DEPARTMENT OF THE INTERIOR

# WATER-SUPPLY
AND
# IRRIGATION PAPERS
OF THE
# UNITED STATES GEOLOGICAL SURVEY

## No. 43

CONVEYANCE OF WATER IN IRRIGATION CANALS, FLUMES,
AND PIPES.—FORTIER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1901

## IRRIGATION REPORTS.

The following list contains titles and brief descriptions of the principal reports relating to water supply and irrigation, prepared by the United States Geological Survey since 1890:

### 1890.

First Annual Report of the United States Irrigation Survey, 1890; octavo, 123 pp.

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geological Survey, 1888–89. Contains a statement of the origin of the Irrigation Survey, a preliminary report on the organization and prosecution of the survey of the arid lands for purposes of irrigation, and report of work done during 1890.

### 1891.

Second Annual Report of the United States Irrigation Survey, 1891; octavo, 395 pp.

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States Geological Survey, 1889–90. Contains a description of the hydrography of the arid region and of the engineering operations carried on by the Irrigation Survey during 1890; also the statement of the Director of the Survey to the House Committee on Irrigation, and other papers, including a bibliography of irrigation literature. Illustrated by 29 plates and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1891; octavo, 576 pp.

Printed as Part II of the Twelfth Annual Report of the United States Geological Survey, 1890–91. Contains "Report upon the location and survey of reservoir sites during the fiscal year ended June 30, 1891," by A. H. Thompson; "Hydrography of the arid regions," by F. H. Newell; "Irrigation in India," by Herbert M. Wilson. Illustrated by 93 plates and 190 figures.

Bulletins of the Eleventh Census of the United States upon irrigation, prepared by F. H. Newell; quarto.

No. 35, Irrigation in Arizona; No. 60, Irrigation in New Mexico; No. 85, Irrigation in Utah; No. 107, Irrigation in Wyoming; No. 153, Irrigation in Montana; No. 157, Irrigation in Idaho; No. 163, Irrigation in Nevada; No. 178, Irrigation in Oregon; No. 193, Artesian wells for irrigation; No. 198, Irrigation in Washington.

### 1892.

Irrigation of western United States, by F. H. Newell; extra census bulletin No. 23, September 9, 1892; quarto, 22 pp.

Contains tabulations showing the total number, average size, etc., of irrigated holdings, the total area and average size of irrigated farms in the subhumid regions, the percentage of number of farms irrigated, character of crops, value of irrigated lands, the average cost of irrigation, the investment and profits, together with a résumé of the water supply and a description of irrigation by artesian wells. Illustrated by colored maps, showing the location and relative extent of the irrigated areas.

### 1893.

Thirteenth Annual Report of the United States Geological Survey, 1891–92, Part III, Irrigation, 1893; octavo, 486 pp.

Consists of three papers: "Water supply for irrigation," by F. H. Newell; "American irrigation engineering" and "Engineering results of the Irrigation Survey," by Herbert M. Wilson; "Construction of topographic maps and selection and survey of reservoir sites," by A. H. Thompson. Illustrated by 77 plates and 119 figures.

A geological reconnoissance in central Washington, by Israel Cook Russell, 1893; octavo, 108 pp., 15 plates. Bulletin No. 108 of the United States Geological Survey; price, 15 cents.

Contains a description of the examination of the geologic structure in and adjacent to the drainage basin of Yakima River and the great plains of the Columbia to the east of this area, with special reference to the occurrence of artesian waters.

### 1894.

Report on agriculture by irrigation in the western part of the United States at the Eleventh Census, 1890, by F. H. Newell, 1894; quarto, 283 pp.

Consists of a general description of the condition of irrigation in the United States, the area irrigated, cost of works, their value and profits; also describes the water supply, the value of water of artesian wells, reservoirs, and other details; then takes up each State and Territory in order, giving a general description of the condition of agriculture by irrigation, and discusses the physical conditions and local peculiarities in each county.

Fourteenth Annual Report of the United States Geological Survey, 1892–93, in two parts; Part II, Accompanying papers, 1894; octavo, 597 pp.

Contains papers on "Potable waters of the eastern United States," by W J McGee; "Natural mineral waters of the United States," by A. C. Peale; "Results of stream measurements," by F. H. Newell. Illustrated by maps and diagrams.

(Continued on third page of cover.)

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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

# CONVEYANCE OF WATER

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# IRRIGATION CANALS, FLUMES, AND PIPES

BY

SAMUEL FORTIER

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Department of the Interior,
United States Geological Survey,
Division of Hydrography,
*Washington, December 17, 1900.*

Sir: I have the honor to transmit herewith a manuscript prepared by Prof. Samuel Fortier, of Bozeman, Montana, with the recommendation that it be printed in the series of Water-Supply and Irrigation Papers. The author has had much experience in the construction of irrigation canals and related hydraulic works used in the reclamation of the arid lands. The results of his experience and observation are of value in considering improved methods of utilizing the water resources of that section of the United States. It is important, therefore, to bring these details to the attention of engineers and others engaged in construction work.

Very respectfully,
F. H. Newell,
*Hydrographer in Charge.*

Hon. Charles D. Walcott,
*Director United States Geological Survey.*

# CONVEYANCE OF WATER IN IRRIGATION CANALS, FLUMES, AND PIPES.

By SAMUEL FORTIER.

## INTRODUCTION.

The vast extent of arid land in the United States—fully two-fifths of its area—includes some of the richest agricultural land on the globe. Its utilization rests not merely upon obtaining water, but to a large extent upon bringing water to the land at a cost commensurate with the value of the crops raised. The question of cost, therefore, enters largely into all considerations of the extent to which the arid region can be redeemed by irrigation. With improved methods and appliances the cost of irrigating works can be greatly reduced and the area of tillable land correspondingly increased. This paper has been prepared for the purpose of calling attention to present practices in the conveyance of water in irrigation canals, flumes, and pipes, and to point out ways in which works of this character can be built with greater permanence and at less cost than those now in existence.

## IRRIGATION CANALS.

The network of ditches and canals which pervades the cultivated portion of arid America varies in size from the furrow of the irrigator to the large canal of the corporation. While the capacity of the smaller may be less than 1 second-foot, that of the larger may exceed 1,000 second-feet. As a rule the small ditches were built by individual settlers, those of medium size by communities of farmers, and the large canals by capitalists.

### LOCATION.

When a canal is to be built to convey water to a tract of land, considerable preliminary work is necessary before its location can be determined. It is not difficult to ascertain the total area of land under any proposed canal, but care and good judgment must be exercised in estimating the percentage of the total area which is arable and irrigable.

The acreage that can be irrigated having been determined, it is necessary to ascertain the volume of water that will be required for the tract—i. e., the net volume after deducting loss due to evaporation and seepage from the volume admitted through the head gates. The preliminary line may start from the source of supply or from the land to be watered. When the boundaries of the tract are known and there is little choice as to the location of the head gates, the better way is to start at the highest point of land to be watered and run toward the source of supply on a proper grade. On the other hand, if there is a particular location on the river from which water can be readily and cheaply diverted, it is well to begin at that point and extend the location, allowing for the necessary grade toward the land to be watered. This mode of procedure is preferable when the territory covered by the proposed canal is extensive and unsettled, and when economy in construction is of greater importance than the area to be served. The zero of the final location should be at the point of diversion.

In locating the center line of a canal the practice of the writer has been to employ two level parties. One level party precedes the transit party and sets temporary stakes on grade, irrespective of the sharpness of the bends or the irregularity of the general alignment. The other party follows the transit party and takes the elevations of the located line. Before proceeding to work the level party ascertains, from standard cross sections of the proposed canal, the depth of the cut at the center. The levelman, with his rodman, chainman, and stake-driver, places a long, slim stake, such as a lath, at each 100-foot station on surface grade. This surface is always at a fixed distance above the bottom of the excavated canal. If the proposed canal were to be 10 feet wide on the bottom, the difference between the bottom grade and the surface grade might be 2 feet; if the proposed canal were to be 16 feet wide, the difference might be 4 feet, and so on, in like proportion. The transit party lays down as straight and direct a location line as is possible, consistent with the grade stakes. These grade stakes are visible to the transitman between transit points, and represent the irregularities of the surface across which he is sighting. When their position is zigzag he usually can locate a straight line or a curve between them, so as to have an equal number on each side of the line and thus equalize, in a measure, the excess and deficiency of excavation. A strict adherence to the grade line makes a bad location. It not only increases the length of the line, but introduces a multitude of sharp curves, which are a serious objection in the operation of canals. The transitman may also lessen the distance by building low embankments at the head of dry ravines. Instead of following the grade stakes from *A* around to *C* and *B*, fig. 1, he may extend the line from *A* to *B*, and build a small embankment on the low side of the located line. In canals of low grade such ponds as *C*, *B*, *A* make good settling basins, where the silt accumulates instead of in the main channel.

## STANDARD CROSS SECTIONS.

When the preliminary lines are being run, notes are taken of the slope of the ground and the character of the materials. From this information, coupled with a knowledge of the required capacity, standard cross sections are made to suit the various slopes and capacities.

In these sections the material excavated is usually placed in such a manner as to form the embankments. On level ground the embankments are equal, on sloping ground the greater part of the excavated material is deposited on the low side, and on steep slopes all of the material excavated goes to form the lower embankment.

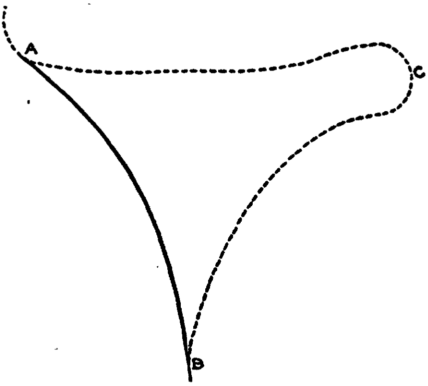

FIG. 1.—Embankment on low side of a canal.

In fig. 2 is shown a half section of a canal on level ground to carry about 100 second-feet of water with a mean velocity of between 2½ and 3 feet per second. It is 12 feet wide on the bottom, with side slopes of 1 to 1, a berm of 3 feet, and embankments 6 feet wide on top. The depth of water is 3 feet. To the right is a half section of the same canal, showing the form it is likely to assume after being in use several years. In comparing this half section with the former half section it will be noted that the center of the bed is slightly eroded, the sharp corner of the berm worn down, and the material deposited along the bottom edge. The embankment also has settled and is of a semielliptical form.

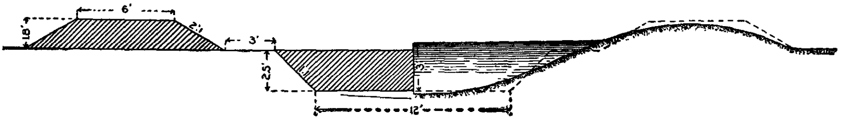

FIG. 2.—Half section of a canal on level ground.

From an examination of many sections obtained from canals long in use the author is led to believe that few channels in earth remain long in the form in which they were first constructed. The materials most commonly met with assume, in time, a cross section similar to that shown in fig. 2. Such being the case, the utility of berms is apparent. In the case under consideration a part of the excavated material would find its way into the channel and have to be removed a second time. In deep cuts or on steep hillsides berms are dispensed with, for the reason that it is more economical to remove once a year the material which rolls down than to enlarge the section sufficiently to introduce them.

The top width of the embankments can not be made much less than 6 feet, unless some kind of large grader is used to remove the dirt. When teams are employed they crowd, unless the driveway is nearly 6 feet wide. The top of the embankment should also be of a uniform grade and parallel to the bottom grade. Any excess of materials should be placed on the outer slope, and not piled up in heaps above the grade of the embankment.

In locating a canal it is difficult to plan for just enough earth to make the embankments—in almost every case there is either a surplus or a deficiency. If the standard cut at the center, or grade rod, as it is termed, is 2½ feet, as in fig. 2, there will be portions with a depth of 2 feet or less and other portions with a depth of 3 feet or more. If these are adjacent, the excess in the one may suffice for the shortage in the other. There are times, however, when borrowing from some other source must be resorted to. Some prefer to borrow from the bed of the canal; but this seems to be a bad practice. By scooping out the bottom in places the grade and mean velocity are no longer uniform, and it is difficult to repair or clean the canal, on account of the pools of stagnant water which are formed in such pits. Others prefer to widen the canal without digging below grade. There are serious objections to these sudden changes of cross section, but on the whole the practice is better than interfering with the grade. Perhaps the better way is to plan the standard cross sections so that the amount excavated will be in excess of that required to form the embankments. When a low place in the location is encountered, the excess material can be hauled a distance of 200 feet or more from each side, to make up the deficiency. When the excavated material is more than sufficient to form the embankments, the surplus can be added to the outer slope without detracting from the appearance of the canal.

## GRADES.

It is difficult to determine aright the proper grade or fall for a proposed canal. It is true that the velocity of water depends primarily on the grade, but there are so many conditions which affect the flow, that, having fixed upon a fall in a given length of canal, it is not easy to predict what the mean velocity will be. This mean velocity is always important, for in nearly every canal in earth there is a rate of motion which is adapted to the character of the materials through which the water flows. If this motion be too great, the finer particles will be carried away, leaving a mass of porous materials through which much water will seep and percolate, thus reducing the volume in the canal. On the other hand, if the motion of the water be too slow, the consequences are also serious. The sediment borne by the swift currents of mountain streams is deposited in the artificial channel and would in time fill it if not periodically removed. The capacity of the canal, owing to deficiency in velocity, is also reduced, and, as is pointed out elsewhere, aquatic plants seem to grow more abundantly and give much more trouble in canals having a low velocity. As already stated, velocity depends on the volume carried, on the form of cross section, and on other factors. The velocity of water in a farmer's lateral on a grade of 50 feet to the mile may not be so great as that of the large canal on a grade of 1 foot to the mile. One of the laterals of the Logan and Hyde Park canal, in Cache County, Utah, has a fall of 52 feet to the mile, and when measured had a mean velocity of 1⅓ feet per second and a discharge of 0.85 second-foot. The Point Lookout canal, in Boxelder County, Utah, on a grade of 1.43 feet to the mile, has a mean velocity of 1.48 feet per second and a discharge of 87¼ second-feet. This great difference in grade, while the velocities are nearly equal, is to be accounted for in both the forms of the channels and the volumes of water carried. In the small lateral the ratio between the water area and the frictional surface was 1 to 4, while in the large canal this ratio was less than 1 to ½.

For ditches and canals built in common earth the mean velocity should not vary much from 2¾ feet per second under a full head. The behavior of such watercourses in the West during the last fifteen years seems to verify this statement. Assuming this to be a fact, it only remains to allow sufficient grade to produce, under given conditions, the required mean velocity.

The injurious effects of either too much or too little grade are well shown on two canals in Gallatin County, Montana. The Middle Creek canal was built about thirty years ago, to divert water from Middle Creek. The grade was established by means of a triangle and plumb line. With the dread ever present in the minds of the operators of getting too little fall, they went to the other extreme and allowed too much fall. The grade near the upper end is nearly 1 per cent, but it diminishes to about 1 in 200 over the fourth mile, while the main branches are on the slope of the valley, which is from 75 to 80 feet to the mile. In consequence, the velocity near the head is, in places, more than 5 feet per second, and the bed of the channel is washed clean of all earth and sediment, leaving a porous mass of coarse gravel and cobbles. So great is the seepage through this formation that the loss in 4 miles was 21.5 second-feet, or 22 per cent of the total flow during the month of July last. The effect of high velocities on the Fowler Switch canal, California, is shown in Pl. I, *A*.

The Kleinschmidt canal, Montana, was built about twelve years ago to divert water from West Gallatin River. It was well located, by a competent engineer, but the grade adopted was only sufficient to produce, when running full, a mean velocity of about 2 feet per second. Had this canal been operated to its full capacity during the last ten years, the effects of the low grade might not have been apparent; but inasmuch as the volumes carried have varied from 25 to 50 second-feet, instead of 100 second-feet, its approximate maximum capacity, the deposition of silt has been very great. In places this silt is found spread over the bottom, but more frequently there is only a thin layer on the bottom and the balance is found fairly regularly deposited on the edges, as represented in fig. 3. If one may judge by present conditions, the bottom width was originally 14 feet, with side slopes of 1 to 1, a berm on the lower side, and the embankment about 4 feet 6 inches above grade. This supposed original section is shown by the dotted line, while the heavy line, with the filling of silt at the edges, represents existing conditions. The grade of this canal, with the exception of the upper 7,000 feet, is 2.64 feet to the mile. While the mean velocity of the present flow is not known, it is presumed to be not more than 1½ feet per second; the calculated velocity, when the depth is 2½ feet, is a trifle more than 2 feet per second.

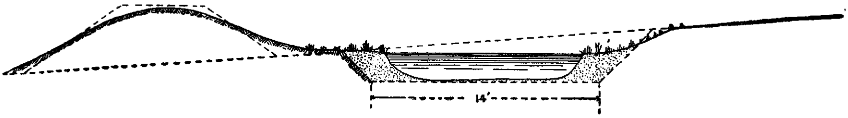

FIG. 3.—Kleinschmidt canal, on West Gallatin River, Montana, showing silt deposit on bottom and edges.

### OPERATING CANALS IN WINTER.

The irrigation canal is frequently the only source of water supply of the new settler. In many unirrigated localities in the West well water is often difficult, if not impossible, to obtain. When extensive areas of land are irrigated every summer for a number of years, a part of the water so used is absorbed by the earth and gradually fills the underlying strata. In this way the water level is brought nearer the surface of the ground, and water can often be obtained by digging inexpensive wells. Until this change is effected, however, the new settler depends on the canal, not only to irrigate his crops, but to furnish water for his home and his stock. Hence, for the accommodation of farmers who have no other means of obtaining water, irrigation canals are frequently operated throughout the year, with the exception of a short period in the early spring when the water is turned out to facilitate cleaning and repairs.

When the water conveyed in the canal performs the dual function of irrigating land and furnishing a domestic supply for a town or city, it is necessary that its efficiency be maintained during the winter months. The small cities of the West, with populations varying from 1,000 to 6,000, have usually a small waterworks plant and the beginning of a

*A.* FOWLER SWITCH CANAL, CALIFORNIA, SHOWING EFFECT OF HIGH VELOCITIES

*B.* BEAR RIVER CANAL, UTAH, LOOKING NORTH.

sewer system. Often their available means will not permit the construction of a conduit to tap the waters of a natural stream, in which case a temporary arrangement is made by extending the distributive system of the water mains to the nearest available canal until such time as means can be provided to carry the supply pipe to the river. This forms the second class of canals that are operated during the winter months.

The third class is operated solely for mechanical purposes, and since power is needed for milling, manufacturing, and mining in winter as well as in summer, efforts are made to keep such canals full of water during even the coldest weather. The difficulties which canal superintendents and mill men experience in doing this consist not in the removal of the surface ice, but in getting rid of and overcoming the bad effects of anchor ice and slush ice. The conduits and canals of the Rocky Mountain region head for the most part in the canyons adjacent to the cultivated valleys. In winter the temperature within these canyons is from 10° to 30° F. lower than that of the bordering plain, which fact, together with the exposed positions and the high velocity of the water, seems to be favorable to the formation of so-called anchor ice. This form of ice differs from surface ice in that it adheres to the bottom and sides of the exposed channel in small, long crystals until the size of the water channel is greatly reduced and in time becomes entirely choked. As the weather grows warmer the ice which has formed beneath the surface is detached, rises to the surface, and, as slush ice, floats down with the current. This slush ice not infrequently grounds in the bed of the channel and other ice accumulates at the same place, until an ice dam is formed which causes a break in the canal bank. The portion which floats down the canal is likely to choke the intake of the waterworks or prevent the operation of the gates and water wheels of the mills.

Usually ice forms in thin sheets on the surface of cold water. The average weight of a cubic foot of clear river water is about 62½ pounds; the weight of a cubic foot of ice is 57½ pounds. Hence, if a block of ice were submerged below the surface of a stream it would, unless held down by some force, immediately rise to the surface. It is, however, true that ice frequently forms on the bottom and sides of canals, streams, and large rivers and remains submerged until a rise in temperature withdraws it from its moorings and causes it to float. In the United States this form of ice is commonly known as anchor ice or ground ice; in Canada it is called frazil ice; while geologists sometimes apply to it the term specular ice. According to Mr. Peterson, chief engineer of the Atlantic and Northwest Railway Company,[1] when soundings were made during the winter of 1881–82 across the channel of St. Lawrence River above Lachine Rapids and below Lake St. Louis

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[1] See discussion of frazil ice in Trans. Can. Soc. Civ. Engrs., Vol. I, Pt. I, p. 20.

for the site of the present St. Lawrence Bridge, anchor ice from 2 to 3 feet deep was found adhering to the bed of the channel. At this bridge the river varies in depth from 5 to 40 feet. The bridge proper is nearly three-fourths of a mile long, and the current at low water varies from 2½ to 6 miles an hour. The anchor ice formed during a period of extremely cold weather, when the temperature was below zero. A subsequent rise in temperature detached it from the bed, when it immediately rose to the surface and floated downstream in the form of slush ice.

From observations in different parts of this continent, the conditions most favorable to the formation of anchor ice seem to be a water surface uncovered by surface ice, a temperature at or below zero, a clear sky, and moving water, caused either by wind on lake surfaces or by currents in stream channels. This form of ice is seldom found in the bed of a channel of water which is frozen over. It rises to the surface on cloudy days, and is usually produced, other conditions being favorable, during starry nights or clear days. It seldom forms in still water, but it is frequently found below rapids or fast-moving currents. A low temperature is the chief cause of this phenomenon. In still water in winter the bed of the channel of a stream or canal is usually several degrees warmer than the surface of the water. When, however, the bed is rough and the grade steep, the upper layers of water move much faster than those nearer the bottom, and instead of moving in straight lines parallel to the axis of the stream, the water advances in irregular curves. A particle of water would thus describe a path similar to a point on the surface of a revolving object of the desired form. At the time of the Johnstown flood, credible witnesses testified that they saw locomotives floating on the surface of the water. As a matter of fact, they could not float, but that they were brought to the surface for an instant by the force of the revolving current was well established. If we accept the statement that the motion of rapidly moving water over a rough surface is extremely complex, it follows that a particle of water which has become chilled by the cold at the surface will in a brief space of time be in contact with the bottom. In this way the temperature of the bed might be reduced considerably below the freezing point, and crystals of ice would then adhere to it in the same manner as to the extension rod of a reservoir valve, which in cold weather is often covered with a mass of ice crystals to the depth of an inch or more. When the wind blows cold over a lake surface, the upper 2 or 3 feet may become as cold as, if not colder than, the surface sheet of still water when ice begins to form. In the former case, the water is full of ice needles to a considerable depth; in the latter case, the needles are congregated in a horizontal plane at the surface.

To successfully operate canals in winter, attention should be given to a few points which, as the writer has learned by experience, it is wise to observe. One of these somewhat general rules is to increase the flow prior to the beginning of the ice-forming period. Many water masters consider it safer to turn out most of the water before a cold spell, in the belief that the canal will be less likely to become choked and overflow. This is a mistaken course, for it exposes a larger proportion of the channel of the canal to the action of frost, and, other conditions being equal, a small flow will be converted into ice more rapidly than a large flow. It is better to maintain an average flow before the beginning of freezing weather, and if all of the water is not needed it may be allowed to flow through wasteways near the lower end. In this way the channel is kept free from frost, and if the head is not allowed to vary a thick coating of ice will in time form across the top. With such a covering and with no frost in the bottom of the canal, the writer has never known anchor ice to form.

It is true that slush ice may be admitted into the canal through the intake; but if care is exercised in by-passing or screening the greater part through wasteways at secondary gates, the remainder which may be allowed to enter the canal will not prove troublesome, since the temperature of the water beneath the ice will be, as a rule, sufficiently high to melt the ice crystals.

### AQUATIC PLANTS IN CANALS.

Two years ago, at a farmers' institute, the following question was asked: Can the growth of water plants in irrigation canals be prevented, and, if not, how can such growth be most economically removed? In the discussion which followed various crude devices for the removal of moss, as it is termed, were described, and the fact that it grew most abundantly in canals of low grade and sluggish velocity was clearly brought out.

In all of the warmer States and Territories of the West the growth of vegetation in canals is the cause of much annoyance and expense to the irrigator. This is particularly true in New Mexico, Arizona, and California, and in the warmer portions of Colorado and Utah. In Montana, Wyoming, and Idaho the temperature of the irrigating waters is frequently too low to promote the growth of these plants. The disadvantages due to this cause consist in the loss of water, in additional trouble in subdividing the water among the several users, and in the greater risk of breaks. Unfortunately the moss grows most rapidly at the time when water is most needed to irrigate crops, and to be compelled to turn out the water, as many are at such a time, until the sun destroys the vegetation frequently results in a scarcity of water.

When no measures are taken either to remove or destroy this vegetation the channel becomes more or less choked, and the capacity may be reduced in extreme cases to one-fifth the normal. It is also difficult under such conditions to divide the water equitably, for the reason that the water level on rating flumes and other measuring devices often rises as the quantity of water diminishes. In other words, the cross section of the water in the canal remains undiminished, or it may be increased, while the velocity is materially lessened. The fact that the water in the canals and flumes stands at a high mark while the volume flowing through is really below the normal is the cause of frequent breaks, since an attempt is usually made to crowd them beyond their safe capacity.

Of the scores of varieties of plants which grow in the water of canals it would be impossible to state with any degree of accuracy the natural conditions best adapted to the growth of each. Some varieties, for instance, seem to flourish in the coldest spring water, while others require a warm temperature. This doubtless accounts, in part at least, for the wide difference of opinion of superintendents of waterworks and irrigation canals in endeavoring to explain the presence of such vegetation in either the storage reservoir or the main canal. Speaking generally, one may say that the conditions most favorable to the growth of fresh-water plants are: (1) Clear water; (2) slow velocity; (3) a surface temperature above 60° F.; and (4) sunshine.

The writer can not now recall a single case in which so-called moss was found growing in turbid water. In 1886 and 1887, before the West Denver reservoir was roofed, immense quantities of fresh-water algæ formed in the clear water of the reservoir, and yet none was ever found in the canal and forebay 100 feet distant. South Platte River supplied both, but in the case of the reservoir the water was filtered through natural underground galleries.

Regarding the second general rule, numerous instances might be cited to show that moss grows more luxuriantly in canals of low grade, but two examples will suffice. The Logan, Hyde Park and Thatcher canal, diverting water from Logan River in Cache County, Utah, has a capacity of about 50 second-feet. Throughout the length of the main canal the grade is quite steep, with the exception of a distance of about 1,000 feet, where it is quite flat. Little, if any, moss grows on the steep portion, where the velocity is high; but on the flat portion the channel is in midsummer nearly filled with vegetable growth. The Bear River canal, in Boxelder County, Utah, branches, at a point some 6 miles below the dam, into what is known as the West canal and the Corinne canal. The West canal has a uniform grade of 1.056 feet to the mile for about 12 miles, and a bottom width at the upper end of 30 feet, which is reduced to 18 feet at the lower end. The Corinne canal has a grade of 2.112 feet to the mile throughout the upper portion, and a bottom width of 22 feet. On August 17, 1897, the West canal was carrying 87 second-feet of water, with a mean velocity of 1.48 feet per second. On August 21, 1897, the

TUNNEL OF BEAR RIVER CANAL, UTAH.

Corinne canal was carrying 110 second-feet, with a mean velocity of 2.36 feet per second. The effect of this difference in mean velocity is shown in the growth of the water plants. For years the West canal has been filled with vegetation from July 15 to September 1, necessitating frequent dredging, at considerable expense, while in the Corinne canal, which has a steeper grade, although moss grows to some extent, it has never demanded any special attention.

As has been stated, some species of these plants exist in cold water, but by far the greater number require water of a temperate heat in order to grow. This fact may readily be proved by noting the temperature of the surface water in reservoirs when moss first begins to appear. The conduit which supplies the distributive reservoir at Ogden, Utah, taps three different sources, viz, Cold Creek, Wheeler Creek, and Ogden River. On July 30, 1897, the temperature of the water in Cold Creek was 51° F., that of Wheeler Creek 55° F., and that of Ogden River 64° F., while the water at the surface of the reservoir was 59° F., with green algæ just beginning to cover portions of the water slope. On that day nearly all of the water in the reservoir came from the two creeks, and showed an increase in temperature of about 6°. If all of the water had been conveyed from Ogden River instead, with a corresponding increase in temperature, the water in the reservoir would have been 70°, and with water at so high a temperature the reservoir would soon have been filled with aquatic plants. Owing, however, to the mingling of cold water from snow-fed creeks with the warmer river water, the moss has never accumulated in sufficient quantities to necessitate removal except by skimming the surface, nor has it proved a nuisance, although it is now eight years since the reservoir was first filled and used. The absence of moss in most of the canals of Montana and Wyoming is doubtless due to the fact that the temperature of the water passing through the head gates remains low throughout the short irrigation period. In the evaporation tank at Bozeman, Montana, the writer noticed last summer that moss began to grow when the water in the tank reached a temperature of about 65° F.

Sunshine also is a prime requisite for plant growth. Water plants die when the rays of the sun are excluded. This was fairly well demonstrated in the summer of 1888, when the writer was building a roof over Cemetery Hill reservoir, at Denver, Colorado, in accordance with plans prepared by Mr. Charles P. Allen, chief engineer of the Denver Union Water Company. During hot weather in the month of June, when a space 44 feet along the center of the reservoir remained uncovered, moss began to grow in 14 feet of water under the exposed surface. When the roof was completed and the sunlight excluded all organic growth ceased to exist, and none has appeared since.

In locating irrigation canals consideration should be given to the grade, in order that the velocity may be sufficient to overcome the injurious effects of silt and vegetation. To accomplish this, the mean velocity should be not less than 2½ feet per second. When the mean velocity is less than 3 feet per second erosion of the canal bed seldom occurs, and in ordinary materials the engineer should fix the grade so as to produce a mean velocity of about 2¾ feet per second. When the physical features of the route are such that the desired velocity can not be obtained, the new canal should be built in a way to facilitate the removal of vegetable growth, by preventing any obstruction in the canal, such as fences, bridge posts, or trestles, and by removing sagebrush or willows from the banks in order to permit the free passage of teams.

Regarding canals already constructed and in operation, the first thing to be done is to ascertain the easiest method of removing the vegetation. In the smaller canals and ditches irrigators often take the old-fashioned scythe and snath and mow the weeds while the canal is full of water. In other sections the proprietors prefer to turn out the water for a week or ten days and allow the sun to destroy the water plants. The latter plan is not to be recommended, on account of the serious injury done to the crops through the lack of water at a time when it is most needed; besides, many of the older canals have not a uniform bottom grade, and although the head gates may be closed stagnant water will usually be found in the channels over the greater part of the line. Harrows and disks have also been tried with some measure of success, but the chief objection to the use of such implements is that they break down and mix the weeds with the clay of the bed and sides instead of removing them.

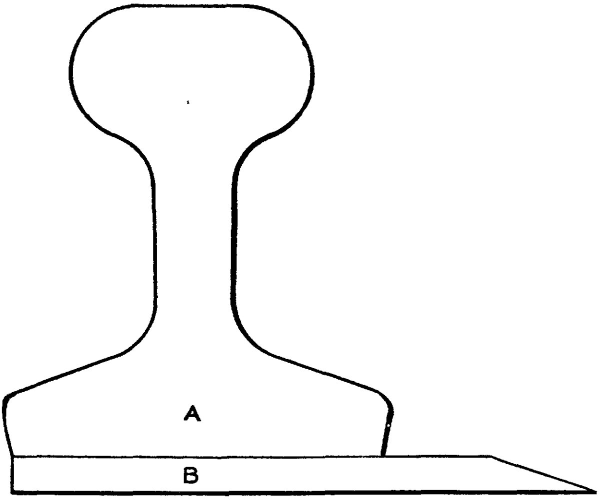

FIG. 4.—Section of rail used for V-shaped drag to remove moss from canal. *A* is rail, *B* is steel plate.

At the time the writer was superintendent of the Bear River canal system his assistants, M. Mortensen and J. L. Rhead, designed a V-shaped drag (fig. 4) that was very effective. It was formed by bending a long 40-pound railroad rail into the shape of an inverted V, the base being extended to equal the bottom width of the canal. To the flanges of this rail there was riveted a plate of plow steel sharpened to a cutting edge, after the fashion of the grain-cycle section. At the apex of the V rail a chain was attached, to which were fastened two rope cables, which extended to either bank and to which teams were hitched. This contrivance was dragged up and down the canal until the plants were all cut and floated down the channel to the most convenient place of removal. In canals carrying more than 4 feet of water the apex of the drag and the rope cables should be fastened to a flat boat. In more shallow canals the apex should be fastened to the axle of a cart or wagon. This drag was used throughout the summer of 1898.

### FLOW OF WATER.

During the summer of 1897 the writer was enabled, with the help of his assistants, T. H. Humphreys, A. P. Stover, and W. D. Beers, to make a number of experiments on the carrying capacities of irrigation ditches and canals. The funds necessary to carry on these investigations were provided by the United States Geological Survey and the agricultural experiment station of Utah. Shortly after the field work was completed, the writer resigned his position with the college to accept that of chief engineer and superintendent of the Ogden waterworks and the Bear River canal system, and since then his time has been so fully occupied with other duties that until now he has not had an opportunity to put into shape for publication the data collected two and a half years ago.

About sixty experiments were made on irrigation channels varying in size from the small ditch carrying a few miners' inches of water to the large canal carrying 225 second-feet. Experiments were made on nearly every form of ditch common to Western America, including many of the crudely formed ditches of the Mormon pioneers made nearly forty years ago, as well as the more modern and better designed canals of the Bear River canal system. The object sought was to ascertain as accurately as possible the present condition of ditches and canals that had been in operation a number of years. In order to determine the volume which flowed in any particular ditch and compare it with some well-known empirical formula, such as Kutter's or Chezy's, it was necessary to ascertain the slope of the surface of the water, the sectional area, the mean velocity, and the ratio between the water area and the wetted perimeter. This additional information regarding the form which channels assume after they are acted on by water and the atmosphere is valuable in that it gives the builder of a new canal some idea as to the proper form to adopt.

In the discussions which follow, the hydraulic elements, whether obtained in the field or computed from data taken in the field, have been referred to two well-known formulæ, Chezy's and Kutter's.

The carrying capacities of the conduits and irrigation canals of the West have been designed in accordance with Kutter's formula. It is therefore proper that experiments on the flow of water in canals should be compared with that formula.

Kutter did not live long enough to adapt his formula to American practice, particularly to American irrigation practice. His values of the coefficient of roughness ($n$) were confined to six different classes of channels, as follows:

Class I, $n=0.010$ for carefully planed boards or smooth cement.
Class II, $n=0.012$ for common boards.
Class III, $n=0.013$ for ashlar masonry.
Class IV, $n=0.017$ for rubble masonry.
Class V, $n=0.025$ for channels in earth, brooks, and rivers.
Class VI, $n=0.030$ for streams with detritus and aquatic plants.

It will be noted that only one of these six applies to irrigation canals. Besides, the mode of building and the character of the materials were different from those which prevail in America, and these differences would no doubt exert some influence on the results. However, the late P. J. Flynn, M. Am. Soc. C. E., of Los Angeles, California, took up the unfinished work of the noted Swiss engineer and adapted the experiments of Ganguillet and Kutter, as well as other hydraulicians, to American practice. Mr. Flynn's tables on the flow of water in open and closed channels have materially lessened the labors of every American hydraulic engineer, and his values for the coefficient of roughness ($n$) which we reproduce have been considered safe guides during the last ten years:

*Table giving the value of coefficient of roughness ($n$) for different channels.*[1]

$n=.009$, well-planed timber, in perfect order and alignment; otherwise, perhaps, .01 would be suitable.

$n=.010$, plaster in pure cement; planed timber; glazed, coated, or enamelled stoneware and iron pipes; glazed surfaces of every sort in perfect order.

$n=.011$, plaster in cement, with one-third sand in good condition; also for iron, cement, and terra-cotta pipes, well joined and in best order.

$n=.012$, unplaned timber, when perfectly continuous on the inside; flumes.

$n=.013$, ashlar and well-laid brickwork; ordinary metal; earthenware and stoneware pipe in good condition, but not new; cement and terra-cotta pipe not well joined nor in perfect order; plaster and planed wood in imperfect or inferior condition; and, generally, the materials mentioned with $n=.010$, when in imperfect or inferior condition.

$n=.015$, second-class or rough-faced brickwork; well-dressed stonework; foul and slightly tuberculated iron; cement and terra-cotta pipes, with imperfect joints and in bad order; and canvas lining on wooden frames.

$n=.017$, brickwork, ashlar, and stoneware in an inferior condition; tuberculated iron pipes; rubble in cement or plaster in good order; fine gravel, well rammed, $\frac{1}{3}$ to $\frac{2}{3}$ inches in diameter; and, generally, the materials mentioned with $n=.013$ when in bad order and condition.

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[1] Flow of Water in Irrigation Canals, etc., by P. J. Flynn, C. E., pp. 19–20.

SANTA ANA CANAL (CEMENT-LINED), CALIFORNIA; CAPACITY 240 SECOND-FEET.

$n$=.020, rubble in cement in an inferior condition; coarse rubble, rough-set in normal condition; coarse rubble set dry; ruined brickwork and masonry; coarse gravel, well rammed, from 1 to 1⅓ inch diameter; canals with beds and banks of very firm, regular gravel, carefully trimmed and rammed in defective places; rough rubble, with bed partially covered with silt and mud; rectangular wooden troughs, with battens on the inside two inches apart; trimmed earth in perfect order.

$n$=.0225, canals in earth above the average in order and regimen.

$n$=.025, canals and rivers in earth of tolerably uniform cross-section, slope, and direction, in moderately good order and regimen, and free from stones and weeds.

$n$=.0275, canals and rivers in earth below the average in order and regimen.

$n$=.030, canals and rivers in earth in rather bad order and regimen, having stones and weeds occasionally, and obstructed by detritus.

$n$=. 035, suitable for rivers and canals with earthen beds in bad order and regimen, and having stones and weeds in great quantities.

$n$=.05, torrents encumbered with detritus.

One of the objects which the writer had in view in making his experiments was to compare the results, particularly the values of the coefficient of roughness ($n$), with those given by Mr. Flynn for canals in similar condition. The results are herein given (pages 27 to 45) in eight groups, beginning with canals which were in excellent condition and ending with those which were in very poor condition.

The field work consisted in selecting a suitable portion of the canal to be investigated, in writing a brief description of the prevailing conditions, and in ascertaining the discharge in second-feet, the slope of the water surface, the sectional area, and the wetted perimeter. The office work consisted in computing, from the data taken in the field, the mean velocity, the hydraulic mean radius, the coefficient of roughness ($n$) as given in Kutter's formula, and the general coefficient ($c$) as given in Chezy's formula where $V = C\sqrt{RS}$.

The discharge was measured either by a current meter or by a trapezoidal weir. The trapezoidal weir designed by the Italian engineer, Cesare Cippoletti, was preferred to the Francis rectangular weir, on account of the simplicity of calculation as well as the probable greater accuracy. The one general equation used in all weir calculations was $Q=3.367\ LH^{\frac{3}{2}}$, where $Q$ equalled the discharge in second-feet, $L$ the bottom length of the weir in feet, and $H$ the depth of the water in feet over the crest of the weir. The conditions necessary for accurate measurement were carefully observed, such as a low velocity of approach, a free fall, complete contraction on the bottom and sides, and a close measurement of the head of water over the weir.

In determining the discharge by means of the current meter the results were not so accurate, but in every case from three to six separate and distinct current-meter measurements were made, and it was thought that the mean of all of these measurements would not vary much from the actual discharge. At the close of the field work the current meter was carefully rerated at the rating station in Washington, and the new rating table was used in the calculation of the velocities of flow in the canals tested.

The average cross section was obtained by plotting, in different colors and on a large scale, the three or more cross sections taken in the field. A new perimeter was then adopted from the typical cross section, which represented the average of the cross sections plotted. Its length was found by a pair of dividers, its area by a planimeter. The depths of water given in the tables are taken from the typical cross section, but approach very nearly to an average of all of those taken in the field at any one point.

The slope of a canal, represented by the fall of a given portion, usually from 100 to 200 feet, divided by the distance, was determined by a new Buff and Berger 18-inch level and a leveling rod reading to thousandths of a foot. The slope of a water surface is difficult to ascertain with accuracy, for the reason that in nearly all channels there are pulsations which cause the surface to rise and fall. Again, in irrigation canals long in use the bottom grade, owing either to abrasion or sedimentation, is seldom uniform, and the flow of water in any comparatively short portion is more or less influenced by the velocity in the section above; e. g., if a portion 100 feet in length had a fall of 4 feet to the mile, and another portion just below had a fall of 3 feet to the mile, the influence of the steeper grade of the higher portion would be felt on the lower portion. One could partially eliminate the error from this source by taking a long distance as a test, but this would introduce greater errors due to alignment and diversity of cross section. The method followed in determining the slope was to drive small wire finishing nails into the tops of submerged oak stakes at each end of the section to be tested. It was not always possible to have the top of the nail coincide exactly with the surface of the water, but this introduced no error in the results, provided the heads of both nails occupied the same relative position to the surface of the water. In the case of pulsations or slight waves caused by winds, the tops of both nails were even with either the highest or the lowest water surface. Under ordinary conditions this method will give as accurate results as those obtained by hook gages.

Having obtained all of the hydraulic elements, either from data taken in the field or from calculations made in the office, the coefficients $c$ in the Chezy formula and $n$ in the Kutter formula were then computed and checked.

The following are the results of 42 of 60 experiments made, arranged, as already stated, in eight groups, beginning with canals which were in excellent condition and ending with those which were in very poor condition.

CEMENT-LINED DISTRIBUTING DITCH AT NORTH POMONA, LOS ANGELES COUNTY, CALIFORNIA

### GROUP No. 1.

[$n$ equals 0.0134 to 0.0184.]

*Experiment No. 21.*—This experiment was made on the main line of the Bear River canal, about 7 miles below the dam and about 200 feet above the division gates. Water was first turned into this portion of the system by the writer in the spring of 1891, and during the six years of operation the action of the water had changed the section from a trapezoidal form having a bottom width of about 15 feet and side slopes of 1 to 1 to that of the segment of an ellipse, as shown in fig. 5. The formation is clayey loam and the channel when measured was covered with a coating of sediment but was entirely free from vegetation, gravel, or pebbles, and was of regular cross section and in excellent condition. Three current-meter measurements were made, with the following results:

| | Second-feet. |
|---|---|
| First measurement | 226.56 |
| Second measurement | 224.94 |
| Third measurement | 225.14 |
| Average | 225.55 |

The results of this experiment are given in the table on page 30.

*Experiment No. 12.*—This experiment was made on the Bear River City canal, 900 feet below the head gates. This canal is a branch of the Bear River canal system, and the conditions regarding materials, length of time in operation, and coating of fine sediment were similar to those of experiment No. 21. When first made, this channel was trapezoidal, with 1 to 1 slopes, but it has since changed to the form outlined in fig 5. Current-meter measurements were made at the top, middle, and bottom of the portion tested, with the following results:

| | Second-feet. |
|---|---|
| Top measurement | 10.54 |
| Middle measurement | 10.91 |
| Bottom measurement | 10.58 |
| Average | 10.68 |

For the results of this test see the table on page 30.

*Experiment No. 38.*—This test was made on a lateral of the Bear River canal in that part of the valley known as Roweville, Utah. This lateral was in good condition and was lined with clayey sediment similar to that referred to in the previous descriptions. The discharge was obtained by means of a trapezoidal weir, the bottom length of which was 3.15 feet. The depth of water on the crest was 0.822 foot. The cross section is shown in fig. 5. For the results of the test see the table on page 30.

*Experiment No. 15.*—The place selected for this experiment was on the Corinne branch of the Bear River canal, about 4 miles below the division gates. This canal had been operated six years, and although its section when new was horizontal on the bottom, with side slopes in excavation of 1 to 1, its form at the time of the test approached the segment of an ellipse, as may be seen by a reference to fig 5. Where the test was made the canal was entirely free from vegetation, and

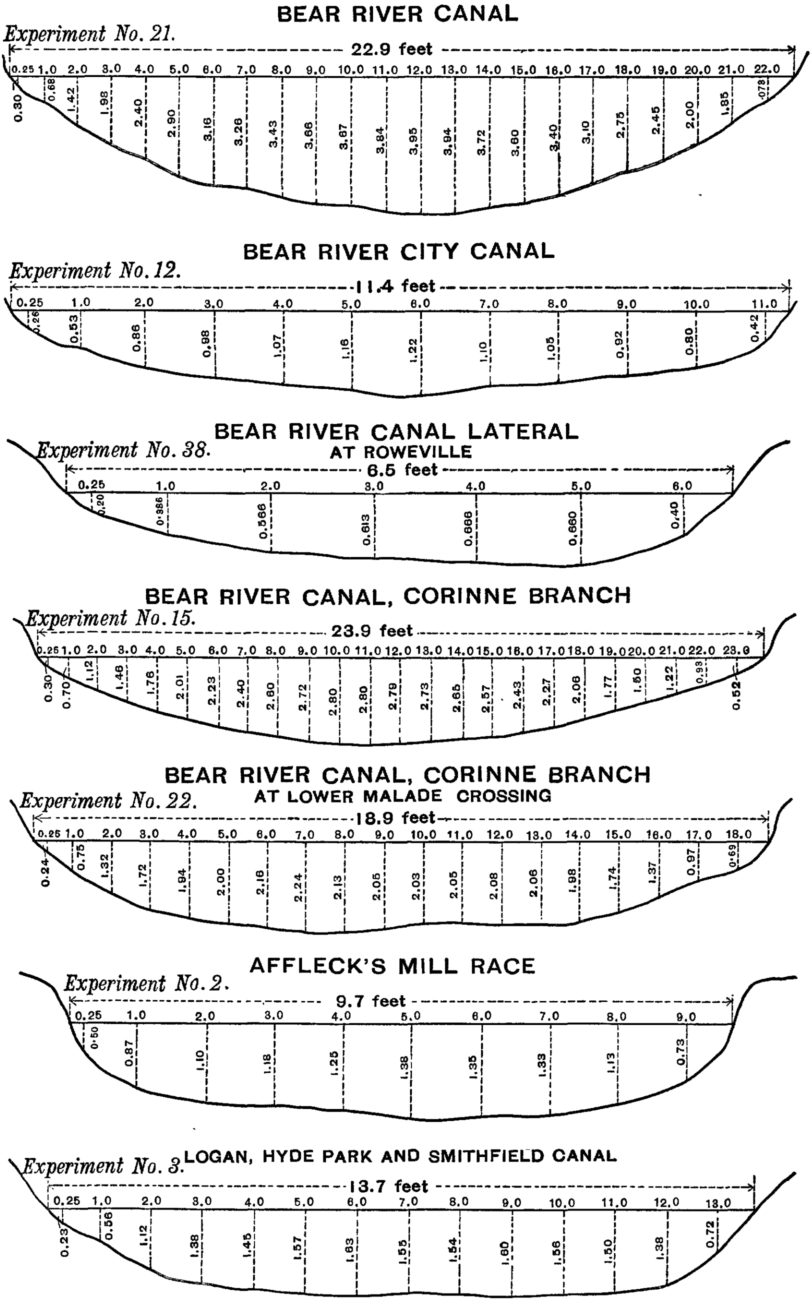


FIG. 5.—Sections of canals experimented upon.

the test was made the canal was entirely free from vegetation, and there was nothing to obstruct the flow except the friction on the smooth perimeter, which was coated with fine silt. Meter measurements were made at the top, middle, and bottom of the portion chosen, which was 100 feet in length, with the following results:

| | Second-feet. |
|---|---|
| Top measurement | 109.09 |
| Middle measurement | 109.52 |
| Bottom measurement | 110.07 |
| Average | 109.56 |

For the results of the test see the table on page 30.

*Experiment No. 22.*—This test was made on the Corinne branch, some 6 miles below the place where the last test was made, at a point about 1,300 feet below the Lower Malade crossing. (Fig. 5.) The date of the experiment was September 9, 1897, which accounts for the small volume in the canal, the irrigation season in that section being nearly past. This canal is similar to those previously described, and was in excellent condition at the time of the experiment. The formation was a clayey loam, and the action of the water for six summers had left the channel quite smooth and well coated with silt. The discharge was obtained by meter measurement in the usual manner. The results of the test are given in the table on page 30.

*Experiment No. 2.*—This test was made on a 60-foot length of Affleck's mill race, near Logan, Utah. The general form of the cross section is shown in fig. 5. The channel was composed of gravel ranging in size from small particles to one-half inch in diameter, with an occasional pebble 2 inches in diameter. The sides were in fair condition, with some weeds near the edges which did not, however, interfere to any appreciable extent with the flow of water. The discharge was obtained from the mean of the following current-meter measurements:

| | Second-feet. |
|---|---|
| Upper measurement | 15.152 |
| Do | 15.360 |
| Middle measurement | 15.574 |
| Do | 15.870 |
| Lower measurement | 15.283 |
| Do | 14.836 |
| Average | 15.346 |

The results of the test are given in the table on page 30.

*Experiment No. 3.*—On June 23, 1897, a site for an experiment was selected on the Logan, Hyde Park and Smithfield canal (fig. 5), near the mouth of Logan Canyon, Cache County, Utah. Water was first turned into this canal in 1882, and at the time of the experiment it had been operated fifteen years. The bottom and sides were smooth and composed of earth and gravel. The particles of gravel varied in size from one-half inch to 1 inch in diameter, with some pebbles from 1 inch to 2 inches in diameter. There was no vegetation save a slight growth of grass on one side. The following current-meter measurements were made:

| | Second-feet. |
|---|---|
| Upper measurement | 46.40 |
| Do | 45.90 |
| Middle measurement | 46.00 |
| Do | 46.03 |
| Lower measurement | 45.31 |
| Do | 45.75 |
| Average | 45.90 |

The results of the test are given in the following table:

*Table showing values of hydraulic elements in group No. 1.*

| Experiment. | Discharge. | Area of water section. | Mean velocity. | Hydraulic mean radius. | Wetted perimeter. | Coefficient of roughness (*n*). | Slope. | Coefficient (*c*).* |
|---|---|---|---|---|---|---|---|---|
| | *Sec.-feet.* | *Sq. feet.* | *Feet per second.* | | *Lineal feet.* | | *Feet per foot.* | |
| No. 21 | 225.55 | 62.30 | 3.62 | 2.49 | 25.00 | 0.0134 | 0.00031 | 130.24 |
| No. 12 | 10.68 | 10.24 | 1.04 | 0.86 | 11.85 | 0.0135 | 0.00012 | 102.16 |
| No. 38 | 7.90 | 3.40 | 2.33 | 0.51 | 6.70 | 0.0137 | 0.00188 | 95.27 |
| No. 15 | 109.56 | 46.44 | 2.36 | 1.86 | 24.98 | 0.0155 | 0.00027 | 105.78 |
| No. 22 | 64.02 | 31.66 | 2.02 | 1.60 | 19.78 | 0.0164 | 0.000273 | 96.75 |
| No. 2 | 15.35 | 10.69 | 1.44 | 1.00 | 10.70 | 0.0177 | 0.00032 | 80.79 |
| No. 3 | 45.90 | 17.80 | 2.58 | 1.20 | 14.80 | 0.0184 | 0.00083 | 81.50 |

*In Chezy's formula.

## GROUP NO. 2.

[*n* equals 0.0194 to 0.0213.]

*Experiment No. 13.*—This test was made on a small lateral from the Corinne branch of the Bear River canal. The section, an outline of which is shown in fig. 6, is very good, and the channel excavated in clayey loam was well lined with fine sediment, but there were numerous footprints of stock throughout the portion tested which were expected to reduce the coefficient of roughness below that (0.0194) given in the table on page 33. There were no weeds or aquatic vegetation to check the flow. The current-meter measurements were as follows:

| | Second-feet. |
|---|---|
| Top measurement | 2.75 |
| Middle measurement | 2.45 |
| Bottom measurement | 2.40 |
| Average | 2.53 |

The results of the test are given in the table on page 33.

*Experiment No. 16.*—The Millville and Providence canal (fig. 6) is the highest one diverting water from Blacksmith Fork, in Cache County, Utah. It was completed in 1864, so that at the time of the experiment water had been flowing through it thirty-three years. This canal was built in compact clay dotted with small rock fragments a half inch across. One side of the channel was perfectly smooth, while the other side had a few willow roots projecting into the water. With this exception, and the presence of a few small cobbles in the bed, the conditions were all favorable. The results of three meter measurements in a 50-foot length were as follows:

| | Second-feet. |
|---|---|
| Top measurement | 22.06 |
| Middle measurement | 22.27 |
| Bottom measurement | 22.51 |
| Average | 22.28 |

The results of the test are given in the table on page 33.

*Experiment No. 17.*—On August 28, 1897, an experiment was made on the Logan and Hyde Park canal, which flows through Logan, Utah. An even stretch of 75 feet within the city limits was chosen, and the following current-meter measurements were made:

| | Second-feet. |
|---|---|
| Top measurement | 23.95 |
| Middle measurement | 23.67 |
| Bottom measurement | 23.04 |
| Average | 23.55 |

This canal, as fig. 6 shows, was more than 14 feet wide on top and only about 2 feet deep, with a mean velocity of 1.08 feet per second. The bed was of clay covered with a thin layer of fine sand, and about one-sixth of the perimeter was covered with a low, creeping water plant. The results of the test are given in table on page 33.

*Experiment No. 20.*—This test was on Solveson & Company's canal, in Cache county, Utah, a section of which is shown in fig. 6. The discharge was obtained by a trapezoidal weir. The channel was composed of small pebbles embedded in sand. Solveson and his neighbors own the ditch, which diverts water from Blacksmith Fork and serves the low land in the river bottom. The results of the test are given in the table on page 33.

*Experiment No. 48.*—This test was made on a lateral of Logan City canal (fig. 6). There was no aquatic vegetation. The bottom and sides were smooth and were composed of gravel about the size of peas embedded in finer material. The discharge was found by weir measurement. For results see the table on page 33.

*Experiment No. 6.*—This test was made on the Logan and Richmond canal (see fig. 6), built in 1864–1867, and the largest ditch diverting water from Logan River. The bottom and sides, which were smooth

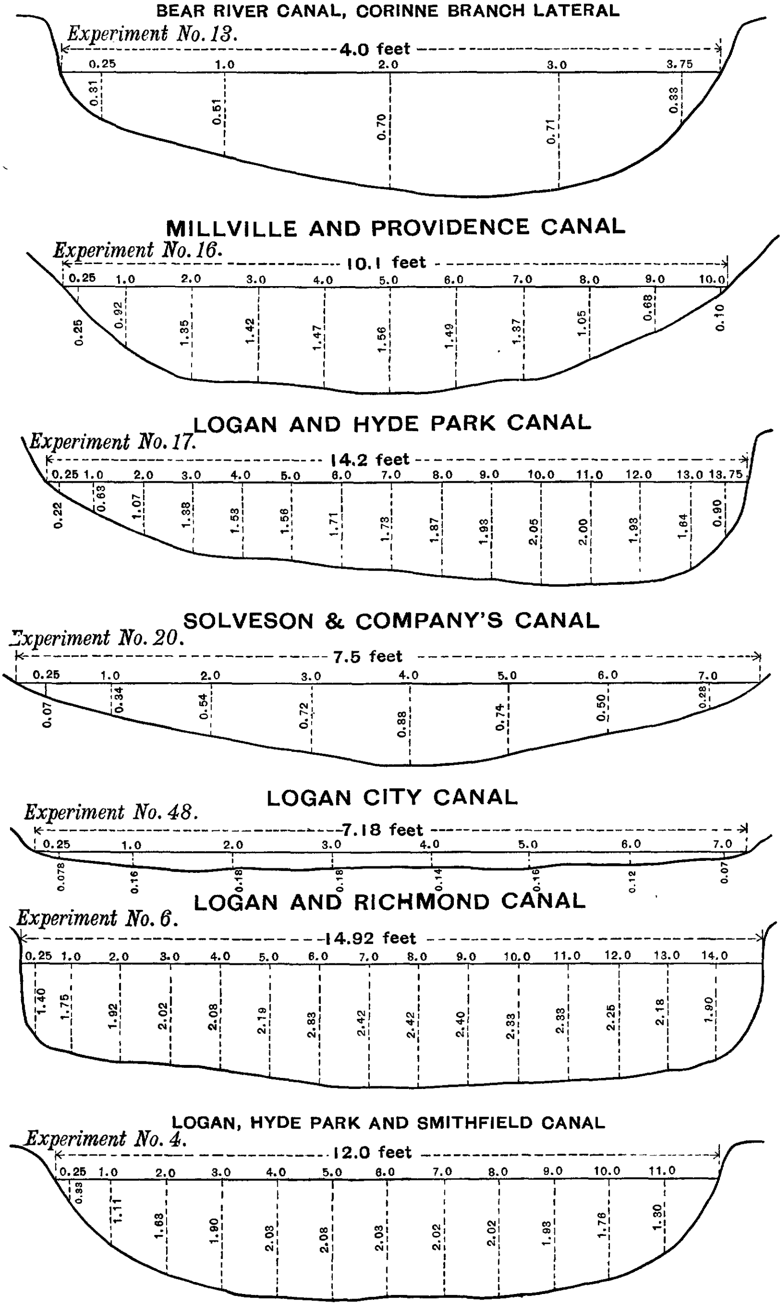


FIG. 6.—Sections of canals experimented upon.

and free from vegetation, were composed of a clayey loam. With the exception of some indentations on the sides near the top the canal was in good condition. Meter measurements were made at three points in the 100-foot section, with the following results:

| | Second-feet. |
|---|---|
| Top measurement | 68.59 |
| Do | 68.76 |
| Middle measurement | 68.80 |
| Do | 68.75 |
| Bottom measurement | 67.90 |
| Do | 68.58 |
| Average | 68.56 |

For results see table on this page.

*Experiment No. 4.*—This test was made on a 60-foot section of the Logan, Hyde Park and Smithfield canal near its point of diversion in Logan Canyon (fig. 6). The channel was composed of well-packed, coarse gravel and small cobbles, the common sizes being 1 inch, 2 inches, and 3 inches in diameter, in about equal proportion. There were some weeds on one edge, but it is doubtful whether they retarded the flow. This canal had been operated since 1882. The following are the results of the current-meter measurements:

| | Second-feet. |
|---|---|
| Top measurement | 51.09 |
| Do | 51.01 |
| Middle measurement | 51.52 |
| Do | 51.07 |
| Bottom measurement | 51.92 |
| Do | 51.57 |
| Average | 51.36 |

The results of the test are given in the following table:

*Table showing values of hydraulic elements in group No. 2.*

| Experiment. | Discharge. | Area of water section. | Mean velocity. | Hydraulic mean radius. | Wetted perimeter. | Coefficient of roughness (*n*). | Slope. | Coefficient (*c*).* |
|---|---|---|---|---|---|---|---|---|
| | *Sec.-feet.* | *Sq. feet.* | *Feet per second.* | | *Lineal feet.* | | *Feet per foot.* | |
| No. 13 | 2.53 | 2.23 | 1.14 | 0.50 | 4.46 | 0.0194 | 0.00068 | 61.55 |
| No. 16 | 22.28 | 11.50 | 1.94 | 1.07 | 10.80 | 0.0195 | 0.00062 | 74.63 |
| No. 17 | 23.55 | 21.78 | 1.08 | 1.40 | 15.60 | 0.0197 | 0.00015 | 75.72 |
| No. 20 | 4.03 | 4.00 | 1.01 | 0.52 | 7.73 | 0.0201 | 0.00056 | 59.22 |
| No. 48 | 0.56 | 1.03 | 0.54 | 0.14 | 7.19 | 0.0204 | 0.00135 | 39.29 |
| No. 6 | 68.56 | 32.02 | 2.14 | 1.74 | 17.80 | 0.0211 | 0.00046 | 75.63 |
| No. 4 | 51.36 | 20.61 | 2.49 | 1.52 | 13.56 | 0.0213 | 0.00077 | 73.05 |

*In Chezy's formula.

## GROUP NO. 3.

[*n* equals 0.0218 to 0.0238.]

*Experiment No. 11.*—This experiment was made on the Point Lookout canal (fig. 7) when the volume carried (87.29 second-feet) was small compared with the maximum capacity, which is nearly 600 second-feet. The surface width was nearly 36 feet; the depth of water at the deepest place about 2¼ feet. The section chosen was entirely free from aquatic plants, but more or less vegetation was to be found both above and below this site. The channel was smooth and composed of a clayey loam lined with sediment. The current-meter measurements were as follows:

| | Second-feet. |
|---|---|
| Top measurement | 87.64 |
| Middle measurement | 87.82 |
| Bottom measurement | 86.40 |
| Average | 87.29 |

For results of test see table on page 37.

*Experiment No. 29.*—The Providence Town canal (fig. 7) was only part full when measured by weir on September 16, 1897. The length of the weir was 2 feet, the depth of water 0.376 foot. The bed was composed of well-packed and smooth gravel about the size of Spanish nuts, embedded in sand and sediment. There was no vegetation. The ditch had been in use about thirty years. The results of test are given in the table on page 37.

*Experiment No. 19.*—The Lewiston canal (fig. 7), begun in 1860 and completed in 1880, diverts water from Cub River and serves the bench lands near Franklin, Idaho, and Lewiston, Utah. It is capable of conveying about 125 second-feet when running full, but at the time of the experiment it contained only 32.72 second-feet. The channel consisted of smooth, light-colored clay, but about one-fifth of the perimeter was covered with a growth of fibrous moss, locally termed "frog moss." The meter measurements were as follows:

| | Second-feet. |
|---|---|
| Top measurement | 33.22 |
| Do | 32.92 |
| Middle measurement | 32.94 |
| Do | 32.54 |
| Bottom measurement | 32.33 |
| Do | 32.39 |
| Average | 32.72 |

For results see table on page 37.

*Experiment No. 31.*—This experiment was made on the Providence Upper canal (fig. 7), near the town of Providence, Utah. The conditions were similar to those of No. 29. The flow was measured over a weir 2 feet in length and having 0.494 foot of water flowing over the crest. The results of test are given in the table on page 37.

*Experiment No. 14.*—This test was made on a lateral of the Bear River canal near Central farm (fig. 7). The formation was a clayey loam; the water channel was coated with sediment, and also contained patches of what is locally termed "horsetail moss"—an aquatic plant which grows to a length of 5 or more feet. The presence of this

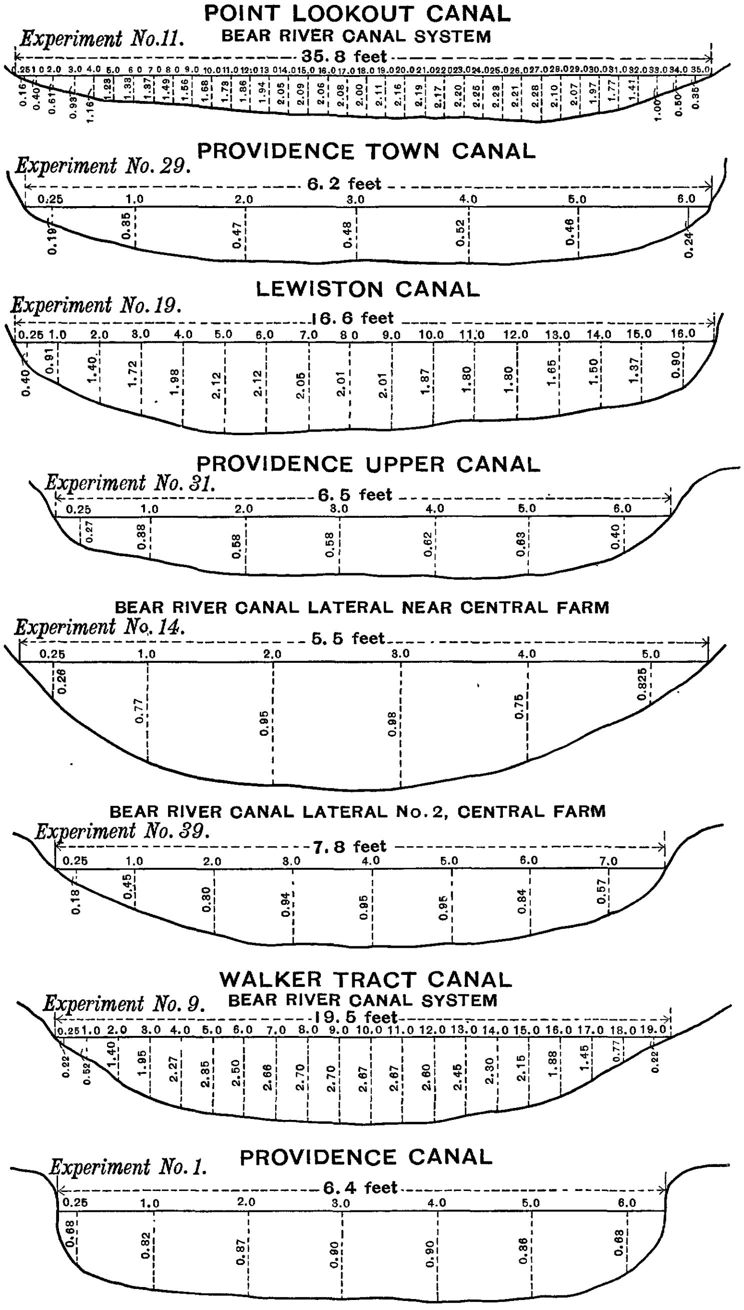


FIG. 7.—Sections of canals experimented upon.

plant, together with somewhat uneven edges, doubtless retarded the velocity.

The discharge was obtained from the average of three meter measurements, which were as follows:

| | Second-feet. |
|---|---|
| Top measurement | 4.69 |
| Middle measurement | 4.67 |
| Bottom measurement | 4.54 |
| Average | 4.63 |

For results see table on page 37.

*Experiment No. 39.*—In this instance a portion, 80 feet in length, of the Central farm lateral No. 2 (fig. 7) in the vicinity of the section tested in experiment No. 14 was used. The conditions were similar to No. 14, except that there was no moss in the bed; a few bunches of grass were, however, scattered along the edges. Clay and sediment formed the bottom. The discharge was measured over a weir. The results of the test are given in the table on page 37.

*Experiment No. 9.*—The Walker Tract canal (fig. 7), a continuation of the Point Lookout canal, was built in 1892, to carry a much larger volume of water than indicated in this experiment. The true grade was between 3 and 4 feet to the mile, but at the time of the experiment the irrigators had inserted dams in the channel at different points, to raise the water surface. This partly accounts for the low grade of 0.63 foot to the mile, although this figure may be too low, owing to the action of waves on the canal at the time the elevations were taken. The channel consisted of clayey loam, and it was free from vegetation. The meter measurements were as follows:

| | Second-feet. |
|---|---|
| Top measurement | 38.70 |
| Middle measurement | 38.72 |
| Bottom measurement | 38.23 |
| Average | 38.55 |

The results of the test are given in the table on page 37.

*Experiment No. 1.*—This test was made on the Providence canal (fig. 7), which diverts water from Logan River. The bed was composed of gravel about the size of peas, with other particles about the size of small walnuts scattered about. There was no vegetation, and the discharge was found by taking the average of the following meter measurements:

| | Second-feet. |
|---|---|
| Top measurement | 10.21 |
| Do | 9.95 |
| Middle measurement | 9.86 |
| Do | 10.20 |
| Bottom measurement | 9.75 |
| Do | 9.93 |
| Average | 9.98 |

The results of the test are given in the following table:

*Table showing values of hydraulic elements in group No. 3.*

| Experiment. | Discharge. | Area of water section. | Mean velocity. | Hydraulic mean radius. | Wetted perimeter. | Coefficient of roughness (*n*). | Slope. | Coefficient (*c*).* |
|---|---|---|---|---|---|---|---|---|
| | *Sec.-feet.* | *Sq. feet.* | *Feet per second.* | | *Lineal feet.* | | *Feet per foot.* | |
| No. 11 | 87.29 | 58.94 | 1.48 | 1.60 | 36.73 | 0.0218 | 0.00027 | 71.19 |
| No. 29 | 1.55 | 2.55 | 0.61 | 0.40 | 6.34 | 0.0223 | 0.00040 | 48.00 |
| No. 19 | 32.72 | 27.53 | 1.19 | 1.52 | 18.08 | 0.0224 | 0.00020 | 68.07 |
| No. 31 | 2.34 | 3.29 | 0.71 | 0.48 | 6.80 | 0.0229 | 0.00043 | 49.34 |
| No. 14 | 4.63 | 3.89 | 1.19 | 0.65 | 6.00 | 0.0230 | 0.00075 | 54.03 |
| No. 39 | 7.90 | 5.74 | 1.38 | 0.71 | 8.12 | 0.0230 | 0.000875 | 55.38 |
| No. 9 | 38.55 | 38.32 | 1.01 | 1.83 | 20.90 | 0.0232 | 0.00012 | 67.83 |
| No. 1 | 9.98 | 5.26 | 1.90 | 0.71 | 7.40 | 0.0238 | 0.00175 | 53.85 |

*In Chezy's formula.

## GROUP No. 4.

[*n* equals 0.0238 to 0.0260.]

*Experiment No. 5.*—This test was of a 50-foot length of the College and City canal (fig. 8), a branch of the Logan, Hyde Park and Smithfield canal. The bed was of coarse gravel, ranging in size from particles one-half inch to 2 inches in diameter, more or less, embedded in finer materials. The edges were somewhat irregular, with some willow roots, but there was no vegetation in the channel. The meter measurements were as follows:

| | Second-feet. |
|---|---|
| First trial | 7.73 |
| Second trial | 7.54 |
| Third trial | 7.48 |
| Fourth trial | 7.63 |
| Average | 7.60 |

The results are given in the table on page 39.

*Experiment No. 27.*—This test was of a 100-foot length of the Logan, Hyde Park and Thatcher canal (fig. 8), near Logan, Utah. The sides of the channel were smooth and coated with sediment. The bottom consisted of earth, gravel, and pebbles, some of the latter being 2½ inches in diameter. The coarser material covered about one-fourth of the perimeter. For results see table on page 39.

*Experiment No. 18.*—This experiment was also made on the College and City canal (fig. 8). There was no vegetation to check the velocity, but the sides were uneven, and the bed was covered with fragments of disintegrated flat rock, ranging in size from one-half inch to 2 inches across the greatest dimension. The meter measurements were as follows:

| | Second-feet. |
|---|---|
| Top measurement | 5.69 |
| Middle measurement | 5.67 |
| Bottom measurement | 5.61 |
| Average | 5.66 |

The results are given in the table on page 39.

*Experiment No. 63.*—The discharge of the small ditch known as the Hyrum canal (fig. 8), on which this experiment was made, was measured over a weir. The sides of the channel were of earth, but about half of the perimeter along the bottom was covered with rock frag-

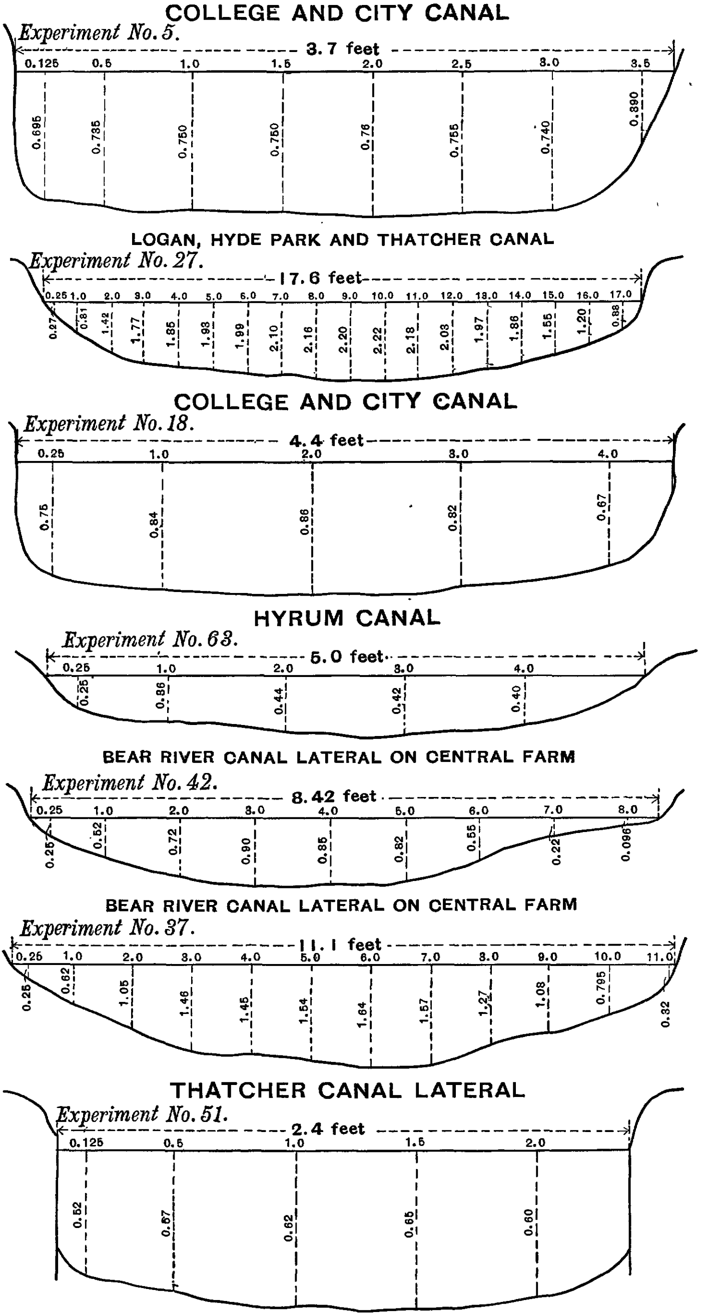


FIG. 8.—Sections of canals experimented upon.

ments from ½ inch to 1 inch across. Weeds and alfalfa grew up to the edge of the water. The results are given in the following table:

*Table showing values of hydraulic elements in group No. 4.*

| Experiment. | Discharge. | Area of water section. | Mean velocity. | Hydraulic mean radius. | Wetted perimeter. | Coefficient of roughness (*n*). | Slope. | Coefficient (*c*).* |
|---|---|---|---|---|---|---|---|---|
| | *Sec.-feet.* | *Sq. feet.* | *Feet per second.* | | *Lineal feet.* | | *Feet per foot.* | |
| No. 5 .. | 7. 60 | 2. 59 | 2. 93 | 0. 55 | 4. 73 | 0. 0238 | 0. 00616 | 50. 43 |
| No. 27 .. | 60. 23 | 30. 60 | 1. 97 | 1. 62 | 18. 90 | 0. 0246 | 0. 0006 | 63. 16 |
| No. 18 .. | 5. 66 | 3. 51 | 1. 61 | 0. 65 | 5. 44 | 0. 0247 | 0. 0016 | 50. 18 |
| No. 63 .. | 1. 57 | 1. 87 | 0. 84 | 0. 35 | 5. 28 | 0. 0260 | 0. 0013 | 38. 92 |

* In Chezy's formula.

## GROUP No. 5.

[*n* equals 0.0293 to 0.0319.]

*Experiment No. 42.*—This experiment was made on a Central farm lateral of the Bear River canal (fig. 8). The discharge was measured over a weir. The bed was composed of clay, but the cross section was not uniform, and there were a few bunches of grass scattered along the edges.

*Experiment No. 37.*—This experiment also was made on one of the Central farm laterals (fig. 8), and nearly the same conditions were found as existed in the preceding experiment.

*Experiment No. 51.*—This experiment was on a small lateral of the Thatcher canal (fig. 8). There was a narrow board on each edge, as shown in the figure. The bottom was coarse gravel and cobbles, ranging in size from large peas to goose eggs. The discharge was determined by weir measurement.

*Experiment No. 64.*—This experiment was on the Hyrum canal (fig. 9), which at the time of the test carried only a large irrigation stream. The flow was measured over a weir. The sides were considerably overgrown with alfalfa and weeds, and the bed consisted of cobbles from the size of hazelnuts to that of walnuts.

*Table showing values of hydraulic elements in group No. 5.*

| Experiment. | Discharge. | Area of water section. | Mean velocity. | Hydraulic mean radius. | Wetted perimeter. | Coefficient of roughness (*n*). | Slope. | Coefficient (*c*).* |
|---|---|---|---|---|---|---|---|---|
| | *Sec.-feet.* | *Sq. feet.* | *Feet per second.* | | *Lineal feet.* | | *Feet per foot.* | |
| No. 42.. | 8. 08 | 4. 79 | 1. 69 | 0. 56 | 8. 56 | 0. 0293 | 0. 0033 | 39. 24 |
| No. 37.. | 7. 83 | 12. 79 | 0. 61 | 1. 08 | 11. 80 | 0. 0295 | 0. 00017 | 45. 08 |
| No. 51.. | 1. 08 | 1. 44 | 0. 75 | 0. 44 | 3. 25 | 0. 0310 | 0. 00113 | 33. 51 |
| No. 64.. | 2. 47 | 2. 82 | 0. 88 | 0. 49 | 5. 79 | 0. 0319 | 0. 0014 | 33. 55 |

* In Chezy's formula.

### GROUP No. 6.

[$n$ equals 0.0329 to 0.0365.]

*Experiment No. 55.*—This experiment was on a Smithfield canal lateral (fig. 9) in Cache County, Utah. The bed consisted of cobbles partially covered with silt. The edges had been made irregular by cattle. The discharge was measured over a weir.

*Experiment No. 47.*—This experiment was on a small lateral of the Logan and Hyde Park canal (fig. 9) on one of the streets of Smithfield, Cache County, Utah. It will be noted, by referring to the table on this page, that the fall is about 1 per cent, but that the mean velocity is only 1.35 feet per second. This small channel was composed wholly of loose, coarse gravel, varying in size from that of a pea to that of a small hen's egg. The discharge was measured over a weir.

*Experiment No. 26.*—This experiment was on the Logan and Benson-Ward canal (fig. 9), in Cache County, Utah. In this case the flow was much impeded by horsetail moss, which covered about three-fourths of the water section. The bed was composed of medium-sized gravel, and the discharge was ascertained by meter measurement.

*Experiment No. 33.*—This is another instance in which a small volume of water flowed very slowly over a rough surface, notwithstanding that the fall was 64 feet to the mile. This experiment was on a lateral of the Hyrum canal (fig. 9), near the town of Hyrum, Cache County, Utah. The channel consisted chiefly of rock, ranging in size from 1 inch to 3 inches in diameter. The flow was measured over a weir.

*Table showing values of hydraulic elements in group No. 6.*

| Experiment. | Discharge. | Area of water section. | Mean velocity. | Hydraulic mean radius. | Wetted perimeter. | Coefficient of roughness ($n$). | Slope. | Coefficient ($c$).* |
|---|---|---|---|---|---|---|---|---|
| | *Sec.-feet.* | *Sq. feet.* | *Feet per second.* | | *Lineal feet.* | | *Feet per foot.* | |
| No. 55.. | 1.29 | 2.97 | 0.43 | 0.52 | 5.70 | 0.0329 | 0.000353 | 32.02 |
| No. 47.. | 0.85 | 0.63 | 1.35 | 0.27 | 2.32 | 0.0337 | 0.00991 | 25.87 |
| No. 26.. | 24.59 | 29.14 | 0.84 | 1.32 | 22.00 | 0.0352 | 0.00033 | 40.33 |
| No. 33.. | 0.81 | 0.80 | 1.02 | 0.20 | 4.00 | 0.0365 | 0.01212 | 20.68 |

* In Chezy's formula.

### GROUP No. 7.

[$n$ equals 0.0377 to 0.0424.]

*Experiment No. 57.*—This test was on a small lateral of the Smithfield City canal (fig. 9), which had a steep grade and a rough channel, made up principally of coarse gravel and cobbles. The flow was measured over a weir. (See table on page 42.)

*Experiment No. 62.*—At the time of the test this small lateral of the Hyrum canal (fig. 9) was partially overgrown with alfalfa, and there was a strip of moss on each side which covered about one-fifth of the channel, which was made up of flat fragments of rock from 1 inch to 3 inches across the longest diameter. A weir was used to determine the discharge.

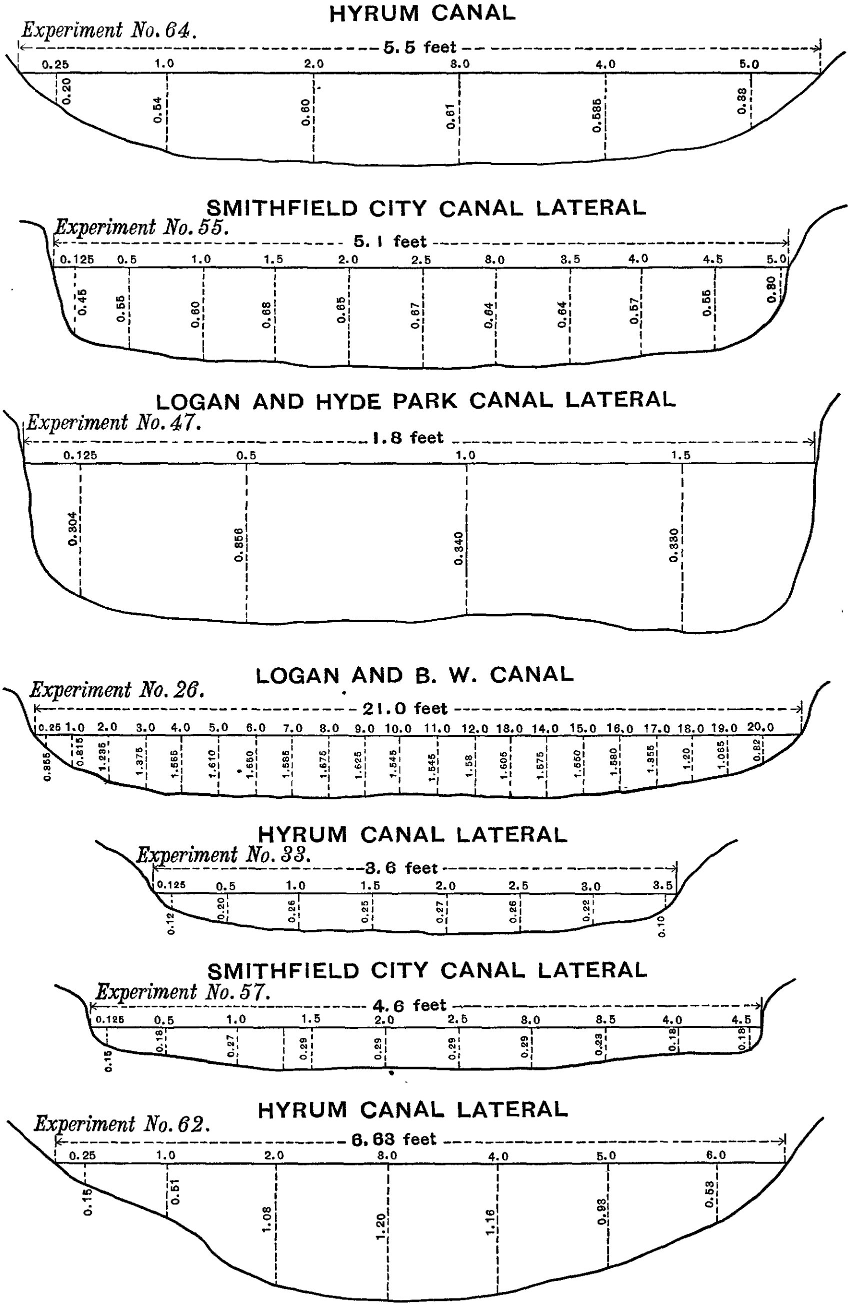


FIG. 9.—Sections of canals experimented upon.

*Experiment No. 56.*—This experiment was on a lateral of the Smithfield City canal (fig. 10) at Smithfield, Utah. The conditions were similar to those of No. 57. The edges of the lateral were rough and uneven, and the bed a mass of pebbles and cobbles washed clean by the large flow in the early part of the season. (See table below.)

*Experiment No. 24.*—This test was on a well-formed canal (fig. 10), the property of the Brigham City Electric Light Company, located near the mouth of Boxelder Canyon, in the county of the same name. The bed consisted of medium-sized gravel, unpacked, and about one-third of the water area was filled with long, waving, water plants, resembling horsetails. The presence of these plants retarded the velocity, and no doubt changed the degree of roughness from a value of about 0.020 to that given in the table—0.0424. Only two meter measurements were made, but these check very closely; they were 30.99 and 31.16 second-feet. The results are given in the following table:

*Table showing values of hydraulic elements in group No. 7.*

| Experiment. | Discharge. | Area of water section. | Mean velocity. | Hydraulic mean radius. | Wetted perimeter. | Coefficient of roughness ($n$). | Slope. | Coefficient ($c$).* |
|---|---|---|---|---|---|---|---|---|
| | *Sec.-feet.* | *Sq. feet.* | *Feet per second.* | | *Lineal feet.* | | *Feet per foot.* | |
| No. 57 | 1.48 | 1.11 | 1.33 | 0.23 | 4.75 | 0.0377 | 0.0171 | 21.07 |
| No. 62 | 2.47 | 5.55 | 0.44 | 0.77 | 7.20 | 0.0393 | 0.00029 | 29.62 |
| No. 56 | 1.17 | 1.06 | 1.10 | 0.23 | 4.70 | 0.0423 | 0.0170 | 17.93 |
| No. 24 | 31.07 | 20.44 | 1.52 | 1.62 | 12.60 | 0.0424 | 0.00115 | 35.19 |

*In Chezy's formula.

## GROUP No. 8.

[$n$ equals 0.0469 to 0.0529.]

The results of the experiments in this group are given in the table on page 44.

*Experiment No. 35.*—This experiment was made on a small stream (fig. 10) which supplies the Temple grounds in Logan, Utah. The natural channel was made up of sand and silt, but at the time the experiment was made it was more than one-third full of horsetail moss. The discharge was ascertained by weir measurement.

*Experiment No. 46.*—This experiment was on a canal at Brigham, Utah (fig. 10), which was more than half filled with horsetail moss. The edges were also overgrown with watercress and weeds, but the part of the bottom which was exposed was covered with fine gravel.

*Experiment No. 53.*—This test was on a small lateral of the Thatcher canal (fig. 10) near Logan, Utah. About two-thirds of the lateral was more or less covered and filled with horsetail moss. The remainder of the exposed surface of the bed was sediment.

*Experiment No. 52.*—This test was on another small lateral of the Thatcher canal (fig. 10). The bed was composed of fine silt, but about three-fourths of the entire channel was covered with aquatic plants similar to those described in the preceding experiments.

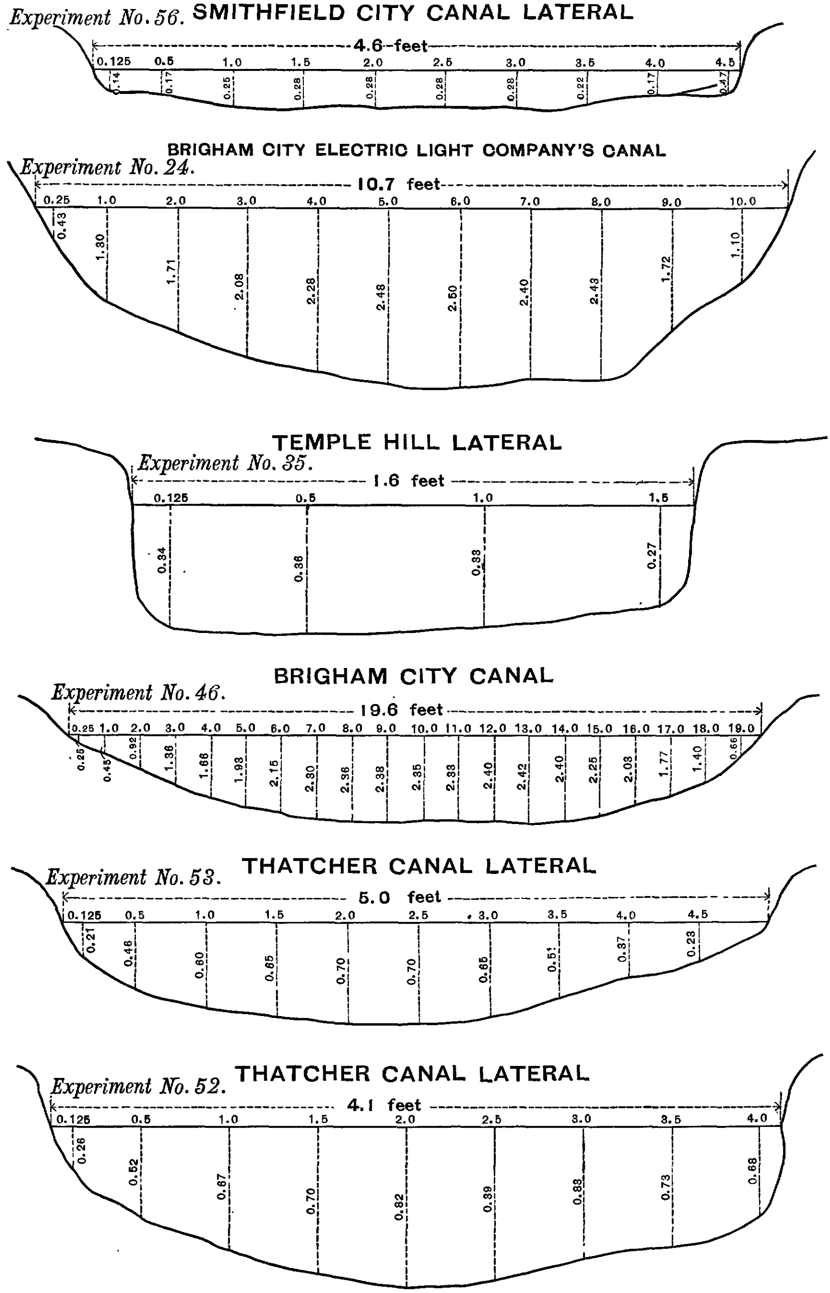


FIG. 10.—Sections of canals experimented upon.

*Table showing values of hydraulic elements in group No. 8.*

| Experiment. | Discharge. | Area of water section. | Mean velocity. | Hydraulic mean radius. | Wetted perimeter. | Coefficient of roughness ($n$). | Slope. | Coefficient ($c$).* |
|---|---|---|---|---|---|---|---|---|
| | *Sec.-feet.* | *Sq. feet.* | *Feet per second.* | | *Lineal feet.* | | *Feet per foot.* | |
| No. 35 . . | 0. 28 | 0. 52 | 0. 54 | 0. 25 | 2. 10 | 0. 0469 | 0. 00442 | 16. 28 |
| No. 46 . . | 23. 40 | 35. 76 | 0. 65 | 1. 74 | 20. 50 | 0. 0499 | 0. 00028 | 29. 60 |
| No. 53 . . | 1. 08 | 2. 57 | 0. 42 | 0. 48 | 5. 30 | 0. 0519 | 0. 00107 | 18. 41 |
| No. 52 . . | 1. 08 | 2. 90 | 0. 37 | 0. 58 | 4. 98 | 0. 0529 | 0. 00064 | 19. 16 |

*In Chezy's formula.

The writer presents these results of experiments in the hope that they may aid those building and operating irrigation systems in the West to arrive at a better understanding regarding the behavior and carrying capacities of irrigation canals. In planning new systems it is necessary to know the approximate volume of water which each new channel will carry. As has been stated, the formula most generally used for this purpose is that of Kutter. But Kutter's formula will give results either too great or too small, in proportion as one chooses too low or too high a value for the coefficient of roughness ($n$).

The experiments made in the past to determine the values of $n$ for canals have been largely confined either to new channels or to conditions somewhat different from those which prevail in Western America. In the case of new canals it is believed that the coefficient of roughness of the wetted surface is much greater than it is in canals of similar form and materials when the wetted surface is well coated with fine sediment. The friction seems to depend quite as much on the way in which the gravel and cobbles are packed as on their size. Again, the effect of water plants in retarding the velocity of water in canals has usually been considered less than our experiments indicate.

On account of the dissimilarity between the physical conditions of the channels from which the present values of $n$ have been derived and the ditches and canals of irrigated America, the writer has attempted, in the following table, to assign values for $n$ which are more in accordance with the conditions now existing in the Rocky Mountain States. Future experiments, however, in which the details are more carefully looked after, may modify these values of $n$.

*Values of n for irrigation ditches and canals.*

$n$=0.0175 for canals in earth in excellent condition, well coated with sediment, regular in cross section, and free from vegetation, loose pebbles, and cobbles.

$n$=0.020 for canals in earth, in good condition, lined with well-packed gravel, partly covered with sediment, and free from vegetation.

$n$=0.0225 for canals in earth, in fair condition, the wetted surface being lined with sediment, with an occasional patch of minute algæ, or composed of loose gravel without vegetation.

$n=0.0250$ for canals in earth, in average condition, having few sharp bends, and being fairly uniform in cross section; the water slopes and bottom being lined with sediment and minute algæ, or composed of loose, coarse gravel and fragments of rock less than 2 inches in diameter, and free from vegetation.

$n=0.0275$ for canals in earth, below the average in grade, alignment, and cross section, having indentations on the sides, the edges in places being partially filled with earth and gravel, and the lining composed of coarse gravel and cobbles unpacked. This value would also apply to a smooth, regular surface if the channel were partially filled with aquatic plants.

$n=0.0300$ for canals in earth, in rather poor condition, having the bed partially covered with débris, or having comparatively smooth sides and bottom, with bunches of grass and weeds projecting into the water and with aquatic plants growing in the channel.

$n=0.0350$ for small ditches having a rough, uneven bed, and for canals in earth in fairly good condition, but partially filled with aquatic plants.

$n=0.040$ for canals in earth the channels of which are about half full of aquatic vegetation.

$n=0.050$ for canals in earth the channels of which are about two-thirds full of aquatic vegetation.

The writer's experiments on the flow of water in irrigation ditches and canals, herein briefly described, seem to justify the following conclusions:

(1) That sections of canals in earth, although carefully built, of a trapezoidal form, with the bottom width horizontal, soon change to segments resembling those of an ellipse.

(2) That in all large or medium-sized canals in earth berms are necessary in order to prevent a portion of the excavated material from rolling into the canal.

(3) That during the first season of their operation the carrying capacities of irrigation canals are less than during subsequent seasons, provided the same conditions are maintained.

(4) That the coefficient of friction in canals well lined with sediment, in good condition and long in use, is less than usually has been supposed.

(5) That the frictional resistance of coarse materials, such as gravel, pebbles, or cobbles, depends to a large extent on whether such material is well packed or loose.

(6) That roughness in a small ditch exerts a greater influence in retarding flow than the same degree of roughness exerts in a large canal or a river.

(7) That in the past canal builders have to a great extent overlooked the injurious effects of the growth of aquatic plants.

(8) That the effects of water plants in checking the flow and lessening the capacity of irrigation canals may be much greater than a rough, uneven channel.

(9) That in the sections of the arid West where such vegetation grows abundantly the canals should be built in such a way as to prevent its growth, or, if that is impracticable, provision should be made to facilitate its removal.

## WOODEN FLUMES.

A half century ago the pioneers of Utah built flumes of native lumber to convey irrigating water across ravines or to strengthen weak places in canals in earth. Since that time their use in the Rocky Mountain States has steadily increased, and the cost of those at present in service would aggregate many million dollars. Notwithstanding their extended use they have not proved satisfactory. The short life of lumber when placed in contact with the soil and the difficulties experienced in making wooden flumes water-tight have been a fruitful source of annoyance and expense and have brought such structures into disfavor.

During the last fifteen years many substitutes have been tried, such as stave pipes, half-round flumes, cemented canals, and inverted syphons, and although these later devices are more durable, as a rule they cost more, and it is questionable whether they will soon supplant the wooden flume. Like the railroad trestle, the wooden flume may be regarded as a temporary structure, but it possesses certain advantages which every canal proprietor or superintendent will appreciate. It is cheap, the materials of which it is composed can be readily and quickly procured, and the time occupied in building is short. So long as lumber is comparatively cheap and other building materials, such as Portland cement, are high, it is reasonable to conclude that the use of wooden flumes will be continued. The question for consideration is, therefore, the discovery of remedies for existing defects, rather than the construction of new structures to take the place of the old ones. The defects, as well as some of the remedies that might be applied, will be pointed out in the following discussion of the various features of the construction of wooden flumes.

### FLUME LINING.

During the infancy of irrigation in the West flumes were put together in so unworkmanlike a manner that leaks were the rule and not the exception. The lumber was frequently of inferior quality, full of knots, unevenly sawed, and imperfectly dried. The lining consisted of 2-inch planks spiked to the posts and sills, and in less than a year the joints between the edges of the planks would be sufficiently open to admit the fingers of a man's hand. Laths and edgings were often driven into these open joints and afterwards they were calked with gunny sacks or oakum soaked in pitch. When the rough edges of the planks were beveled so as to leave a space at the joint having the form of a V, as shown in fig. 11, at *a*, it was possible to calk the joint, but if the edges sloped in the opposite direction and left the opening on the outside, as in fig. 11, at *b*, the calking would not remain in place.

Engineers and canal superintendents first tried to remedy these defects by putting on a double lining—an extravagant use of lumber. These linings were made by nailing battens over each longitudinal joint (fig. 11, *c*), by placing a 2-inch layer over inch boards (fig. 11, *d*), by using two layers of inch boards (fig. 11, *e*), or by using 2-inch planks beneath inch boards (fig. 11, *f*). In Montana 1-inch by 4-inch and 1-inch by 6-inch battens over joints are common, but they invariably are placed on the side next to the water, while in the opinion of the writer they should be placed on the outside. If, for example, battens were laid on the sills and the planks placed above them, the joints in the latter would fill with sediment; besides, the action of the sun would not warp or curl the battens. If double linings of uneven thickness are used, it is preferable to lay the thinner layer first; otherwise the action of the sun will cause inch boards, particularly when

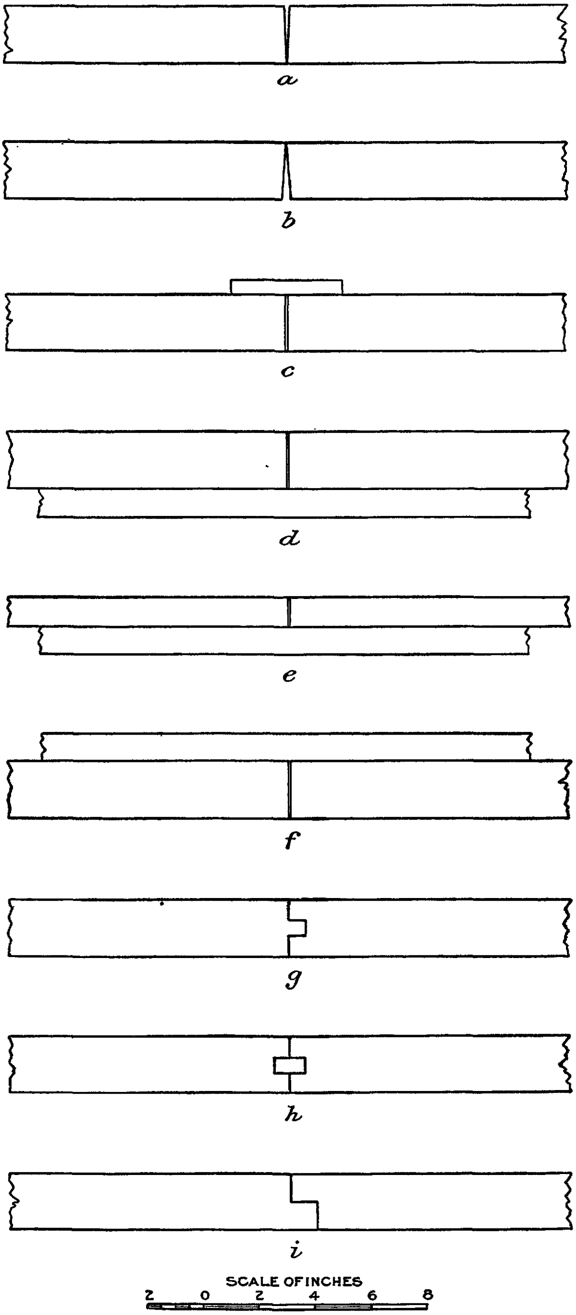


FIG. 11.—Methods of making joints in floor of flume.

they become partially decayed, to draw through the nails. This same objection applies to the use of a double lining of inch boards.

The double-lined flumes of Colorado have not fulfilled the expectations of their builders. By using 2-inch planks over inch boards the cost is increased nearly 50 per cent and the durability is diminished. Experience has shown that a double lining will decay more rapidly than a single 2-inch lining. Besides, sand and sediment are likely to accumulate between the two floors, and to freeze in winter and cause displacement of the upper floor, so that the main object of the double floor—the prevention of leaks—is not always accomplished.

The common tongue and groove joint (fig. 11, *g*) has also been tried, but with little success. The cost of milling the edges of planks, the difficulty experienced in laying them, and the liability that the projections on each side of the groove will split off when the lining warps, have prevented this form of joint from being extensively used.

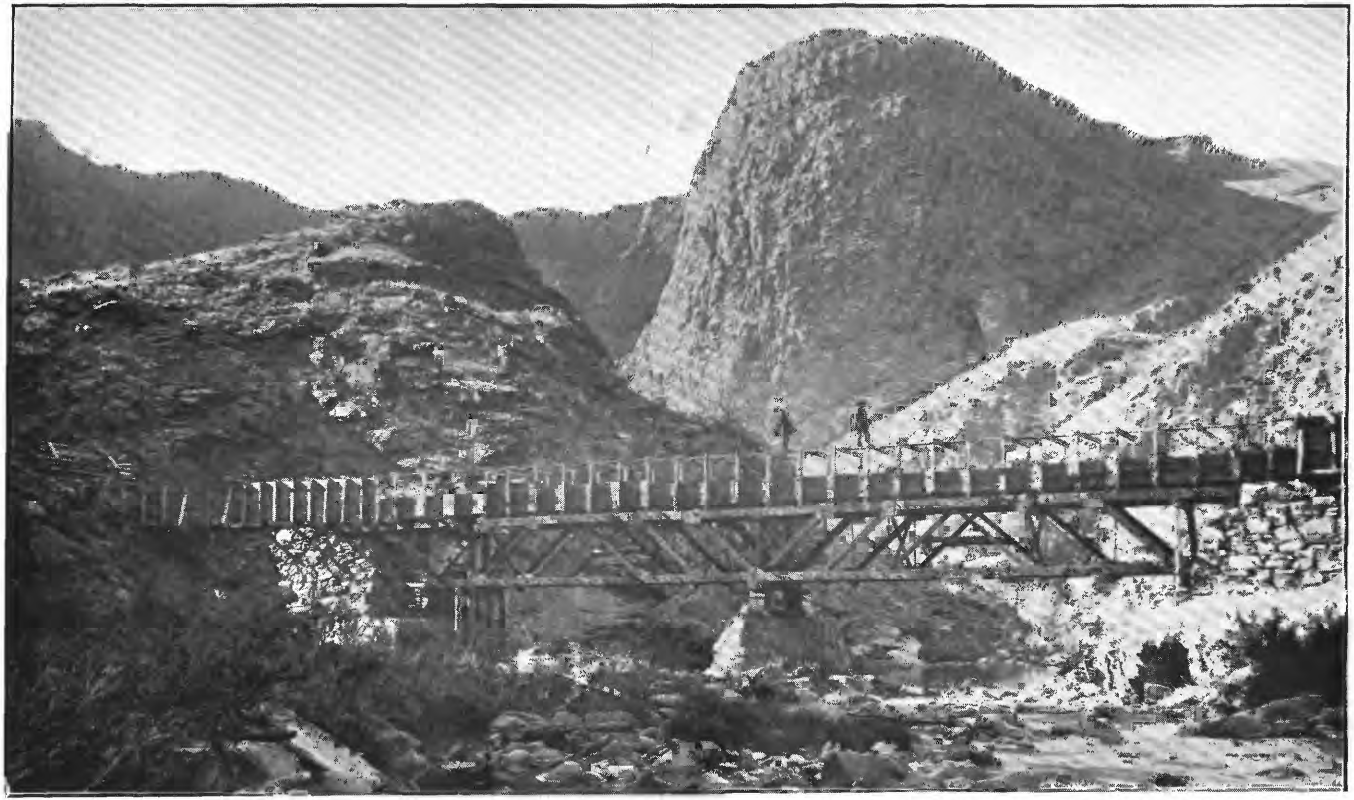
At the present time the tendency among irrigation engineers and superintendents is to demand a better grade of lumber for flume linings, to insist that the work shall be planned far enough in advance of construction to secure well-seasoned lumber, and to prepare the lumber at the mills in such a manner that the liability to leak may be either wholly prevented or greatly lessened. Only one lining is used, and its thickness may vary from 1½ to 2½ inches, depending on the size of the flume and other conditions.

The writer would recommend either the driven-tongue joint or the ship lap joint. The half-timbered or ship lap joint (fig. 11, *i*) is well adapted to linings varying in thickness from 1½ to 1¾ inches. It is true that it requires from 8 to 9 per cent more lumber to allow for the lap, besides the extra cost of milling; but notwithstanding this, the total cost is much less than that of a double lining, and if shrinkage occurs there is an excellent opportunity to calk the open space, in which case there is no chance for the filling to work through the joint. In the smaller flumes the edges are usually painted with white lead, and in the larger flumes with hot asphalt, both being applied during the process of construction.

The driven-tongue joint (fig. 11, *h*) requires thicker lumber; otherwise the projections at the edges of the groove would be likely to split off. A lining 2½ inches thick may have a groove on each edge five-eighths inch deep, which will admit a tongue five-eighths inch thick and seven-eighths inch wide. These tongues are milled from clear lumber and have the four sharp edges removed. The flooring is first laid, and as each plank is fitted to its place the tongue is inserted in the groove. No tongue is inserted in the last joint of the floor until after the planks have been matched and sprung into position, after which the tongue is driven into the groove from one end. The longitudinal joints in the sides of the lining are rendered water-tight

*A.* LOWER END OF FLUME IN WEST CANAL BRANCH OF BEAR RIVER CANAL, UTAH.

*B.* OLD FLUME OF DAVIS AND WEBER COUNTY CANAL COMPANY, WEBER CANYON, UTAH.



NORTH POUDRE FLUME, NEAR GREELEY, COLORADO, 300 FEET BELOW DAM, SHOWING CANAL CROSSING THE STREAM FROM WHICH ITS WATERS ARE TAKEN.

by driving wedges between the tiebeam and the upper edge of the lining.

### FRAMEWORK.

Flumes are placed either on piles, on trestles, or on mudsills, and the form of the framework is modified to suit the foundation.

A cross section of a flume resting on piles is shown in fig. 12. Each set of piles is sawed off, after being driven, and capped with a dimension timber which is secured to each pile by means of a drift bolt. The stringers are then laid on the caps and the flooring is nailed to the stringers. The chief objection to this form of construction is the early decay of the piles at the surface of the ground. When thus exposed, ordinary piles decay in about seven years. Frequently the top of the piles next to the cap is sound, as well as the portion that is covered with earth more than 2 feet in depth. In repairing flumes of this kind the practice of the writer has been to excavate the earth around each pile to a point beyond the decayed portion, remove the decayed wood, then recap the sound portion and introduce a trestle between the new cap and the flume.

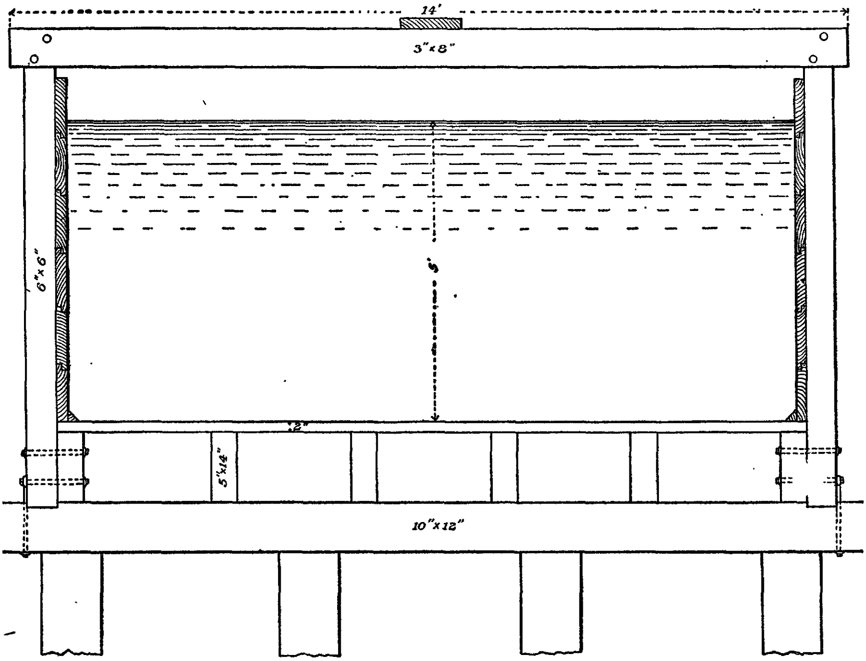


FIG. 12.—Cross section of flume resting on piles.

When flumes are placed on trestles the ordinary railroad trestle is used. Small flumes, such as that shown in fig. 13, have only two inclined supports; in the larger flumes one or more vertical posts are inserted between the inclined posts. Sometimes farmers make use of round poles to support flumes across ravines, in the manner shown in Pl. VII, *B*, which represents the Wilson canal flume, east of Ogden, Utah. As a rule, it is a mistake to make use of a wooden flume when trestles more than 10 feet high are required. Some other form of construction, such as the inverted siphon, should be adopted.

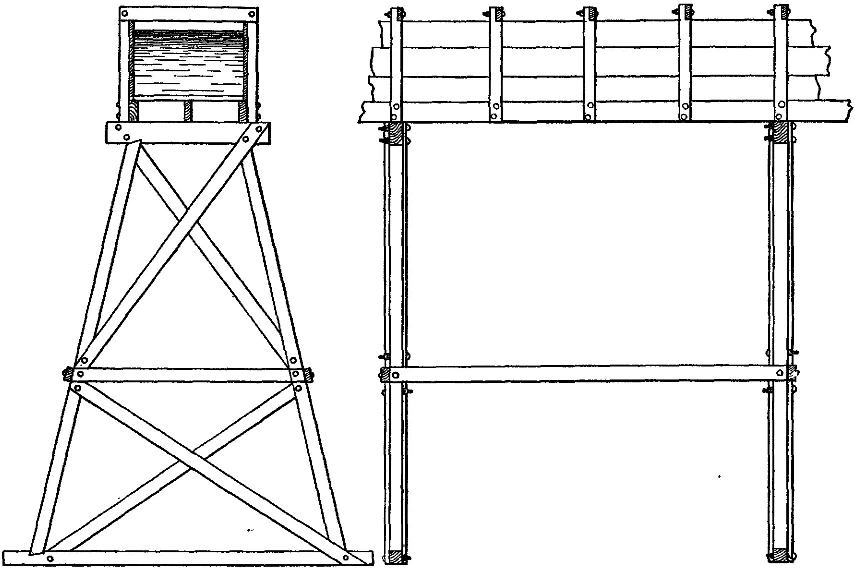


FIG. 13.—End and side elevation of flume on trestle.

Very often portions of canals in earth, when located on steep hillsides, absorb so much moisture as to become a source of danger to the canal and a menace to the property owners in the vicinity. In the past the canal in such weak places has usually been replaced by a

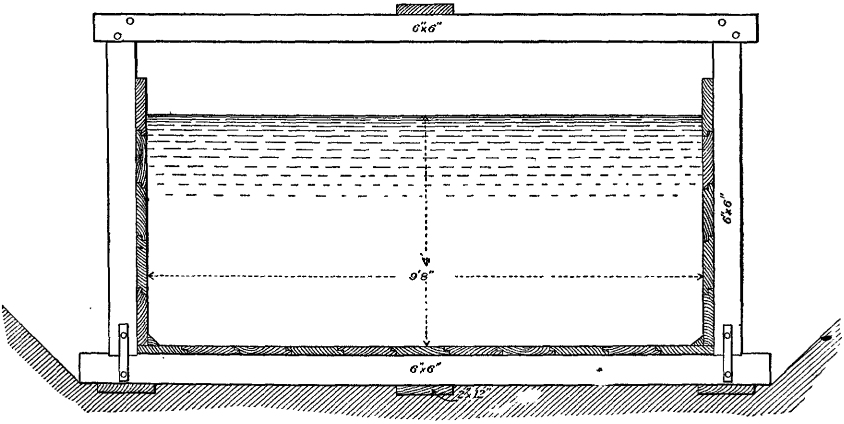


FIG. 14.—Details of construction of flume for steep hillsides.

*A.* FLUME ON HEDGE CANAL, BITTERROOT VALLEY, MONTANA.

*B.* WILSON CANAL FLUME, WEBER COUNTY, UTAH.

wooden flume somewhat similar in construction to that shown in fig. 14. The same kind of flume, with the exception of the mudsills, is frequently seen in rocky canyons, where a shelf has been blasted out to a sufficient width to support it. Occasionally, too, one sees, as in fig. 15, a flume which rests partly on rock and partly on timber supports. Fig. 15 is a cross section of the Dolores canal No. 2, in La Plata County, Colorado.

Flumes may also be divided into two classes, readily distinguishable by the manner of supporting the vertical posts. In the Rocky Mountain States the posts are usually held in position by a horizontal tiebeam bolted at its ends to a pair of vertical posts. In California it is customary to dispense with the tiebeam, and substitute therefor an inclined brace extending from the floor sill to a point in the upper half of each post. If one takes the trouble to compute the total amount of lumber required for each of these types, it will be found that the use of a tiebeam is more economical of lumber in all except the largest flumes. When a flume is more than 20 feet wide it may pay

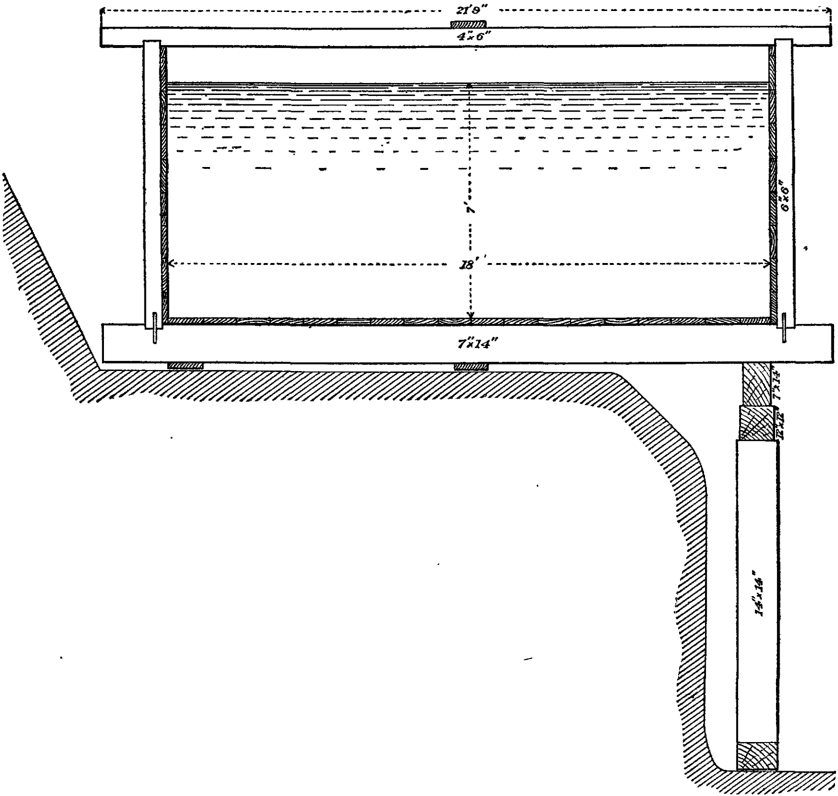


FIG. 15.—Cross section of Dolores canal No. 2, La Plata County, Colorado.

to introduce inclined braces to secure the vertical posts; otherwise the horizontal tiebeams are preferable.

Fig. 16 shows a joint designed by the writer to connect tiebeams with vertical posts. This kind of joint leaves the tiebeam undiminished in thickness at the ends, where it is liable to split and be cracked by the sun; it provides an ample shoulder to prevent wind or earth pressure from overturning the sides; and, being dovetailed, it is stronger than the common half-timbered joint.

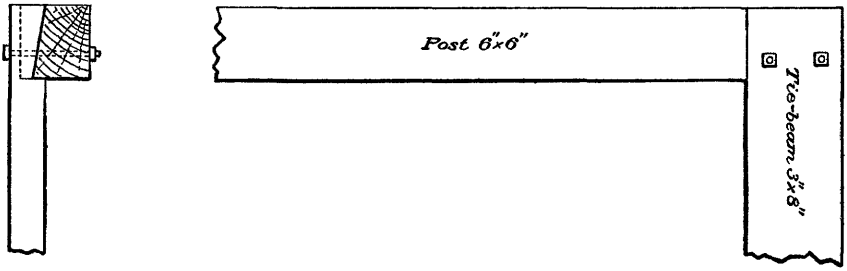


FIG. 16.—Joint designed to connect tiebeams with vertical posts.

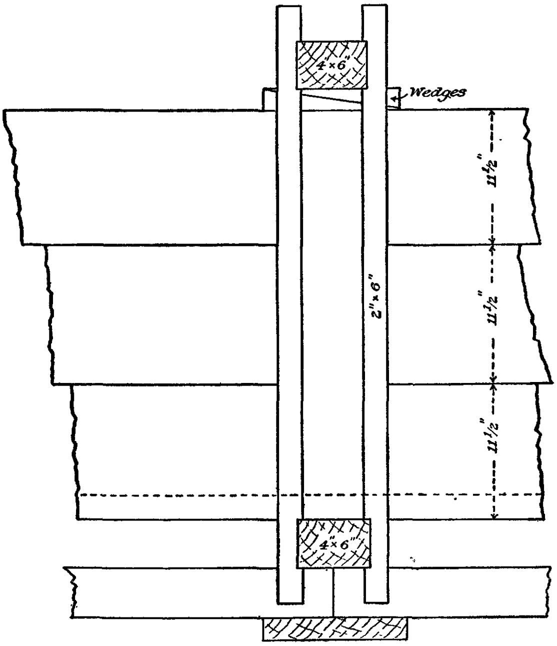


FIG. 17.—Detail of connection of post with sill of flume.

Mortise joints are now seldom used in building flumes; experience has shown that the sills first decay around the mortise. Besides, the holding power of a pinned-tenon joint in saturated pine wood is but slight. Vertical posts are now usually toe-nailed onto the sills, and if there is any likelihood of the flooring settling away from the posts and sides, straps of steel should be bolted to each post and to the sill on which it rests, in a manner similar to that shown in fig. 14.

On the Bitterroot stock farm, owned by the late Mr. Marcus Daly and located near Hamilton, Montana, there are, in all, more than 5 miles of flumes on the various canals which supply water to that extensive ranch. These flumes are similar to those shown in Pl. VIII. They were designed by Mr. F. A. Jones, of Anaconda, Montana, chief engineer of the Anaconda Copper Company. The vertical posts, spaced 4 feet between centers, consist of two pieces of 2-inch by 6-inch joists, spiked with 40-penny wire nails to a 4-inch by 6-inch sill and tiebeam. The drawing shows a 3-inch by 6-inch tiebeam, but this was afterwards replaced by a 4-inch by 6-inch piece. These flumes are lined with 2½-inch plank, surfaced, edged, and grooved in the manner shown in Pl. VIII, and although built of green lumber they have always been practically water-tight. At the time of the writer's visit to this farm, in May, 1900, there were flumes of this design that did not leak one gallon per second in the length of a mile. In discussing this form of framework for flumes with Mr. Carlson, the carpenter and contractor who built them, he was of the opinion that the 2-inch by 6-inch posts should be gained into the sills and the tiebeams as shown in fig. 17. The following tables give a list of the lumber required for a 16-foot length of the flume and the dimensions of the standard trestle bents of various heights:

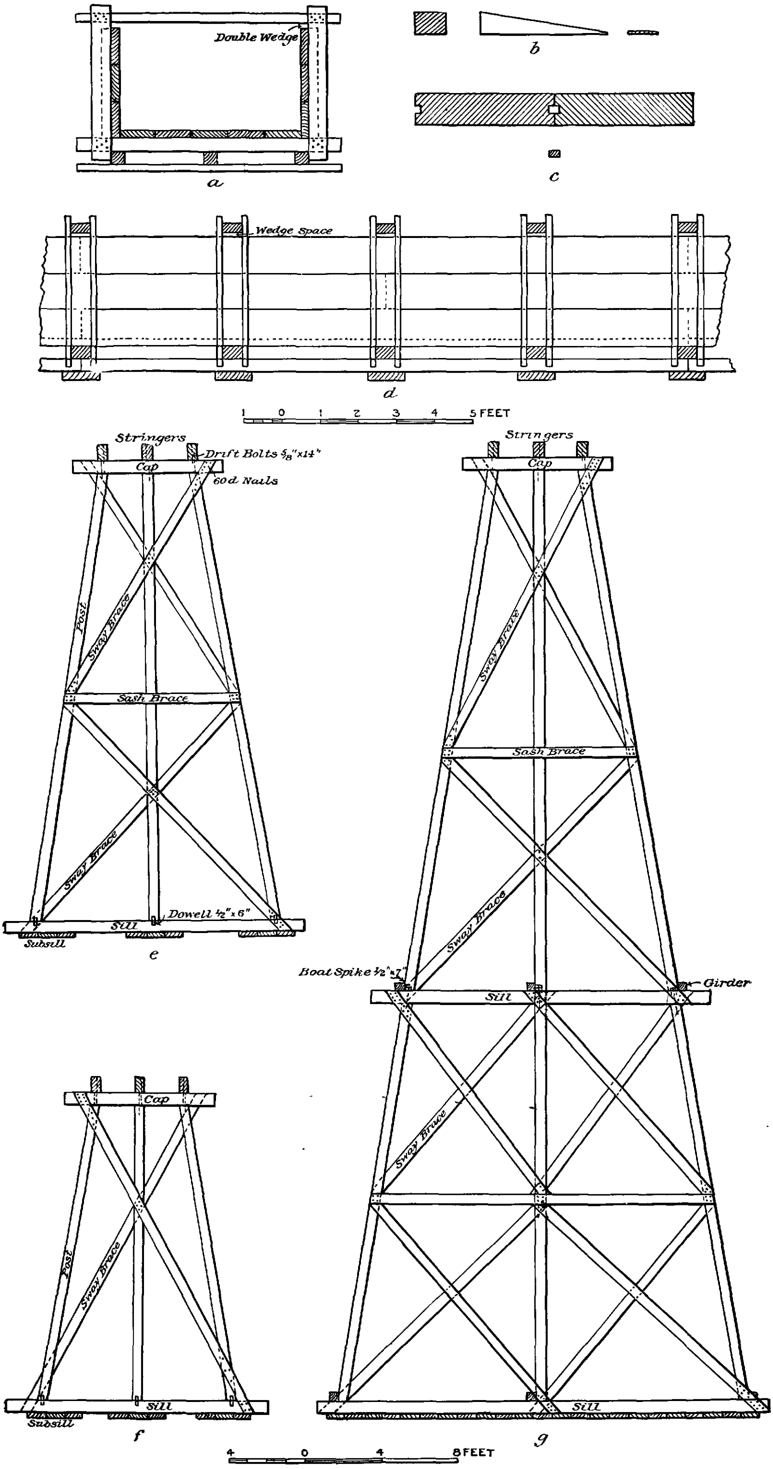
*List of lumber required for a 16-foot length of 3-foot by 5-foot flume used in Skalkaho ditch, on Bitterroot stock farm, near Hamilton, Montana.*

| Parts. | Number of pieces. | Size. | Board measure. | Kind of lumber. |
|---|---|---|---|---|
| | | *Ins. Ins. Ft.* | *Feet.* | |
| Sides and bottom | 11 | 2½×12 ×16 | 440 | Surfaced one side, both edges, and grooved. |
| Bottom yoke | 4 | 4 × 6 × 7 | 56 | Common rough. |
| Top yoke | 4 | 3 × 6 × 7 | 42 | Do. |
| Side yoke | 16 | 2 × 6 × 4 | 64 | Do. |
| Side-joint covers | 4 | 3 × 6 × 3 | 18 | Do. |
| Tongues | 8 | ⅝ × ⅞×16 | 20 | Clear first-class. |
| Wedges | 16 | $\left\{\begin{matrix}1\frac{3}{4}\\ \frac{1}{4}\end{matrix}\right\}$× 2½×10 | 5 | Common rough. |
| Stringers | 3 | 4 × 4 ×16 | 64 | Do. |
| Subsills | 4 | 2½ ×12 × 7 | 70 | Do. |
| Total | | | 779 | |

*Dimensions of parts of standard trestle bents for 3-foot by 5-foot flume as used in Skalkaho ditch, on Bitterroot stock farm, near Hamilton, Montana.*

| Bottom of sill to top of stringer. | | Plumb post, top of sill to bottom of cap. | | Material for batter and plumb posts. | Sill. | Sway braces. | Sash. | Diagonal braces. |
|---|---|---|---|---|---|---|---|---|
| *Ft.* | *ins.* | *Ft.* | *ins.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| 3 | 8... | 1 | 7½ | 2 | 8 | .......... | .......... | .......... |
| 4 | 8... | 2 | 7½ | 3 | 8 | 8 | .......... | .......... |
| 5 | 8... | 3 | 7½ | 4 | 10 | 10 | .......... | .......... |
| 6 | 8... | 4 | 7½ | 5 | 10 | 10 | .......... | .......... |
| 7 | 8... | 5 | 7½ | 6 | 10 | 12 | .......... | .......... |
| 8 | 8... | 6 | 7½ | 7 | 10 | 12 | .......... | .......... |
| 9 | 6... | 7 | 5½ | 8 | 10 | 12 | .......... | 18 |
| 10 | 6... | 8 | 5½ | 9 | 12 | 14 | .......... | 18 |
| 11 | 6... | 9 | 5½ | 10 | 12 | 14 | .......... | 20 |
| 12 | 6... | 10 | 5½ | 11 | 12 | 14 | .......... | 20 |
| 13 | 6... | 11 | 5½ | 12 | 12 | 16 | .......... | 20 |
| 14 | 4... | 12 | 3½ | 13 | 12 | 16 | .......... | 22 |
| 15 | 4... | 13 | 3½ | 14 | 12 | 18 | .......... | 22 |
| 16 | 4... | 14 | 3½ | 15 | 14 | 18 | .......... | 22 |
| 17 | 3... | 15 | 2½ | 16 | 14 | 20 | .......... | 22 |
| 18 | 3... | 16 | 2½ | 17 | 14 | 12 and 14 | 10 | 24 |
| 19 | 3... | 17 | 2½ | 18 | 14 | 14 | 10 | 24 |
| 20 | 3... | 18 | 2½ | 19 | 14 | 14 and 16 | 10 | 26 |
| 21 | 2... | 19 | 1½ | 20 | 14 | 14 and 16 | 10 | 26 |
| 22 | 2... | 20 | 1½ | 21 | 16 | 14 and 16 | 10 | 20 |
| 23 | 2... | 21 | 1½ | 22 | 16 | 16 and 18 | 10 | 20 |
| 24 | 2... | 22 | 1½ | 23 | 16 | 16 and 18 | 10 | 20 |
| 25 | 2... | 23 | 1½ | 24 | 16 | 16 and 18 | 10 | 22 |
| 26 | 1... | 24 | 0½ | 25 | 16 | 16 and 18 | 10 | 22 |
| 27 | 1... | 25 | 0½ | 26 | 16 | 16 and 18 | 10 | 22 |
| 29 | 4... | 25<br>1 | 0½<br>7½ | 26<br>2 | 16 and 18 | 16, 18, and 8–10 | 10 | 22 |
| 31 | 4... | 25<br>3 | 0½<br>7½ | 26<br>4 | 16 and 18 | 16, 18, and 10 | 10 | 22 and 18 |
| 33 | 4... | 25<br>5 | 0½<br>7½ | 26<br>6 | 16 and 18 | 16, 18, and 10–12 | 10 | 22 and 18 |
| 35 | 2... | 25<br>7 | 0½<br>5½ | 26<br>8 | 16 and 20 | 16, 18, and 12–14 | 10 | 22 and 18 |
| 37 | 2... | 25<br>9 | 0½<br>5½ | 26<br>10 | 16 and 20 | 16, 18, and 14 | 10 | 22 and 20 |
| 39 | 2... | 25<br>11 | 0½<br>5½ | 26<br>12 | 16 and 20 | 16, 18, and 14–16 | 10 | 22 and 20 |
| 41 | 0... | 25<br>13 | 0½<br>3½ | 26<br>14 | 16 and 20 | 16, 18, and 16–18 | 10 | 22 |
| 42 | 11... | 25<br>15 | 0½<br>2½ | 26<br>16 | 16 and 22 | 16, 18, and 18–20 | 10 | 22 and 24 |
| 44 | 11... | 25<br>17 | 0½<br>2½ | 26<br>18 | 16 and 22 | 16, 18, 12, and 12–14 | 10 and 18 | 22 and 26 |
| 46 | 10... | 25<br>19 | 0½<br>1½ | 26<br>20 | 16 and 22 | 16,18,12-14, and 14–16 | 10 and 18 | 22 and 20 |
| 48 | 10... | 25<br>21 | 0½<br>1½ | 26<br>22 | 16 and 24 | 16, 18, 14, and 14–16 | 10 and 18 | 22 and 20 |
| 50 | 10... | 25<br>23 | 0½<br>1½ | 26<br>24 | 16 and 24 | 16,18,14-16, and 16–18 | 10 and 18 | 22 |
| 52 | 9... | 25<br>25 | 0½<br>0½ | 26<br>26 | 16 and 24 | 16, 18, and 16–18 | 10 and 18 | 22 |

A common type of the small distributing flume is shown in fig. 18. The lining is usually 1¼ inches thick and 16 feet long. The bottom is



DETAILS OF FLUMES AND TRESTLES ON BITTERROOT STOCK FARM, NEAR HAMILTON, MONTANA.

At *a* is shown an end elevation of flume; *b*, wedge detail; *c*, tongue-and-groove detail; *d*, side elevation of flume; *f*, trestle bents for heights to 16 feet; *e*, trestle bents from 16 feet to 28 feet in height; *g*, trestle bents from 28 feet to 50 feet in height. Diagonal braces should be used on all bents from 10 feet up.

12 inches and the sides are 8 inches, with collars every 4 feet. The lumber is usually prepared at the mills, and each section of the flume is dipped in hot coal tar or asphalt as soon as completed. In the orchards of southern California such flumes are frequently used to distribute water to the various furrows, by means of 2-inch holes spaced midway between every two collars and controlled by a galvanized-iron slide. Fig. 19 illustrates a modification of these standard distributing flumes which was built by the writer to convey a small stream of water to experiment plats on the farm of the experiment station of Utah.

### PROTECTION OF ENDS.

It is often difficult to make a secure and water-tight connection between the end of a flume and an earthen canal. Various devices to accomplish this object have been used, but space will not permit more than a brief description of those most commonly adopted. This is an important feature of canal construction, for a large percentage of the breaks which have occurred are traceable to defective connections at the ends of the flumes. When flumes are built to convey water across ravines they should extend some distance beyond the edges of the ravines; otherwise a small leak, if unobserved, may wreck a costly structure.

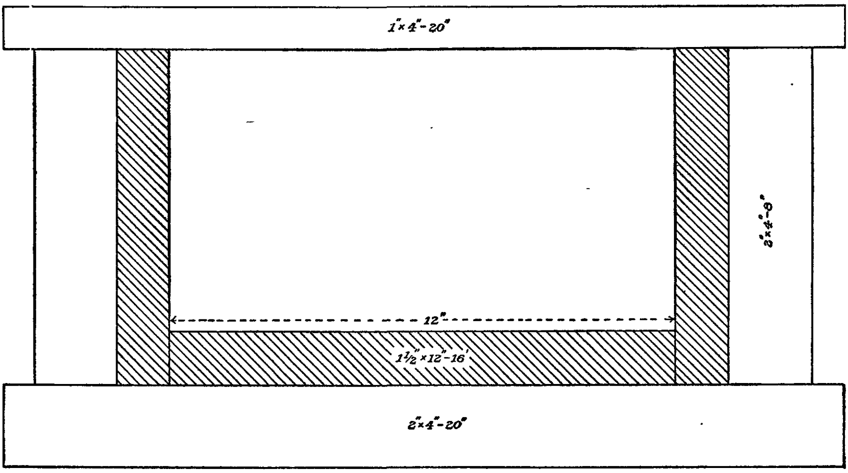


FIG. 18.—A common type of small distributing flume.

Two forms of apron are used to prevent the passage of water either beneath or at the sides of a wooden flume, viz, the inclined apron and the vertical apron. The inclined apron extends downward from the floor, below grade, at an angle of about 20°, at which slope the lower ends of apron planks 10 feet long would be 3 feet below the bed of the canal. The side wings extend into the banks at even a greater angle, and impervious earth is carefully tamped around both bottom and sides. This mode of protecting the ends is reasonably secure, but there are serious objections to it. In the first place, it requires a large amount of material, and if we except the floor, which is below grade and always moist, this material, in the form of planking and dimension timbers, is placed in contact with earth and will decay in a few years.

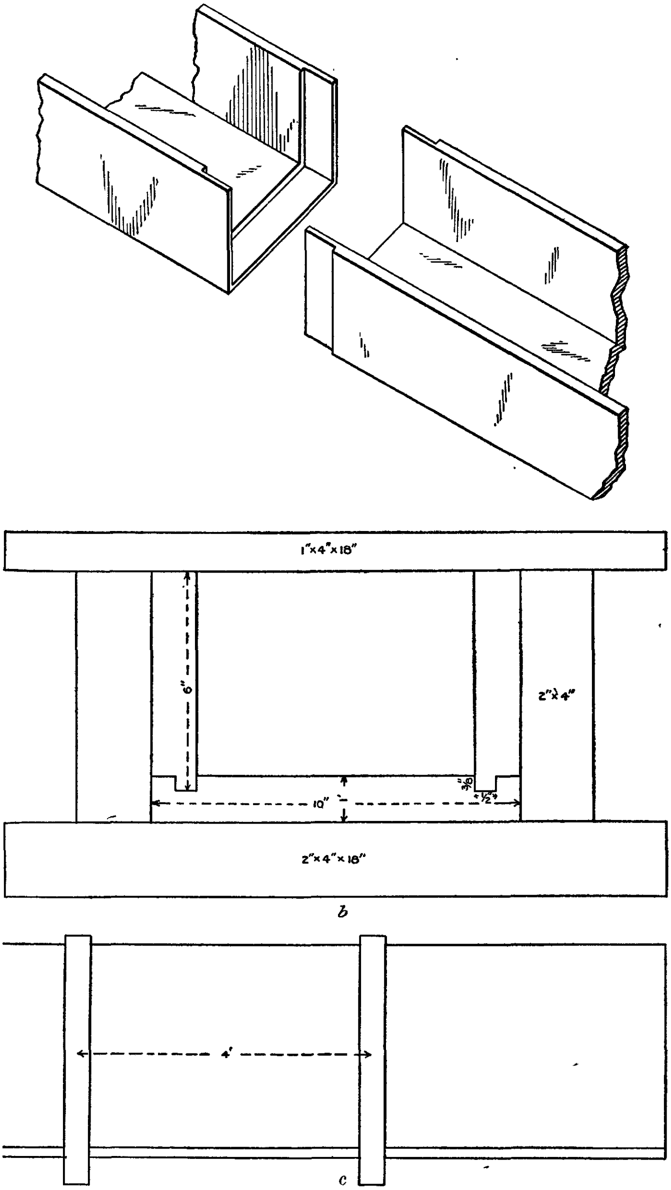
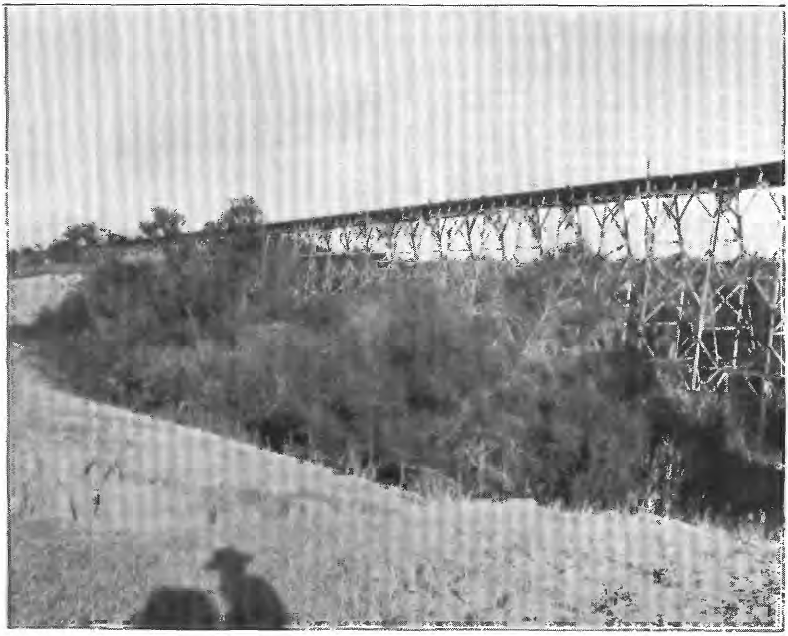


FIG. 19.—Modifications of standard distributing flume. At *a* is a view of flume showing method of joining ends; *b* is a cross section of flume and yoke; *c* is a side elevation of flume and yokes.

*A.* FLUME OF KERN VALLEY POWER DEVELOPMENT WORKS, CALIFORNIA.



*B.* FLUME AT SANGER, CALIFORNIA.

There is another objection to the side wings: Every sudden change in cross section of water channels is likely to produce eddies. When water flows through a rectangular flume and the section is suddenly enlarged by wings placed at an angle of from 30° to 45° to the axis of the canal, the main body of water in the center flows on down the canal, but there is a part on each side which is deflected toward the banks and which forms eddies. These eddies are very destructive to the banks, and the form of construction which has a tendency to produce them should be avoided if practicable. Fig. 20 shows, in plan and elevation, the end of a flume with inclined aprons. When protected by riprap the vertical apron possesses certain advantages over the inclined apron. At the end of the flume a trench is dug 3 or more feet below grade and extending beyond the flume on each side to a distance of about half the width of the flume. An additional mudsill is laid in the bottom of the trench, and additional posts are placed at the ends, with an extended tiebeam on top. Planks are then spiked to these timbers and the earth is carefully tamped around them. This makes a water-tight bulkhead around each end of the flume. Since the amount of lumber required for this kind of apron is small compared with that required for the inclined apron, the writer has frequently obtained California redwood for the purpose. Pine lumber, if treated by some of the well-known and now much-used preservative processes, would, however, answer as well. To prevent erosion and the formation of eddies, riprap should be placed on the bottom and

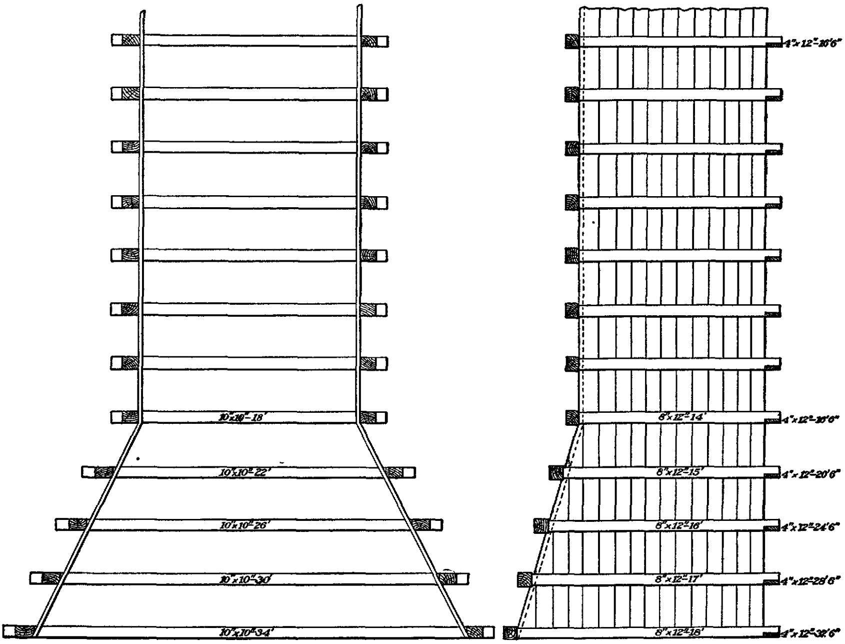


FIG. 20.—Plan and elevation of end of flume with inclined aprons.

sides, in the manner shown in fig. 21. If care is used in riprapping the sides, it is possible to so gradually change the cross section of the water in the flume to that of the canal that the flow will be but slightly disturbed.

There is a modification of the vertical apron introduced by Mr. J. C. Ulrich, civil engineer, of Colorado,[1] which is deserving of mention. In addition to the vertical apron, Mr. Ulrich builds at each end a short flume which he places 3 or more feet below grade and fills the additional space thus made with well-tamped earth.

## CARRYING CAPACITIES.

As a rule the cross sections of flumes are too small. In calculating the size of a flume for a canal it is customary to take a high coefficient of roughness for the canal and a low coefficient of roughness for the flume, for the reason that the flume is lined with lumber and the canal is composed of earth. The result of such theorizing is to overtax the upper ends of the flumes. In reality there is little difference between the carrying capacity of the flume as ordinarily built and the carrying capacity of an earthen canal of the same sectional area. All of the shorter flumes have their floors covered with sediment, gravel, and occasionally with cobbles, and the friction in them, if the lining be rough, may be greater than in the ordinary canal.

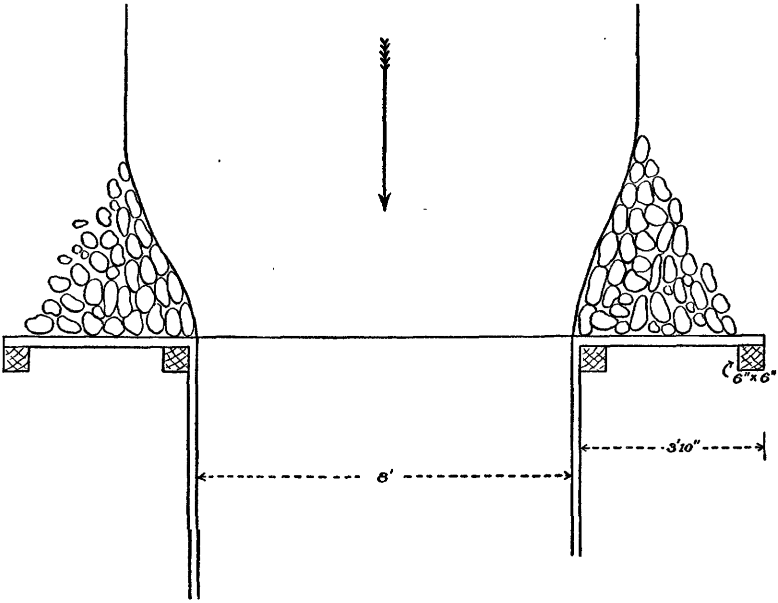


FIG. 21.—Section of canal, showing riprap placed on the bottom and sides to prevent erosion.

When a flume is built on the same grade as the portion of the canal

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[1] See discussion on flumes in Ann. Am. Soc. Irrig. Engrs. for 1892-93, p. 181.

adjacent to it, its width in the clear should be about equal to the mean width of the bottom and the surface of the canal; that is to say, if a canal has a bottom width of 10 feet and a surface width of 16 feet, the proper width of a flume for such a canal would be nearly 13 feet in the clear.

When water is to be conveyed through a flume crossing a ravine several hundred feet in width, it is customary to allow an extra fall for the flume, in order to reduce its size and lessen the expense. This extra fall can not be utilized to advantage if the size of the flume is uniform throughout, since the water moves with ordinary speed as it enters the upper end, and the effect of a steep grade is to increase the velocity and diminish the depth, so that the flume at the lower end may not run half full. In order to utilize an extra fall of this kind, either the width or the depth of the flume should be gradually diminished from the upper end. By making the upper end as wide and as deep as the water in the canal, the width, for example, may be gradually lessened as the velocity of the water increases. This would make the most economical flume as regards material, but the cost of construction would be increased, which may account for the fact that few flumes have been built in that way. Some of these disadvantages may be overcome, however, by gradually enlarging the upper part of the flume, and allowing a steeper grade for this tapering part. By this means the entire volume would be admitted without damming back the water, and the extra grade would increase the velocity sufficiently to allow the flume proper to convey the volume admitted.

The following experiments were made on the carrying capacities of flumes:

*Experiment No. 23.*—This test was on a flume of the Bear River canal at the lower Malade River crossing. About 200 feet of the upper portion is of iron and steel, lined with riveted plates; the lower portion, for a distance of more than 125 feet, is of wood. The test was made in the latter portion, and the results are given in the table on page 60. The discharge, 64.34 second-feet, was obtained by current-meter measurement. There was no sediment or gravel in the bottom, and the planks which formed the lining were planed.

*Experiment No. 45.*—This test was on a small flume on the Elm farm, near Corinne, Utah. The lumber forming the bottom and sides was planed, but some of the oakum with which the joints were calked projected in places. The discharge was measured over a trapezoidal weir.

*Experiment No. 8.*—This test was on a large flume of the Bear River canal, located near the mouth of Bear River Canyon. The lining was of planed lumber, but the floor of the flume was almost entirely covered with sediment and fragments of soft rock. Three current-meter measurements were made at the top, middle, and bottom of a 150-foot section, and the results were 197.40, 197.32, and 197.78 second-feet, respectively.

*Experiment No. 10.*—This test was on a large flume of the Bear River canal, located about 2 miles above that of the flume of experiment No. 8. In this case the floor was covered with sediment, gravel, and small cobbles. The results of the current-meter measurements, taken at the top, middle, and bottom of a 100-foot section, were 206.36, 207.74, and 206.89 second-feet, respectively.

*Table showing values of hydraulic elements in experiments to determine carrying capacities of flumes.*

| Experiment. | Discharge. | Area of water section. | Mean velocity. | Hydraulic mean radius. | Wetted perimeter. | Coefficient of roughness (*n*). | Slope. | Coefficient *c*.* |
|---|---|---|---|---|---|---|---|---|
| | *Sec.-feet.* | *Sq. feet.* | *Feet per second.* | | *Lineal feet.* | | *Feet per foot.* | |
| No. 23.. | 64.34 | 11.78 | 5.46 | 0.87 | 13.62 | 0.0142 | 0.0032 | 103.37 |
| No. 45.. | 0.97 | 1.49 | 0.65 | 0.33 | 4.51 | 0.0184 | 0.00038 | 57.64 |
| No. 8.. | 197.50 | 66.60 | 2.97 | 2.86 | 23.32 | 0.0201 | 0.0004 | 87.72 |
| No. 10.. | 207.00 | 84.05 | 2.46 | 2.94 | 28.60 | 0.0217 | 0.00031 | 81.85 |

*In Chezy's formula.

## SEMICIRCULAR FLUMES.

This form of flume, which resembles the modern stave pipe more than the rectangular flume, was invented by Guy Sterling, civil engineer, nearly nine years ago. His claims for a patent were filed in the summer of 1892, and in August, 1893, a patent was issued. The first flume of this type was built by William Ham. Hall, chief engineer of the Santa Ana canal, near Redlands, California, from a small model and a rough sketch prepared by Mr. Sterling. Inasmuch as the Santa Ana flume differs in many particulars from those built under the Sterling patent in Utah, it is reasonable to conclude that Mr. Hall modified Mr. Sterling's design. In this flume the 8-foot staves are milled from 2-inch by 6-inch joists, in a manner exactly similar to the staves for wooden pipes, and are supported at the ends by T irons curved to coincide with the exterior of the flume. These T irons rest on wooden sills which are concave in the center and are supported by either blocks of concrete or by redwood mudsills. Each section of the flume is also bound by two five-eighths-inch round steel rods, fastened by means of nuts to two horizontal tiebeams which rest on the top edges of the flume. At their ends the staves are tightened by means of wedges driven between the tiebeams and iron straps, and throughout the middle portion they are tightened by cinching the nuts onto the two iron rods.[1]

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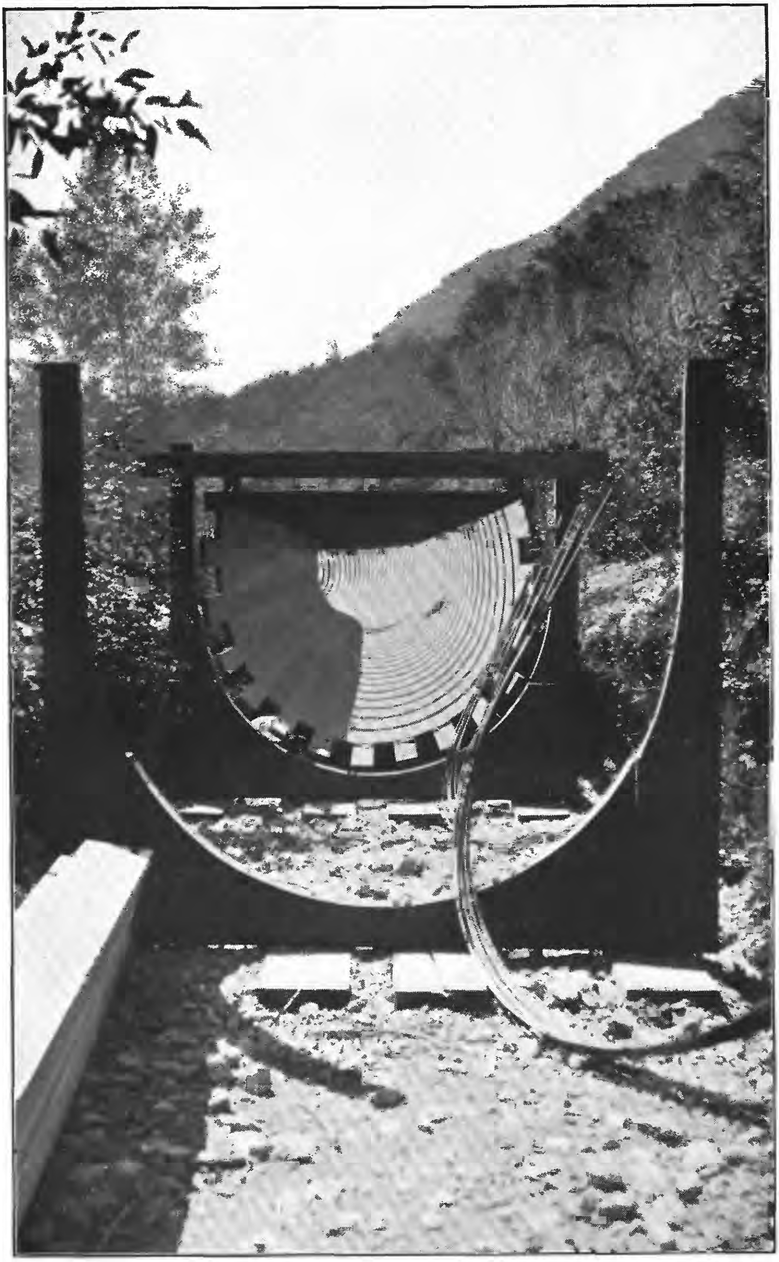
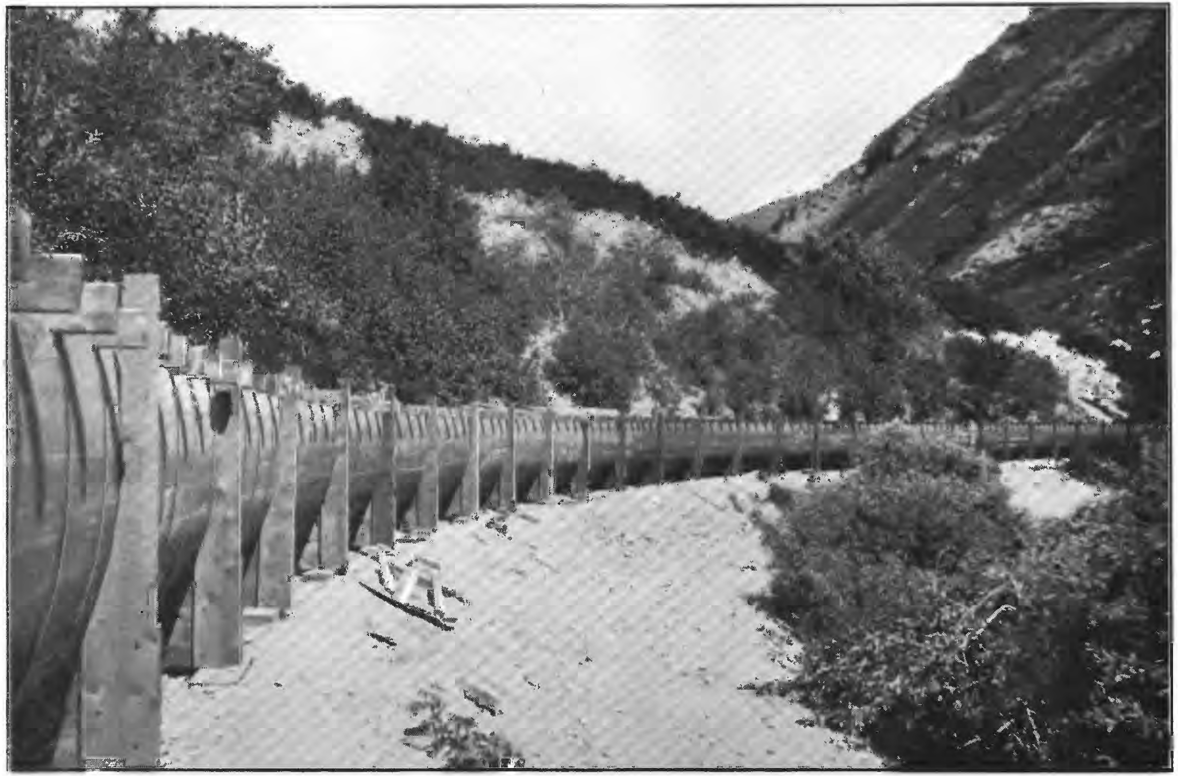
[1] See Trans. Am. Soc. Civ. Engrs., Vol. XXXIII, p. 100.



END VIEW OF STERLING FLUME IN PROVO CANYON, UTAH.



SIDE VIEW OF STERLING FLUME IN PROVO CANYON, UTAH.

At least four lines of this type of flume are now in successful operation. Their lengths, areas, and locations are as follows:

*List of Sterling patent semicircular flumes in operation.*

| Location. | Length. | Sectional area. |
|---|---|---|
| | *Lineal ft.* | *Square ft.* |
| Santa Ana canal, Redlands, California | 11,394 | 15.50 |
| Mount Nebo Irrigation Co., Goshen, Utah | 5,800 | 14.14 |
| Utah mining camp | 500 | 8.00 |
| Telluride Power Transmission Co., Provo, Utah | 8,400 | 28.00 |

With the exception of the Santa Ana, all of the flumes named have been built in accordance with one general plan, differing only in size and relative proportions. The Mount Nebo Irrigation Company's flume is a true semicircle of 6 feet inside diameter; the mining camp flume resembles a parabola, its depth being about 4 feet and its greatest width about 3 feet; and the Telluride Power Transmission Company's flume is shown in fig. 22. The staves are connected at their ends by metallic tongues inserted in saw kerfs, and are broken-jointed in that every two adjacent staves overlap at least 2 feet. The form of the staves, the end joints, and the manner of breaking joints are thus similar to those of stave pipe. The semicircular flume rests on wooden chairs placed 10 to 12 feet between centers. Each chair consists of a bolster, two vertical pieces curved by band sawing to suit the exterior of the flume, and a straight tiebeam. The chairs for the large flume of the Telluride Power Transmission Company in Provo Canyon are placed 12 feet apart, and the half-inch steel bands which hold the staves together are spaced 2 feet 8 inches between centers.

The Sterling semicircular flume possesses certain advantages over the common rectangular flume. In canyons where the line of the flume is made up for the most part of curves, it is comparatively easy to adjust the Sterling flume to ordinary curvatures. In case of shrinkage the flume may readily be made water-tight by screwing up the nuts at the ends of each threaded band. It also possesses the advantage of not being in contact with the soil, so that air is allowed to circulate freely around all portions, with the exception of the small mudsills, which may be replaced at trifling cost. No nails or spikes are driven through the lining of the flume, and by making a girder of each 12-foot length fewer supports and less lumber are required.

The Provo Canyon line, shown in Pls. X and XI, has been successfully operated for nearly three years, and the only breaks that have occurred have been caused by bowlders becoming detached from the canyon sides and striking the exposed flume. The bottom staves sagged in places to such an extent that additional supports had to be inserted midway between the chairs. This is the most serious structural weakness which has developed in this flume, and the remedy is evidently a shorter span between the chairs.

In order to determine the carrying capacities of semicircular flumes, two current-meter measurements were made in 1898 by the late W. B. Dougall, civil engineer, who was then assisting the writer. One of these measurements was made near the intake, in what is known as the old flume, and the other was made at a point about a mile below, in what is known as the new flume. At the time these experiments were made the flume was not carrying its maximum quantity of water, for some repairs were being made. There was also considerable leakage between the two places of measurement, which may account for the greater part of the difference in discharge. The following are the results of Mr. Dougall's experiments:

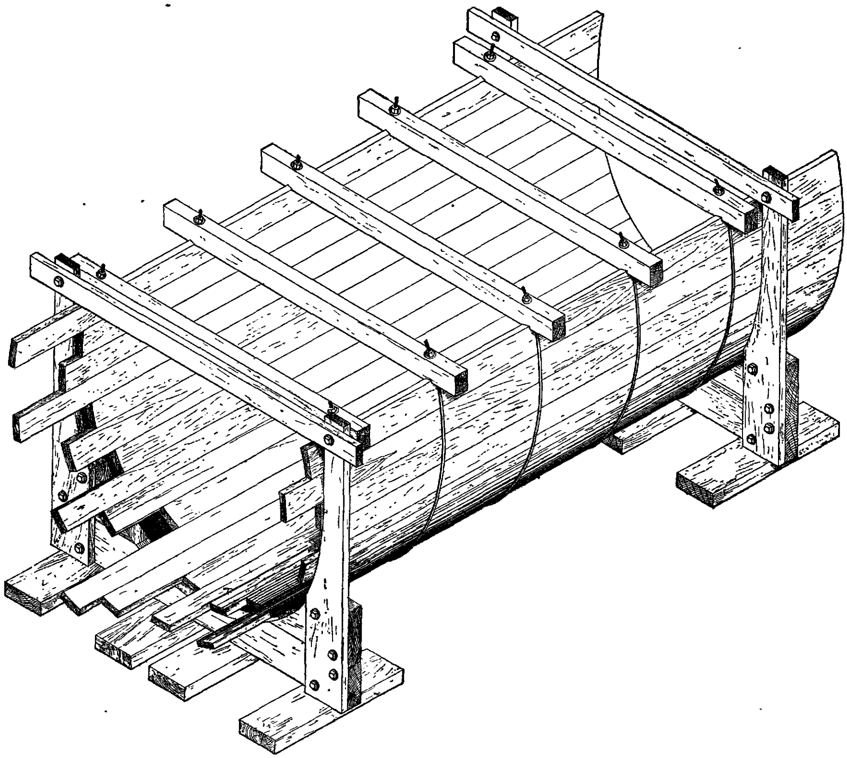


FIG. 22.—Flume of Telluride Power Transmission Company in Provo Canyon, Utah.

*A.* TEMPORARY HEADWORKS OF SANTA ANA CANAL, CALIFORNIA.

*B.* CONNECTION BETWEEN TUNNEL AND FLUME OF SANTA ANA CANAL, CALIFORNIA.

*Table showing results of tests made by W. B. Dougall to determine the carrying capacities of semicircular flumes.*

| Measurement. | Discharge. | Area of water section. | Mean velocity. | Hydraulic mean radius. | Wetted perimeter. | Coefficient of roughness (*n*). | Slope. | Coefficient.* |
|---|---|---|---|---|---|---|---|---|
| | *Sec.-feet.* | *Sq. feet.* | *Feet per second.* | | *Lineal feet.* | | *Feet per foot.* | |
| Upper measurement. | 74.39 | 13.24 | 5.62 | 1.45 | 9.12 | 0.0111 | 0.001 | 147.74 |
| Lower measurement. | 72.40 | 13.49 | 5.37 | 1.46 | 9.26 | 0.0116 | 0.001 | 140.84 |

* In Chezy's formula.

## STAVE PIPE.

The use of wood to convey water for domestic purposes was common a hundred years ago. Many of the present extensive and costly waterworks systems of the New England cities had their origin in one or more lines of bored logs. Owing, however, to their small capacity and the imperfect manner of joining the lengths, their use in the United States has been wholly superseded by some form of metal pipe. One frequently reads of these old bored logs being dug up to give place to modern improvements, and the excellent state of preservation in which they are found, after being buried a lifetime, speaks well for the lasting qualities of wood under favorable conditions.

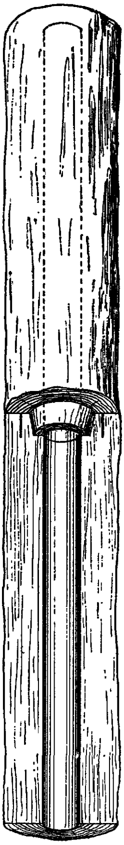


FIG. 23.—Water pipe of bored logs.

In some parts of Canada bored logs are still extensively used for water pipes, on account of the cheapness of suitable lumber. Tamarack wood is preferred, both on account of its durability when in contact with the soil and the suitable form of the trees, which are frequently not larger than a stovepipe at the butt end and maintain a nearly uniform size throughout two-thirds of their entire length. When tamarack is not available, Canada balsam makes a good substitute. In many sections this can be had for the cutting. It is so soft that a man can bore with ease a 2-inch hole through a section length, and when kept moist it lasts well. The trees are cut in lengths of from 9 to 12 feet, and each length is placed on a platform, where it is bored by a long auger revolving in guides and operated by hand. The sections are joined by reaming a long, tapering socket in the larger end of each length and by shaving or turning the smaller end into a spigot. Formerly a band of wrought iron encircled the socket end to prevent the shell from splitting when the spigot was being driven into it; but in more recent practice the iron band is driven into the end, as shown in fig. 23.

Illustrations of the next stage of the development of wooden pipe are to be seen in the penstocks of many of the old gristmills and sawmills of New England and eastern Canada. Originally these pipes, or penstocks, were built in sections of narrow pine or balsam planks, the edges being planed, by hand, to the required bevel. These staves were encircled by flat bands, to which were welded short pieces of round iron threaded and secured by nuts to cast-iron saddles. The weak feature of this construction was in the joints between the sections. By using a tapering stave the ends of each section were made to differ in size, and by shaving down the smaller end it was made to telescope the larger. The lap, however, was only a few inches at most, so that the joints usually leaked, or the sections slipped apart altogether. In some cases this defect was remedied by building the pipe in the trench and avoiding distinct joints at regular distances, the ends of the staves being united by an iron dowel and the joints broken by a lap of 2 or more feet.[1] The 6-foot wooden conduit laid in 1881 and 1882 as part of the intake of the Toronto waterworks may be cited as a sample of this type of stave pipe. The staves were made of white oak 6 inches wide and 5 inches thick, beveled on the edges and curved on the outer surface to conform to an arc having a radius of 3 feet 5 inches, as shown in fig. 24. The metallic tongue between abutting stave ends was one-eighth inch thick, 6 inches long, and the full width of the center of the stave. The hoops were of wrought iron, three-fourths inch thick by 3 inches wide, welded together, washtub fashion, and spaced 2 feet between centers.

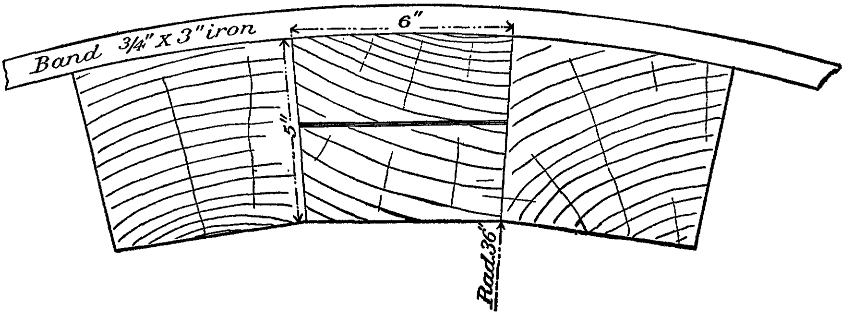


FIG. 24.—Section of stave pipe used in wooden conduit of Toronto waterworks.

It is a modified form of this kind of stave pipe that has been so extensively used in the Western States during the last twelve years.[2] The first line of this kind was built under the supervision of Mr.

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[1] See paper by T. J. McMinn in Trans. Can. Soc. Civ. Engrs., Vol. I, Pt. I, p. 67.

[2] Wooden-stave pipe, by Samuel Fortier: Ann. Am. Soc. Irrig. Engrs. for 1892–93.

STAVE PIPE OF ELECTRIC-LIGHT WORKS AT BRIGHAM, UTAH.

Charles P. Allen, chief engineer of the Denver Union Water Company, of Denver, Colorado, and extended from the West Denver reservoir to the underground galleries on South Platte River, 3½ miles distant.

The results of Mr. Allen's experiments were finally embodied in a patent issued March 22, 1887. This patent embraced stave pipe as a whole as well as each of its main features, viz, the round iron or steel bands, the cast-iron shoes or saddles, and the metallic tongues. Many modifications and some improvements, now covered by other patents, have since been made, and in order that the reader may obtain some idea of the modern forms of this pipe, a brief description of each will be given.

Fig. 25 illustrates the mode of connecting the butt joints of the staves, the forms of the steel bands and the malleable iron saddles, and a portion of a completed pipe of the Allen type. The staves are dressed from joists varying in size from 2 inches by 4 inches to 3 inches by 10 inches, depending on the diameter of the pipe to be built, and their ends are slotted to admit the metallic tongue. The malleable-iron saddle is so designed that it holds in position the T end of the band, and allows the insertion of the threaded end, which is secured by means of a nut.

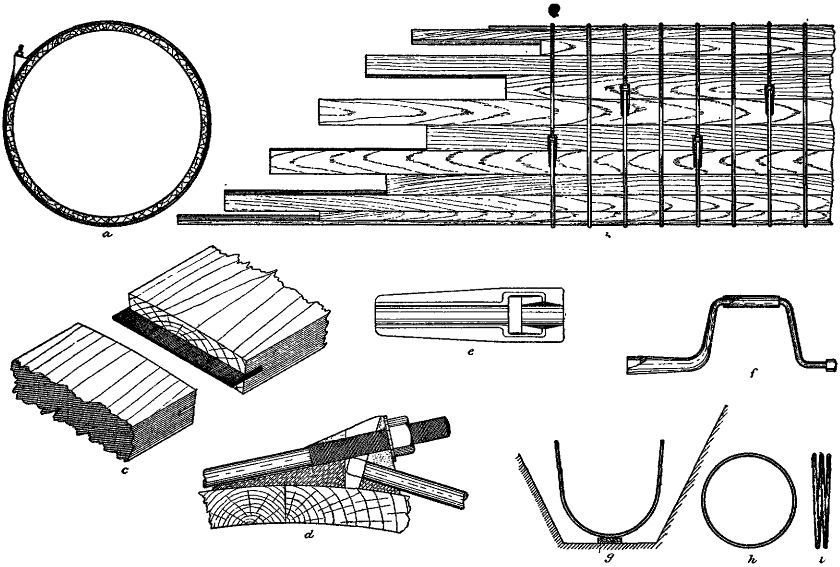


FIG. 25.—Details of Allen type of stave pipe. *a*, section of wooden pipe, showing position of steel bands and iron saddle; *b*, elevation of pipe, showing method of breaking joints and position of steel bands; *c*, ends of staves, showing metallic tongue; *d*, ends of steel band and malleable-iron saddle; *e*, plan of saddle; *f*, wrench or bitstock for screwing up nuts on steel bands; *g*, outside form used in building pipe, consisting of a bent gas pipe on a block of wood in the trench; *h* and *i*, inside form used in building pipe, consisting of a coil of ¾-inch gas pipe.

Fig. 26 shows the construction of the Dwelle type of stave pipe. It differs from the Allen type in several important particulars: The ends of the staves are connected by means of a tongue and groove; the band is threaded at each end and is secured to the casting by two corresponding nuts which abut against shoulders; the edges of the staves, instead of being radial, are dressed to a kind of ogee curve.

Fig. 27 shows the construction of the stave pipe recently built by the Pioneer Electric Power Company, of Ogden, Utah. The shape of the staves and the metallic tongues used to connect their ends are similar to those of Allen's patent, but the steel bands and saddles are widely different; they were designed by the late J. C. O'Melveny, civil engineer, of Salt Lake, Utah. The band is in two parts. One part encircles the upper circumference of the pipe and is attached to two steel saddles by means of two loop eyes; the other part encircles the lower circumference of the pipe and is attached to the same saddles by means of nuts screwed to each threaded and upset end of this part of the band. The saddles are U shaped, being curved to suit the outer arc of the staves, and pressed, when hot, out of three-sixteenth-inch steel plates.

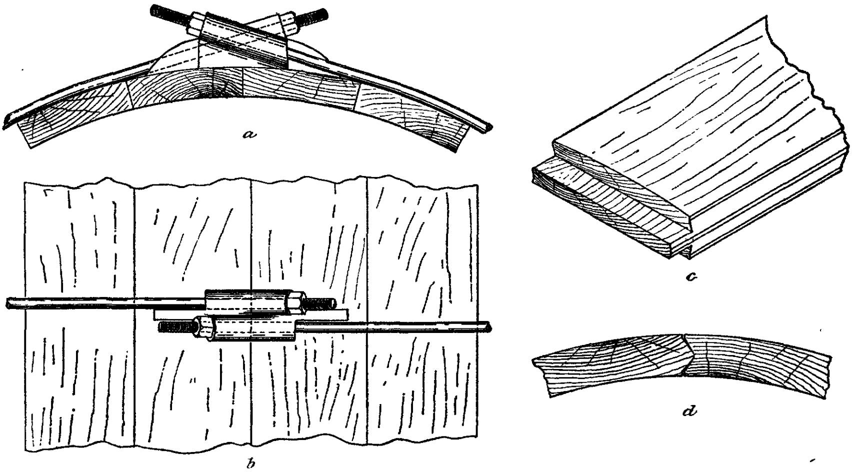


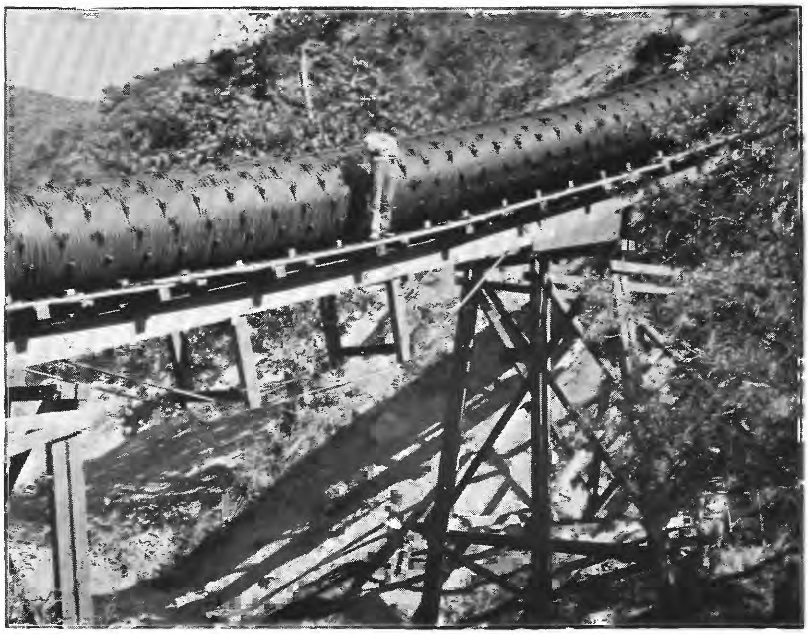
FIG. 26.—Details of Dwelle type of stave pipe. *a*, portion of section of pipe, showing ends of bands; *b*, plan of pipe; *c*, end of stave, showing tongue; *d*, portion of section, showing edges of stave dressed to ogee curve.

There are various other modifications of staves, bands, and saddles, but their use has been confined to short lengths of pipes and to few localities.

### LUMBER FOR STAVES.

Colorado pine (*Pinus ponderosa*) was used on the first pipe lines built in the West. Its tendency to warp, the large number of knots which it contains, and its short life when exposed to unfavorable conditions, render it an unsuitable wood in every respect save that of first cost.

*A.* OLD FLUME AND NEW REDWOOD STAVE PIPE REPLACING IT, REDLANDS CANAL, CALIFORNIA.



*B.* REDWOOD STAVE PIPE UNDER 160 FEET HEAD, SANTA ANA CANAL, CALIFORNIA.

Long-leaf yellow Texas pine (*Pinus palustris*) was next tried and was found to possess many advantages over the native pine. There were few knots, the staves were longer, and there was less warping on exposure to the action of the sun and atmosphere. The resin-filled ducts in the quarter-sawed lumber were among the worst defects, since the fluctuating water pressure within the pipe washed out the resinous substance and allowed the water within to ooze through the thin shell.

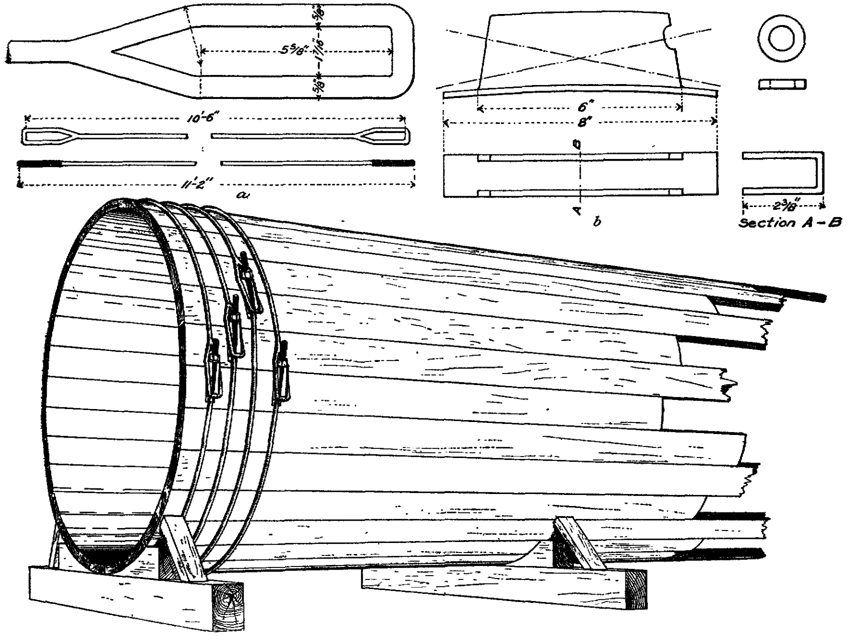


FIG. 27.—Details of stave pipe built by Pioneer Electric Company, of Ogden, Utah. *a*, details of steel bands; *b*, plan and elevation of saddle.

California redwood (*Sequoia sempervirens*), on account of its great durability, its freedom from knots, and its fine, close texture, has been extensively used for this purpose on the Pacific coast and as far east as Utah, Montana, and Colorado. More than twenty carloads of finished redwood staves were used by the writer in the spring of 1890 to build a 2-foot stave conduit for the Ogden waterworks, and two years later the same kind of wood was used on the 18-inch conduit of the Logan waterworks. Both of these lines have given excellent satisfaction and bid fair to last thirty years or longer.

Douglas spruce (*Pseudotsuga douglasii*), commonly called Oregon fir, or Oregon pine, was used to the extent of 1,500,000 feet B. M. on the 27,000 lineal feet of 6-foot conduit of the Pioneer Electric Power Company, of Ogden, Utah. In appearance this lumber was perhaps the finest ever used in construction work on this continent. It was strong and smooth, and entirely free from knots and other defects common to most timbers. The only question yet to be settled in regard to the use of Douglas spruce for staves is: Will it last long? We know that the life of a redwood railroad tie, if protected by thin metal plates from the crushing effect of the rail, is more than twice as long as that of either a pine or a spruce tie. The greater part of the conduit just mentioned is considerably below the level to which the water would rise if a hole were bored in the pipe, and the lumber in all such portions will be continuously soaked. Such being the case, the lumber used was perhaps the most economical. If, however, a pipe or conduit has to be located on grade, or in a position where the pipe will be only partially filled with water, there can be no question that redwood, although its first cost may be greater, will prove the cheapest wood in the end.

### STEEL FOR BANDS.

In specifying the quality of steel for the bands, the strength of the metal has been considerably reduced in order to increase its toughness and ductility. Mr. Allen was the first to use a mild steel made by the open-hearth process, very similar in quality to that used for steam boilers. The average tensile strength of the specimens tested was about 61,000 pounds per square inch, the elastic limit 40,000 pounds, the elongation in 8 inches more than 25 per cent, and the reduction area more than 50 per cent. This kind of steel will not only bend flat upon itself through 180 degrees when cold, but after being so bent it may be hammered to half its diameter without sign of fracture.

In the first lines built in the West the rods were not upset at their threaded ends. This omission was probably due to the extra cost of upsetting small rods. This work can now be done, however, for a mere trifle, and any one can readily see that in pipes of large diameters, requiring long bands, the saving in upsetting the threaded ends is considerable.

### CONSTRUCTION.

The bottom width of the trench is made from 1 to 2 feet wider than the diameter of the pipe, in order to give space for workmen to stand on either side of the pipe when it is being put together, and the side slopes of the trench are as steep as the nature of the material will permit.

Ordinarily inch gas pipes bent in the form of a U, the lower portion conforming to the outer circumference of the pipe, answer very well for outside forms in which to hold the staves in place until the lower half is put together. To prevent the staves from falling while the upper half is being built, the same kind of iron pipe is used in the

REDWOOD STAVE PIPE (52-INCH) CROSSING WARMSPRINGS CANYON, NEAR REDLANDS, CALIFORNIA.

form of a coil, the outer diameter of which is nearly equal to that of the inside diameter of the pipe. The bottom staves are kept slightly in advance of the top staves, in order to facilitate building and to make a stronger joint. The lengths are joined by lapping the staves a distance of from 20 to 30 inches. An oak driving bar banded with Norway iron and struck with a 12-pound sledge hammer is the only device used to drive the staves and make tight all end joints. The metallic tongues are inserted in the slots made in the ends of the staves after each section or length has been driven, when all is in readiness for the building of the next section.

The steel rods for the bands are bent by hand after being shaped on turning tables, and are afterwards either dipped in hot asphalt or painted. Specially designed braces are used to screw the nuts on the bands, and a leather-faced wooden mallet handled by a man inside of the pipe has been found to be the best tool to adjust the staves to the proper alignment and true circle.

The strength of the pipe depends on the number and size of the steel bands. If there is little pressure within the pipe, the bands are spaced far apart, but seldom more than 14 inches. As the pressure within increases—i. e., as the pipe dips—the bands are placed nearer together, so that a pipe under a head of 100 feet may be as strong as a pipe under a head of 5 feet.

## LOCATION OF PIPE LINE.

It is very bad practice to locate a wooden pipe line on a grade, for the reason that when so placed the pipe is seldom full of water, and moist air and gases collect in the upper portion, which, with the earth without, soon cause the wood to rot. An ideal location is over gently undulating ground where each low, flat valley ends in a narrow ridge. Seen from the side, a pipe so placed would remind one of a big cable supported at regular intervals and sagging between every two supports. Hence, in laying out a line for wooden pipe, no matter how rough or uneven the country traversed may be, an attempt should be made to rise to grade only at intervals which might vary from a quarter to a half mile, while the line between the rising points might be 5 or more feet below grade. The main object of such a location is to keep the pipe not only full of water but under some internal pressure. Other conditions being favorable, and the shell being kept continuously moist, wooden pipe should last a lifetime.

## DURABILITY.

Stave pipe built of native pine lumber, placed in a dry soil, and kept only partially full of water, may rot along the top staves to such an extent that in five years those staves will have to be renewed. The same kind of pipe, however, if kept continuously full of water and under pressure and buried 2 or 3 feet beneath the surface, may be in good condition twenty years after being laid.

Ten years ago the city of Cheyenne, Wyoming, laid about 9,000 lineal feet of stave pipe from wells in Crow Creek to a standpipe near the reservoir. The low standpipe kept the lower portion of the pipe line under pressure, but the upper portion was seldom full of water, often only half full, and rotted so rapidly that in about eight years 2,000 feet of it was replaced by sewer pipe, and during the year 1897 an additional length of 2,200 feet was replaced by sewer pipe 24 inches in diameter. Through the courtesy of Walter D. Pease, civil engineer, of Laramie, Wyoming, the writer obtained three samples of the old staves, which Mr. Pease graded best, second best, and third best. The best sample was in fairly good condition, having been kept moist, the third-best sample was greatly decayed, while portions of the top staves were reduced to rotten fragments and could not be photographed.

The durability of stave pipe when made of good lumber and properly laid is shown by the following extract from a report on the Ogden waterworks to the Ogden council, by N. W. Bethel, city engineer, and the writer as consulting engineer:

> In consideration of the fact that this wooden stave pipe has been in operation for nearly eight years, its present condition is excellent. We have uncovered portions of the pipe throughout its entire length in at least forty different places, and have found without exception the redwood of which the staves are composed to be in a sound condition.

The life of this kind of pipe is prolonged by an earth covering of 2 feet or more. When laid near the surface, with little or no covering of earth, the combined action of earth, air, and sunlight causes decay.

## USE.

The most expensive portions of irrigation canals in earth are the ravines. During the last thirty years the common practice in the Rocky Mountain region has been either to go around these ravines with a grade canal or to erect across each a flume on trestles. The first method is often impracticable, and in any event the length of the canal is unnecessarily increased. The latter method proves expensive, not because of the first cost, but on account of the annual expense of maintenance and the frequent renewals. Such flumes usually have to be calked every spring, while both trestles and flume are exposed to landslides, fires, and windstorms, or, escaping these, are inevitably subject to early decay. Stave pipe, on account of its cheapness and the large sizes that can be constructed, is rapidly taking the place of flumes on trestles. One or more lines of pipe are laid in a trench dug across the bottom of the ravine, and are connected with the grade canal at either end by means of shallow wells or rectangular boxes. The cost of an inverted pipe siphon is frequently less, and it may last two or three times longer than a flume on trestles.

The old-fashioned way of conveying water to gristmills, sawmills, or manufacturing plants was to make use of a short, open raceway from the stream to the mill and utilize the low head thus created. Wooden pipe, on account of its general adaptability, is now being extensively used for this purpose. It permits the conveyance of an equal amount of water a much longer distance, increasing the fall and consequently the power produced.

This kind of pipe is also frequently used to convey water to domestic distributing reservoirs, from which the water is conducted through iron pressure pipes laid in the streets of the city.

### COST.

On account of the fluctuation in the prices of lumber and steel, as well as the variation in freight rates and many other causes, it is impossible to state the cost of stave pipe. In the Rocky Mountain States the price of redwood joists dressed into staves is about $40 per 1,000 feet B. M. A pipe 20 inches in diameter requires about 13 feet of lumber to each lineal foot of pipe; a 24-inch pipe requires 16 feet of lumber, a 30-inch pipe requires 18 feet, a 36-inch pipe requires 22 feet, and so on in about that ratio. The cost of the iron and steel per lineal foot of pipe depends on the pressure of water within the pipe. When a stave pipe is laid near grade the bands may be spaced 12 or more inches apart. If, on the other hand, it is laid across the bottom of a ravine 100 feet below grade, the bands should be about 3 inches apart.

The figures given below may convey some idea of the present comparative cost of stave pipe, cast-iron pipe, and riveted-steel pipe in the city of Salt Lake. The following bids were received March 24, 1900, for furnishing all of the materials and laying the City Creek pipe line:

4,390 lineal feet of 30-inch stave pipe, $2.95 and $3.10; or
4,390 lineal feet of 30-inch cast-iron pipe, $10.20 and $10.85; or
4,390 lineal feet of 30-inch riveted-steel pipe, $8.65 and $9.15.
4,390 lineal feet of 24-inch stave pipe, $2.60 and $2.55;
5,920 lineal feet of 24-inch cast-iron pipe, $7.45 and $8.15; and
5,920 lineal feet of 24-inch riveted-steel pipe, $5.75 and $6.05.

## RIVETED-STEEL PIPE.

Riveted-steel pipe is extensively used in southern California to convey water for orchard irrigation, but its use in the Rocky Mountain States has been confined to power plants and domestic water supplies.

It is well adapted to high heads, and irrigators who desire to conduct water across deep gulches would do well to write to the makers of this kind of pipe for prices. The principal manufacturers of riveted-steel pipe on the Pacific coast are the Union Iron Works and Francis Smith & Company, of San Francisco, and the Lacy Manufacturing Company and J. D. Hooker, of Los Angeles. The writer has also obtained prices at various times from the Carroll-Porter Boiler and Tank Company, of Pittsburg, Pennsylvania.

Riveted-steel pipe ranges in size from 3 inches to 72 inches internal diameter. The smaller sizes are made into lengths of 25 feet or more at the shops and are thoroughly coated with asphaltum. The larger sizes are usually made in temporary shops erected near the site where the pipe is to be laid.

The following extracts from general specifications furnished by the secretary of the Carroll-Porter Boiler and Tank Company will give the reader some idea of the manner of making this kind of pipe:

*Requirements for steel plates.*—The steel shall be of the class termed "soft" and shall be made by the basic or acid open hearth process. If by the basic open hearth process it shall contain not more than .04 of phosphorus and .04 of sulphur. If acid it shall contain not over .08 of phosphorus and .05 sulphur.

The amount of manganese and carbon to be in such quantities as shall produce the best results.

Chemical analysis of each "heat" or "melt" shall be made by the Engineer or his representative, and properly certified copies of the final analysis of the material shall be furnished to the Engineer as the work progresses.

Physical tests to determine the tensile strength, elastic limit, elongation, softness, and ductility of the material of each "heat" or "melt" shall also be made by experienced Inspectors whose services may be satisfactory to the Engineer. For the purpose of identification the "heats" or "melts" shall be numbered consecutively, and the corresponding number stamped upon each plate or sheet produced therefrom.. The test specimens shall in all cases be taken from the shearings of such plates produced from each "heat" or "melt" as is thought necessary, and such sheets or plates to be selected at random by said Inspector or Engineer, and properly certified copies of the record of such test shall be furnished the Engineer as the work progresses.

Tensile test specimens to be eight (8) inches long and one and one half (1½) inches wide between measuring points. Tensile strength is to be between the limits of fifty two thousand (52,000) and sixty two thousand (62,000) pounds per square inch. Elastic limit to be not less than one half the tensile strength required. For plates three eighths (⅜) inch thick or more, the elongation to be not less than twenty-five (25) per cent. For plates thinner than three eighths (⅜) inch, elongation to be not less than twenty-two and one half (22½) per cent.

Bending test specimens cut lengthwise or crosswise from the sheet to be six (6) inches long and one (1) inch wide, to be bent one hundred and eighty (180) degrees upon itself when cold, and hammered down flat without sign of fracture on the outside of the bent portion.

The plates must also admit of cold hammering or scarfing to a fine edge at the laps without cracking; and the test pieces must furthermore withstand such quenching, forging, and other tests as may suffice to exhibit fully the temper, soundness and fitness for use of the material. The failure of said test specimens, when taken at random as aforesaid from the finished product of any "heat" or "melt," to conform to the above requirements will be sufficient cause for the rejection of the entire product of such "heats" or "melts."

The plates shall be free from lamination and surface defects and be fully up to the required gauge for thickness on the edges. Any plate whose thickness at any point may be found less than ninety-five (95) per cent of the required thickness shall be rejected without appeal; furthermore, at least ninety (90) per cent of the plates must be of the full required thickness at all points. Said plates shall be rolled as flat and sheared as accurately as good mill practice will permit, but in no case shall they be scant of the prescribed or intended dimensions, and must be in all respects of a good merchantable condition. The Engineer shall have the right at all times to inspect the manufacture and testing of any and all plates and shall have, if so required, one fourth ($\frac{1}{4}$) of the number of test pieces to be prepared as above, to test or to have tested under his own supervision.

It is further understood and agreed that any plate that shows any defects during the process of punching, bending, and riveting for manufacturing into pipes shall be rejected, notwithstanding that the same may previously have been satisfactorily tested.

*Requirements for steel rivets.*—Rivet steel shall be soft and have a tensile strength between the limits of fifty thousand (50,000) and fifty eight thousand (58,000) pounds per square inch, with an elastic limit of not less than thirty thousand (30,000) pounds per square inch, and with an elongation of not less than twenty-eight (28) per cent, in a test bar eight inches long between measuring points and full diameter of rivet, and with a reduction of cross sectional area at the point of fracture of not less than fifty (50) per cent. The material shall also be of such quality as will stand bending double and flat before and after heating to a light yellow heat, and quenching in cold water, without sign of fracture on the convex surface of the bend. All steel rivets not conforming to the above requirements will be rejected.

*Manufacture of pipe.*—The sheets or plates must be of such dimensions as to admit of being rolled into true cylinders not less than five (5) feet in length and of the required internal diameter with ample allowance for the necessary overlap at the single longitudinal seam of each such cylinder. The pipe shall be made telescopic and the plates when formed shall be a cylinder whose external diameter at one end shall be equal to its internal diameter at the other end and forming a tight fit with each other before any protective coating is applied to the material.

The edges of each plate must be properly beveled for calking all around; and at the end of each course, where the lap of the longitudinal seam occurs, the plate must be reduced by cold hammering or planing, or both, to a fine edge, through which one of the rivets of the round seam must be driven to insure tightness. In addition to this rivet, still another rivet must be driven through the three thicknesses of plate at such joints. Each plate must be rolled to a perfect cylinder of the required diameter.

All rivet holes must be spaced with precision. In punching said holes the best and sharpest dies and punches are to be used. The holes must all coincide to within one thirty-second ($\frac{1}{32}$) of an inch; otherwise they are to be enlarged by a sharp reamer or drill. No drift pins shall be used in forcing rivet holes to coincide at any seam or lap; and all plates in which the said holes cannot be made to receive a rivet of the specified diameter, with such slight drifting or reaming as will not, in the opinion of the Inspector, reduce the strength of the plates, will be rejected.

All riveting in the shop must be done with hot steel rivets and by steam, compressed air, or hydraulic machinery exerting a slow pressure and retaining it sufficiently to perfectly form the rivet heads before the metal loses its red color. All rivets when driven must fit the holes completely. Care must in all cases be taken to have the rivets of the right heat to produce the best and most solid work, and any rivet that may at any time or place be found defective or appear to have been overheated, shall be cut out and replaced at the Contractor's expense by one which is sound in all respects. All rivet heads must be perfect in form and truly concentric with the shank or shaft.

All circular seams may be single riveted but all longitudinal seams on the straight pipe shall be double riveted. The proportions to be used in laying out and making the riveted joints or seams shall in general be as follows, all figures being in inches.

* * * * * * *

The dimensions given in the foregoing table are to be regarded as approximate, and subject to modification before the material for the pipe is definitely ordered by the Contractor; and any modification proposed by said Contractor shall be subject in detail to the approval of the Engineer before being carried into effect.

The pipe is to be manufactured in lengths of four or more courses each, and so laid that all longitudinal seams will at all times be on top and within a foot of the center line of the pipe.

Where angles or curves occur in either the alignment or the grade of the conduit, the plates must be cut and punched to the required lines for forming a small oblique angle at the round seams of as many courses as may be needed to produce the given total deflection or curvature in each locality, and the courses must be put together with the straight seams alternating as aforesaid. Where greater angles and special pieces are necessary they shall be made as ordered by the Engineer.

All rivet seams and joints of every description shall be thoroughly calked both on the inside and outside in the best and most workmanlike manner for first class boiler work, while for the necessary distance from all laps the seams shall be both chipped and calked.

*Testing.*—During its manufacture, sample lengths of pipe to be selected by the Inspector as frequently as he may deem necessary, shall be tested after coating, under a water pressure equal to one and one half (1½) times the maximum hydrostatic head for which it is designed, and shall be tight under that pressure. All such tests will be made at the Contractor's expense, and he shall furnish all the necessary appliances and labor for their performance to the Inspector's satisfaction.

*Coating.*—When the pipes are finished, they are to be thoroughly coated by dipping in a bath of refined asphaltum, as follows: Each length of pipe must be thoroughly clean inside and outside, free from dust, earth or sand, and without rust upon any part of it. Any rust that may have formed must be removed by brushing and scrubbing with a wire brush and diluted acid, followed by mopping or brushing with milk of lime, or a saturated solution of soda, to remove the acid, until all the rust and acid shall have been removed. All alkali used shall be washed off and the surface dried.

The pipes are then to be heated, after which they are to be dipped in the bath of coating material. The coating shall consist of the best quality of California or Trinidad refined asphalt, such as is used for pipe coating purposes. The coating must be durable, smooth, glossy, hard, tough, perfectly water-proof, not affected by any salts or acids found in the soil, strongly adhesive to the metal under all circumstances, and with no tendency to become soft enough to flow when exposed to the sun in summer, or to become so brittle as to scale off in winter.

After having been prepared as aforesaid, the coating composition shall be placed in a vertical tank and carefully heated to a temperature of about three hundred (300) degrees F., or such other temperature as may hereafter be found best adapted for the purpose, and kept at this temperature during the whole time of dipping.

Fresh materials must be added to the aforesaid bath from time to time in the right proportion to keep the mixture of the proper consistency. Such proportions may also be varied according to the season of the year, as will be directed by the Engineer or found necessary to produce a coating of the required quality.

# CAST-IRON PIPE.

## HISTORY.

According to Mr. Jesse Garrett,[1] the first cast-iron pipe was used for the water service of Versailles, France, in 1685. The first iron pipe was laid in London in 1746, and in 1835 the various water systems of that metropolis included more than 1,000 miles of that kind of pipe.

During the early part of this century James Watt laid cast-iron pipes with flexible joints across the River Clyde, to convey water to Glasgow. These pipes had ball and socket joints, were 9 feet long, and from 15 inches to 36 inches in diameter.

The first cast-iron pipes used by the city of Philadelphia were molded by Mark Adams from designs prepared by Frederic Graff, sr., the engineer of the Philadelphia waterworks. These pipes were cast direct from melted native bog ore. The pipe molds were placed in a nearly horizontal position and sufficiently low to tap the flow from the furnace, the excess of each pouring being run into pigs.

Fanning states[2] that the earliest pipes had joints with a packing ring of leather. These were 2½ feet in length. Then followed somewhat longer pipes, with screw joints, which, however, were not satisfactory, the rigid joints preventing free contraction in winter and expansion in summer. For screw joints there were soon substituted slightly tapering cylindrical socket joints, in which both hub and spigot ends were accurately dressed on a lathe. In forming the joint, a heavy lubricant, like tallow, was first spread over the dressed surface, after which each spigot end was driven into its socket. This kind of joint is still used for water and gas pipes in parts of Great Britain and Canada.

The bell and spigot joint so common at the present time was first adapted to wood instead of lead packing. Dry pine, dressed in the form of a stave to suit the diameter of the pipe to be calked and about 3 inches in width, was cut into lengths a trifle longer than the depth of the socket. From four to eight of these pine wedges, which tapered slightly, were entered at the top, bottom, and middle of the joint and driven home together. The remaining annular spaces were filled by other wedges somewhat wider than the spaces.[3]

## MANUFACTURE.[4]

The first process in the manufacture of cast-iron pipe consists in making the core, which is formed on a cylindrical iron spindle. The

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[1] The Early History of Cast-Iron Pipe, by Jesse Garrett; Read before the New England Water Works Association in 1896.

[2] Hydraulic Engineering and Manual for Water Supply Engineers, p. 458.

[3] For description of pine packing in cast-iron pipes see paper by F. A. Creighton in Trans. Can. Soc. Civ. Engrs., Vol. VIII, Pt. I, p. 145.

[4] The writer is indebted to Mr. W. F. McCue, of the Colorado Fuel and Iron Company, for much of the information contained in this description.

spindle is first wrapped with machine-made hay rope, and around the rope tempered clay is firmly packed. After this coating is dried a second coat is put on. Then the spindle is revolved in its bearings and a third coat, consisting of blacking made from coal dust, is added. After this last coat has been applied the core is trimmed to exact dimensions and is then placed in a drying oven.

The next step in the process is to center a cylindrical iron pattern inside of the flask in which the mold is formed. The outside diameter of this pattern is the inside diameter of the pipe to be made. Sand and a small portion of clay slightly tempered are firmly rammed around the pattern, so as to form the mold. The flask is then ready for the drying pan. When the several parts are sufficiently dried they are taken from the oven and placed in the casting pit. The core is placed in the molds and is accurately centered in the bevel at the bottom and to the bead ring at the top in order to insure the desired dimensions of pipe. The molten metal is taken from the cupola in a ladle swung from a crane and is poured into the molds around the core. The intense heat from the metal causes the hay rope on the spindle to burn, leaving the spindle loose and capable of being easily withdrawn. As soon as the metal has become sufficiently cooled the pipe is lifted from the flask, taken outside of the building and placed upon skids, where it is thoroughly cleaned and prepared for the coating. After being cleaned it is placed on a car, run into an oven, and heated to a temperature of 300° F. It is then removed from the oven and immersed in a bath of coal pitch and varnish, which is maintained at a temperature of about 210°. After the coating has dried the pipe is weighed and the weight is marked with white-lead paint on the inside of the bell end. It is then subjected to a hydrostatic test, the pressure varying from 250 to 300 pounds per square inch, according to the thickness of the shell and the size of the pipe, and while under this pressure it is subjected to an additional test, consisting of a series of blows from a 3-pound hammer attached to a handle 16 inches long, the blows being applied by hand at various points throughout the length of the pipe.

## DIMENSIONS AND WEIGHTS.

A few years ago a committee was appointed by the American Water Works Association to draft suitable specifications for standard cast-iron water pipe. Mr. S. B. Russell, who was chairman of the committee, recommended[1] three weights for each size of pipe, to be designated A, B, and C. The weight of class B was determined from the average weight of the pipe used in a large number of American cities

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[1] Report of proceedings of the annual meeting of the American Water Works Association (1890), p. 23.

and towns; class A was 10 per cent lighter than class B, and class C was 10 per cent heavier than class B. The following table embodies the recommendations of the committee regarding the outside diameter, the average thickness, and the weight of each 1,000 feet of each size and class. To determine the weight per lineal foot, including bell ends and spigots, the weights given should be divided by 1,000.

*Dimensions and weights of cast-iron water pipe adopted by American Water Works Association in 1890.*

| Size (internal diameter). | Class. | Outside diameter. | Average thickness of barrel. | Weight per 1,000 feet.[a] |
|---|---|---|---|---|
| | | *Inches.* | *Inches.* | *Pounds.* |
| 3-inch | A | | | 14,000 |
| | B | 3.856 | 0.428 | 15,580 |
| | C | | | 17,170 |
| 4-inch | A | | | 19,170 |
| | B | 4.904 | 0.452 | 21,330 |
| | C | | | 23,500 |
| 6-inch | A | | | 31,330 |
| | B | 7.000 | 0.500 | 34,830 |
| | C | | | 38,330 |
| 8-inch | A | | | 44,750 |
| | B | 9.094 | 0.547 | 49,750 |
| | C | | | 54,750 |
| 10-inch | A | | | 60,570 |
| | B | 11.190 | 0.595 | 67,330 |
| | C | | | 74,080 |
| 12-inch | A | | | 78,250 |
| | B | 13.286 | 0.643 | 86,920 |
| | C | | | 95,580 |
| 16-inch | A | | | 119,170 |
| | B | 17.476 | 0.738 | 132,420 |
| | C | | | 145,580 |
| 20-inch | A | | | 165,330 |
| | B | 21.666 | 0.833 | 183,750 |
| | C | | | 202,080 |
| 24-inch | A | | | 220,750 |
| | B | 25.856 | 0.928 | 245,250 |
| | C | | | 269,750 |
| 30-inch | A | | | 316,250 |
| | B | 32.142 | 1.071 | 351,420 |
| | C | | | 386,580 |
| 36-inch | A | | | 428,750 |
| | B | 38.428 | 1.214 | 476,420 |
| | C | | | 524,080 |
| 48-inch | A | | | 710,670 |
| | B | 51.000 | 1.500 | 789,670 |
| | C | | | 868,670 |

[a] Including bell ends and spigots.

The following table gives the dimensions and weights per lineal foot of the various sizes of cast-iron water pipe made by the Colorado Fuel and Iron Company, of Pueblo, Colorado. The thickness of each shell is calculated to withstand a hydrostatic pressure of 125 pounds per square inch.

*Dimensions and weights of cast-iron water pipe made by the Colorado Fuel and Iron Company.*

| Size (internal diameter). | Weight per foot. | Inside diameter of bell at face. | Outside diameter of bell at face. | Outside diameter at spigot. | Thickness of shell. |
|---|---|---|---|---|---|
|  | *Pounds.* | *Inches.* | *Inches.* | *Inches.* | *Inch.* |
| 3-inch | 15 | $4\frac{1}{2}$ | 7 | $4\frac{3}{8}$ | $\frac{13}{32}$ |
| 4-inch | 22 | $5\frac{1}{2}$ | $8\frac{1}{4}$ | $5\frac{3}{8}$ | $\frac{7}{16}$ |
| 6-inch | 32 | $7\frac{5}{8}$ | $10\frac{7}{8}$ | $7\frac{1}{2}$ | $\frac{1}{2}$ |
| 8-inch | 42 | $9\frac{7}{8}$ | $13\frac{3}{8}$ | $9\frac{3}{4}$ | $\frac{17}{32}$ |
| 10-inch | 62 | $11\frac{7}{8}$ | $15\frac{5}{8}$ | $11\frac{3}{4}$ | $\frac{19}{32}$ |
| 12-inch | 75 | $13\frac{3}{4}$ | $17\frac{3}{4}$ | $13\frac{5}{8}$ | $\frac{5}{8}$ |
| 16-inch | 125 | 18 | $22\frac{1}{2}$ | $17\frac{7}{8}$ | $\frac{3}{4}$ |
| 20-inch | 185 | $22\frac{1}{8}$ | $26\frac{7}{8}$ | 22 | $\frac{27}{32}$ |

## TESTING AND INSPECTING.

The defects common to cast-iron pipe are chiefly due either to the use of poor material or to bad workmanship. The essential elements in cast iron are metallic iron and a low percentage of carbon. Its quality depends to a large extent on the amount of impurities it contains. The presence of sulphur produces a hard, weak, and brittle metal. W. F. Keep states[1] that good foundry iron should contain not more than 0.15 per cent of sulphur nor more than 0.55 per cent of phosphorus. From 2 to 5 per cent of phosphorus produces a brittle metal. The same writer adds that the addition of a small amount of silicon eliminates blowholes and produces sound castings, but that an excess of silicon increases the shrinkage and hardness.

The quality of the material can best be determined by testing samples. Samples for the beam or tranverse test are usually 2 inches wide, 1 inch deep, and 24 inches between supports. Such a bar should support a weight of 2,000 pounds at the center and bend at least one-fourth inch before breaking.

The tenacity of the metal is commonly found by testing small specimens having cylindrical centers and enlarged ends. The specimen is first dressed to a known area (1 square inch) at the middle section, and is then placed in the grip blocks and pulled until broken. An average grade of iron suitable for water pipe should withstand a strain of 20,000 pounds per square inch before breaking.

A common error in the manufacture of cast-iron pipe is to remove the pipe from the flasks before it is properly cooled. Unequal cooling has been known to reduce the strength of small test samples 10 per cent. Besides, these cooling strains are very difficult to detect. It not infrequently happens that a pipe which has been tested in the proving press to 300 pounds per square inch fails when laid in the ground and subjected to bending stresses and water ram. J. Nelson Tubbs, formerly chief engineer of the Rochester waterworks, made use of a steel pick weighing about 3 pounds to test pipes for internal

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[1] See The Materials of Construction, by J. B. Johnson, p. 97.

cracks caused by unequal cooling, honeycombed shells, and other defects.

The pressure test consists in placing each length of straight pipe in a proving press and increasing the water pressure to 300 pounds per square inch. While the pipe is under pressure it is struck at different places throughout its entire length by a 3-pound hammer attached to a handle 16 inches long.

Another defect, caused by careless molding, is unequal thickness in the shell of the pipe. Heavy-sided pipes can usually be detected by placing them on horizontal skids. If any doubt exists as to the uniform thickness of the shell, the pipe should be set aside and carefully calipered. A difference of 10 per cent in the thickness of the pipe at different points should warrant its rejection. The real test, however, comes after the pipe has been laid and connected. The whole system should then be subjected to a pressure somewhat in excess of any it will likely be called upon to withstand, and this pressure should be increased rapidly and shut off quickly, in order that the pipe may be tested for the extra strain due to pressure suddenly raised and lowered.

### LAYING.

It is best to lay the outlet pipes of storage reservoirs in the natural soil, on stable, uniform beds, with wing walls of cement near the upper end and near the center, to prevent the passage of water along the outside of the pipe.

If it is necessary to lay the outlet pipe in made ground, a parabolic curve with the inner end at the vertex is perhaps the best, as the arched form increases the strength of the pipe and the subsidence of the embankment will tend to tighten the joints.

Pipe lines should be accurately located, either by transit lines or by measurements from permanent objects. The location of all fittings, valves, hydrants, etc., should also be shown on the maps. The depth of the trench depends, as a rule, on the amount of frost. In Leadville, Colorado, water pipes have frozen at a depth of 6 feet, while in California a covering of 18 inches is ample.

The pipe should be inspected while it is being removed from the cars, the weight of each length being noted, and then distributed along the trench line, with the bell ends forward. After the bottom of the trench has been reduced to a uniform grade, a hole should be dug at the place for each joint, for the reception of the bell end, and the pipe should be lowered into the trench, by means of derricks or chain falls, and calked. The practice of leading several lengths of pipe on the bank and lowering two or three lengths at a time into the trench is not to be encouraged, because the joints are often sprung in lowering and placing. In leading, a part of the vacant space in each bell surrounding the spigot is first filled with yarn or oakum, inserted by the use of a yarning tool; the remaining space is filled with lead and thoroughly calked. Narrow-edged calking tools are first used, to compact the metal at the inner edge of the lead space; these are followed by tools that nearly fill the joint.

In back filling the trench the earth should be carefully tamped beneath and at the sides of the pipe until it is about two-thirds covered. Earth bridges can then be made, to prevent flotation, and the trench partially filled with water, after which the remainder of the earth can be filled in without tamping.

In American practice the usual form of joint consists of a spigot inserted into a bell or socket and calked with yarn and lead. In Great Britain, however, and occasionally on the Continent, the turned and bored joint is still used. In this form of joint the socket is bored to a depth of 4 or more inches, the spigot end is turned to fit the socket, and after painting, the spigot end is inserted and driven into the drilled socket. Both of the dressed surfaces are slightly conical.

Owing to the hemp packing and the softness of the lead, a lead joint is much less rigid than a turned and bored joint, and conforms more readily to uneven grade lines and to expansion and contraction produced by unequal temperature. On the other hand, lead joints are more likely to leak after a sudden change in the temperature. Leaky joints are common in the spring of the year when the frost is leaving the ground. Both lead and cast iron contract in the winter and the joints remain tight, but with the advent of spring both expand, but in unequal ratios—cast iron expands nearly three times as much as lead—and leaks frequently result.

The following table gives the approximate cost of the various items in laying cast-iron water pipe. The amount of lead required for a joint depends upon the size and shape of the bell and spigot, which vary at the different manufactories; also upon the degree of water tightness desired. In the sixth column of the table is given the cost of trenching and back filling as computed by Mr. James B. Hopkins, who was for years the writer's foreman.

*Table showing cost, per lineal foot, of laying cast-iron water pipe.*

| Size (internal diameter). | Weight of filling, per joint. | | Cost of lead and oakum, per foot of pipe. | Cost of laying, per foot. | Cost of trenching and back filling, per foot. | Total cost, per lineal foot. |
|---|---|---|---|---|---|---|
| | Lead. | Oakum. | | | | |
| | *Pounds.* | *Ounces.* | | | | |
| 4-inch | 7 | 3 | $0.04 | $0.02 | $0.08 | $0.14 |
| 6-inch | 10 | 5 | 0.06 | 0.02 | 0.08 | 0.16 |
| 8-inch | 13 | 7 | 0.07 | 0.03 | 0.09 | 0.19 |
| 10-inch | 15 | 9 | 0.09 | 0.03 | 0.09 | 0.21 |
| 12-inch | 18 | 11 | 0.10 | 0.04 | 0.10 | 0.24 |
| 14-inch | 22 | 13 | 0.12 | 0.04 | 0.10 | 0.26 |
| 16-inch | 26 | 15 | 0.14 | 0.045 | 0.11 | 0.29 |
| 18-inch | 32 | 16 | 0.17 | 0.05 | 0.12 | 0.34 |
| 20-inch | 38 | 18 | 0.20 | 0.06 | 0.12 | 0.38 |
| 24-inch | 42 | 20 | 0.23 | 0.08 | 0.14 | 0.45 |
| 30-inch | 60 | 24 | 0.32 | 0.16 | 0.16 | 0.64 |
| 36-inch | 80 | 30 | 0.43 | 0.18 | 0.20 | 0.81 |

### DURABILITY.

There is, properly speaking, no substitute for cast iron as a material for water mains. Cast-iron pipe has stood the test of a century, and is now universally regarded as superior to all other pipes for the conveyance of water. Hydraulic engineers have recommended it as safe and reliable, and private and municipal corporations have purchased and laid millions of tons in the various waterworks systems of the country. It is true that substitutes have been introduced in small cities and towns of the West, where the cost of transportation is high, and while some of these substitutes have given satisfaction the majority have proved partial failures at least. On permanent streets, beneath reservoir embankments, and wherever durability is an essential element, cast-iron pipe should be used. For waterworks conduits which may soon be replaced by larger ones, and for irrigation works, there are other kinds of piping that may be preferred.

### COST.

In the Rocky Mountain States the price of cast-iron pipe has decreased from about $42 a ton in 1888 to about $30 a ton in 1898.

In the following table three different weights—light, medium, and heavy—are included. The light-weight pipe should safely withstand a static pressure of 120 pounds per square inch as well as ordinary water ram.

*Table showing cost, per lineal foot, of cast-iron pipe at $30 a ton.*

| Size (internal diameter). | Light-weight pipe. | | Medium-weight pipe. | | Heavy-weight pipe. | |
|---|---|---|---|---|---|---|
| | Weight per foot. | Price per foot. | Weight per foot. | Price per foot. | Weight per foot. | Price per foot. |
| | *Pounds.* | | *Pounds.* | | *Pounds.* | |
| 3-inch... | 14 | $0.21 | 15 | $0.23 | 17 | $0.26 |
| 4-inch... | 19 | 0.29 | 21 | 0.32 | 23 | 0.35 |
| 6-inch... | 31 | 0.47 | 35 | 0.53 | 38 | 0.57 |
| 8-inch... | 45 | 0.68 | 50 | 0.75 | 55 | 0.83 |
| 10-inch... | 61 | 0.93 | 67 | 1.01 | 74 | 1.11 |
| 12-inch... | 78 | 1.17 | 87 | 1.31 | 96 | 1.44 |
| 16-inch... | 119 | 1.69 | 132 | 1.98 | 146 | 2.19 |
| 20-inch... | 165 | 2.48 | 184 | 2.76 | 202 | 3.03 |
| 24-inch... | 221 | 3.32 | 245 | 3.68 | 270 | 4.05 |
| 30-inch... | 316 | 4.74 | 351 | 5.27 | 386 | 5.79 |
| 36-inch... | 429 | 6.44 | 476 | 7.14 | 524 | 7.86 |
| 48-inch... | 711 | 10.67 | 790 | 11.85 | 869 | 13.04 |

The cost of laying the pipe has been given in the table on page 80.

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## WATER-SUPPLY AND IRRIGATION PAPERS.

1. Pumping water for irrigation, by Herbert M. Wilson, 1896.
2. Irrigation near Phœnix, Arizona, by Arthur P. Davis, 1897.
3. Sewage irrigation, by George W. Rafter, 1897.
4. A reconnaissance in southeastern Washington, by Israel C. Russell, 1897.
5. Irrigation practice on the Great Plains, by E. B. Cowgill, 1897.
6. Underground waters of southwestern Kansas, by Erasmus Haworth, 1897.
7. Seepage waters of northern Utah, by Samuel Fortier, 1897.
8. Windmills for irrigation, by E. C. Murphy, 1897.
9. Irrigation near Greeley, Colorado, by David Boyd, 1897.
10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker, 1898.
11. River heights for 1896, by Arthur P. Davis, 1897.
12. Underground waters of southeastern Nebraska, by N. H. Darton, 1898.
13. Irrigation systems in Texas, by W. F. Hutson, 1898.
14. New tests of pumps and water lifts used in irrigation, by O. P. Hood, 1898.
15. Operations at river stations, 1897, Part I, 1898.
16. Operations at river stations, 1897, Part II, 1898.
17. Irrigation near Bakersfield, California, by C. E. Grunsky, 1898.
18. Irrigation near Fresno, California, by C. E. Grunsky, 1898.
19. Irrigation near Merced, California, by C. E. Grunsky, 1899.
20. Experiments with windmills, by Thomas O. Perry, 1899.
21. Wells of northern Indiana, by Frank Leverett, 1899.
22. Sewage irrigation, Part II, by George W. Rafter, 1899.
23. Water-right problems of Bighorn Mountains, by Elwood Mead, 1899.
24. Water resources of the State of New York, Part I, by George W. Rafter, 1899.
25. Water resources of the State of New York, Part II, by George W. Rafter, 1899.
26. Wells of southern Indiana (continuation of No. 21), by Frank Leverett, 1899.
27. Operations at river stations, 1898, Part I, 1899.
28. Operations at river stations, 1898, Part II, 1899.
29. Wells and windmills in Nebraska, by Erwin Hinckley Barbour, 1899.
30. Water resources of the Lower Peninsula of Michigan, by Alfred C. Lane, 1899.
31. Lower Michigan mineral waters, by Alfred C. Lane, 1899.
32. Water resources of Puerto Rico, by H. M. Wilson, 1900.
33. Storage of water on Gila River, Arizona, by J. B. Lippincott, 1900.
34. Geology and water resources of southeastern South Dakota, by J. E. Todd, 1900.
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36. Operations at river stations, 1899, Part II, 1900.
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39. Operations at river stations, 1899, Part V, 1900.
40. The Austin dam, by Thomas U. Taylor, 1900.
41. The windmill: its efficiency and economic use, Part I, by E. C. Murphy, 1901.
42. The windmill: its efficiency and economic use, Part II, by E. C. Murphy, 1901.
43. Conveyance of water in irrigation canals, flumes, etc., by Samuel Fortier, 1901.

In addition to the above, there are in various stages of preparation other similar papers. Provision has been made for printing these by the following clause in the sundry civil act making appropriations for the year 1896–97:

"*Provided*, That hereafter the reports of the Geological Survey in relation to the gaging of streams and to the methods of utilizing the water resources may be printed in octavo form, not to exceed 100 pages in length and 5,000 copies in number; 1,000 copies of which shall be for the official use of the Geological Survey, 1,500 copies shall be delivered to the Senate, and 2,500 copies shall be delivered to the House of Representatives, for distribution." [Approved June 11, 1896; Stat. L., vol. 29, p. 453.]

The endeavor is made to send these pamphlets to persons who have rendered assistance in their preparation through replies to schedules or who have furnished data. Requests made for a certain paper and stating a reason for asking for it are granted whenever practicable, but it is impossible to comply with general demands, such as to have all of the series sent.

Application for these papers should be made either to Members of Congress or to

THE DIRECTOR, UNITED STATES GEOLOGICAL SURVEY, WASHINGTON, D. C.

### 1895.

Sixteenth Annual Report of the United States Geological Survey, 1894-95, Part II, Papers of an economic character, 1895; octavo, 598 pp.

Contains a paper on the public lands and their water supply, by F. H. Newell, illustrated by a large map showing the relative extent and location of the vacant public lands; also a report on the water resources of a portion of the Great Plains, by Robert Hay.

A geological reconnoissance of northwestern Wyoming, by George H. Eldridge, 1894; octavo, 72 pp. Bulletin No. 119 of the United States Geological Survey; price, 10 cents.

Contains a description of the geologic structure of portions of the Big Horn Range and Big Horn Basin, especially with reference to the coal fields, and remarks upon the water supply and agricultural possibilities.

Report of progress of the division of hydrography for the calendar years 1893 and 1894, by F. H. Newell, 1895; octavo, 176 pp. Bulletin No. 131 of the United States Geological Survey; price, 15 cents.

Contains results of stream measurements at various points, mainly within the arid region, and records of wells in counties in western Nebraska, western Kansas, and eastern Colorado.

### 1896.

Seventeenth Annual Report of the United States Geological Survey, 1895-96, Part II, Economic geology and hydrography, 1896; octavo, 864 pp.

Contains papers on "The underground water of the Arkansas Valley in eastern Colorado," by G. K. Gilbert; "The water resources of Illinois," by Frank Leverett, and "Preliminary report on the artesian waters of a portion of the Dakotas," by N. H. Darton.

Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896; octavo, 230 pp., 19 plates. Bulletin No. 138 of the United States Geological Survey; price, 20 cents.

Gives a description of the geologic conditions of the coastal region from Long Island, N. Y., to Georgia, and contains data relating to many of the deep wells.

Report of progress of the division of hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge, 1896; octavo, 356 pp. Bulletin No. 140 of the United States Geological Survey; price, 25 cents.

Contains a description of the instruments and methods employed in measuring streams and the results of hydrographic investigations in various parts of the United States.

### 1897.

Eighteenth Annual Report of the United States Geological Survey, 1896-97, Part IV, Hydrography, 1897; octavo, 756 pp.

Contains a "Report of progress of stream measurements for the calendar year 1896," by Arthur P. Davis; "The water resources of Indiana and Ohio," by Frank Leverett; "New developments in well boring and irrigation in South Dakota," by N. H. Darton, and "Reservoirs for irrigation," by J. D. Schuyler.

### 1899.

Nineteenth Annual Report of the United States Geological Survey, 1897-98, Part IV, Hydrography, 1899; octavo, 814 pp.

Contains a "Report of progress of stream measurements for the calendar year 1898," by F. H. Newell and others; "The rock waters of Ohio," by Edward Orton, and "A preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian," by N. H. Darton.

Part II of the Nineteenth Annual contains a paper on "Principles and conditions of the movements of ground water," by F. H. King, and one on "Theoretical investigation of the motion of ground waters," by C. S. Slichter.

### 1900.

Twentieth Annual Report of the United States Geological Survey, 1898-99, Part IV, Hydrography, 1900; octavo, 660 pp.

Contains a "Report of progress of stream measurements for the calendar year 1898," by F. H. Newell, and "Hydrography of Nicaragua," by A. P. Davis.

### WATER-SUPPLY AND IRRIGATION PAPERS, 1896-1900.

This series of papers is designed to present in pamphlet form the results of stream measurements and of special investigations. A list of these, with other information, is given on the outside (or fourth) page of this cover.

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