration of the relative height of the source of the water and the land to be irrigated, if not more so, are the effects of the slope of the canal upon the velocity of the water and the consequent cutting or filling of its channel. With steep grade the water moves with such rapidity as to pick up and carry along fine particles, and with increasing velocity larger and larger grains of sand or pebbles are moved, eroding the channel and carrying the loose material to points where it may be a source of annoyance or injury. The power of the stream to cut its bottom and sides increases very rapidly with higher velocities. Experiments indicate that by doubling the velocity of the stream its power to carry is not merely doubled but is increased sixty-four times; thus a very slight change in the rate at which water flows makes a very great difference in its behavior as regards carrying or depositing loose materials.

When, because of its great velocity, water has taken up and is carrying silt, sand, or gravel, and the velocity is reduced in any way, the heavier particles are immediately dropped. A torrential



A. SEMICIRCULAR FLUME IN SANTA ANA CANAL, CALIFORNIA.



B. CEMENT LINING OF SANTA ANA CANAL, CALIFORNIA.

stream, entering a pond or reservoir, deposits at once the boulders or gravel, then the sand, this being dropped a little farther on, and finally the clay or silt in the broader, stiller portions. A similar condition occurs in a ditch or a canal. Water from the river is sometimes muddy, especially in times of flood. On entering the canal, if the velocity is reduced at any point, some of this material will settle, forming a deposit along the sides or bottom. In this way the enlarged portions of the canal, such as a little embayment along its sides, will be gradually filled with sand or mud, the tendency being for a stream of uniform grade and volume to fill in the depressions or nooks along its course and to wear away projecting points or obstructions.

If, for a given volume of water, the cross-section of a portion of a canal is too large, the velocity will be checked and sediment deposited, reducing the size of the channel until this reduced area reacts by causing a slight increase in the velocity of the water. In other words, the flowing water tends to enlarge obstructions and to fill up and reduce the channels which are too capacious for its volume. Such a result is seen in the accompanying figure (39), where the broken lines show the original slope of the ground, and also the form of the canal. The flowing stream has gradually deposited mud and sand on each side, as shown by the dotted portions of the drawing, diminishing