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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 376

Washington, D. C. ▼ Issued November 25, 1916
Revised October, 1925

# THE FLOW OF WATER IN WOOD-STAVE PIPE

By

**FRED. C. SCOBEY, Irrigation Engineer**
**Bureau of Public Roads**

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## INTRODUCTION.

During the past 10 or 15 years the use of wood pipe for the conveyance of water has been greatly increased. Such pipe is now quite commonly used to convey water for the irrigation of land, the domestic needs of towns and cities, and the development of power. So long as wood pipe consisted of bored logs its carrying capacity was limited to a small flow and its adaptation to a limited set of conditions, but the conversion of clear, sound lumber into staves and the making of stave pipe into sizes from 12 to 72 inches in diameter led to a great expansion in both carrying capacities and uses. More recently it has been found that stave pipe can be successfully built

NOTE.—This bulletin treats of the subject of flowing water in wood-stave pipes. It is based on field tests made on pipes in commercial operation. New formulas are developed that more accurately fit all known data than any others now used. This publication is offered for use of engineers designing and measuring wood-stave pipes for irrigation, power, municipal, mining, or other purposes and for courts and attorneys at law interested in cases involving the carrying capacities of wood-stave pipes. As revised this bulletin contains all data bearing on capacity of wood-stave pipe that have been brought to the attention of the writer up to October, 1925.

and operated in sizes up to 12 and 13 feet in diameter, the largest to date being 13½ feet. This great increase in size and carrying capacity has been brought about by providing yokes or cradles which support the lower part of the pipe and thus prevent its collapse.

Being well adapted to low heads and large diameters, such pipe has proved one of the best and cheapest means of conducting large volumes of water under low or medium heads from the sources of supply to the places of use, regardless of whether the latter be a power plant, a storage reservoir, the highest portion of an irrigated tract, or the distributing reservoir of a municipality. Stave pipe is also frequently used in the construction of inverted siphons, so called, in conjunction with canals and grade pipe lines, to convey water across gulches, ravines, or other depressions or down chute drops to lower levels. It is likewise well adapted to rolling ground where the building of canals on grade might be impracticable. Finally, in the smaller sizes it is often used to convey and distribute water to orchard tracts, manufacturing plants, and municipalities.

The present economic importance of stave pipe in this country, which arises from its adaptation to so many diverse uses, its wide range of capacities, the ease with which it can be laid on rough ground, and its cheapness when compared with other pressure pipes, has led this department to investigate and report upon its merits and demerits. About three years ago a study was begun which comprised the types, materials, methods of construction, and durability of wood pipe. The results of this study were summarized in a recent department bulletin.[1] During the past two years another phase of the same general subject has been investigated. This investigation has included the making of tests and the collection of data on the flow of water in wood-stave pipe, the results of which are embodied in this report. Field work during the summer seasons of 1914 and 1915 consisted in the performance of 64 experiments on the flow of water in wood-stave pipes ranging in diameters from 8 inches to 13½ feet, while the office work consisted in the collection and analysis of available records of all previous experiments of a similar character and the preparation of the data herein presented. From the results of all experiments made, which combined reach a total of 286, there has been deduced a new set of formulas for the flow of water in stave pipe which is here presented. (See p. 48.)

In another publication [2] the writer has endeavored to show that Kutter's formula is applicable to the design of any open channel and that the recommendations of the earlier writers on this subject concerning the values of $n$ (which comprises all the influences retarding

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[1] Wood Pipe for Conveying Water for Irrigation, by S. O. Jayne, Bulletin 155, U. S. Department of Agriculture.

[2] The Flow of Water in Irrigation Channels, by Fred. C. Scobey, Bulletin 194, U. S. Department of Agriculture.

the flow) were in the main correct. But a thorough study of the flow of water in pipes, and more particularly wood-stave and concrete pipes, has convinced him that Kutter's formula is not best adapted to flow through pipes running full and under pressure. The work of recent experimenters indicates that the exponential type of formula is best adapted to such flow. Therefore the new formula is of the exponential type.

Much uncertainty has existed in the minds of hydraulic engineers during the past 30 years with regard to the carrying capacities of stave pipe. If the new formula helps to clear up former uncertainties and give to those engaged in the design and operation of stave pipes a reliable guide by which to determine flow through such conduits, it will have served its purpose.

## NOMENCLATURE.

Unless otherwise noted, the various symbols used throughout this publication will have the following significance:

d—The mean inside diameter of the pipe in inches.
D—The mean inside diameter of the pipe in feet.
r—The mean inside radius of the pipe, or $\frac{1}{2}$D, in feet.
Q—The mean discharge of the pipe, during the test, in second-feet.
A—The mean area of the pipe bore, in square feet, $=\pi r^2$.
V—The mean velocity of the water, during the test, in feet per second.
L—The length of reach tested, in feet.
$h_f$—The head of elevation lost in overcoming internal resistances within a fairly straight pipe of uniform size, in feet, $=\frac{HL}{1000}$.
H—The above loss (termed friction loss) per 1,000 linear feet of pipe, $=\frac{1000\,h_f}{L}$.
$h_v$—The head of elevation lost in creating the mean velocity, V, in feet. Called velocity head.
$h_v'$—The velocity head recovered as the velocity is reduced at the pipe outlet, in feet.
$h_e$—The head of elevation lost at a pipe intake due to impact and entrance resistances, in feet, here called entry head.
P—The wetted perimeter; in a pipe under pressure, the inside circumference, $=\pi D$ or $2\pi r$, in feet.
R—The hydraulic radius, $=\frac{A}{P}$; in a circular pipe, under pressure, $=\frac{D}{4}$.
s—The hydraulic grade or slope, in feet per foot of length of a pipe of uniform size, $=\frac{h_f}{L}$.
n—The coefficient of retardation in Kutter's formula.
C—The coefficient of retardation in Chezy's formula.
$C_w$—The coefficient of retardation in the Williams-Hazen formula. Not to be confused with C in the Chezy formula.
f—The coefficient of retardation in the Weisbach formula. (This formula is variously known as Weisbach's, Weston's, Darcy's, and Chezy's.) (See p. 6.)
$H=m\,V^z$.—The general equation for the flow of water in a pipe, in which m is the intercept on the vertical axis and z is the slope of the line, expressed on logarithmic paper as the tangent of the angle between the line and the horizontal axis. (See equation 17, p. 49.)

$m=K d^x$.—The equation for the variation in m for a series of pipes of various sizes but with the same characteristics; K is the intercept on the vertical axis, and x is the slope of the line, when values of m are plotted as ordinates and values of d as abscissæ on logarithmic paper. (See equation 19, p. 49.)

$m'$—The special values of m found for each series of pipes, by drawing lines from the centers of gravity for the observations in each series, at a constant slope, to an intersection with the vertical axis, all plotting being on logarithmic paper.

No. —.—Wherever a pipe number is given, the reference is to the corresponding number in Tables 2 and 3, to Plate VII, and to the description of the pipe under that number.

## FORMULAS FOR FLOW OF WATER IN WOOD-STAVE PIPE.

Water is caused to flow and velocity created by the force of gravity. Thus the flow follows the general law of falling bodies, and the velocity tends to become constantly accelerated. This tendency is just balanced by the influences retarding the flow. For a pipe carrying flowing water under pressure, the difference in elevation, $H_E$

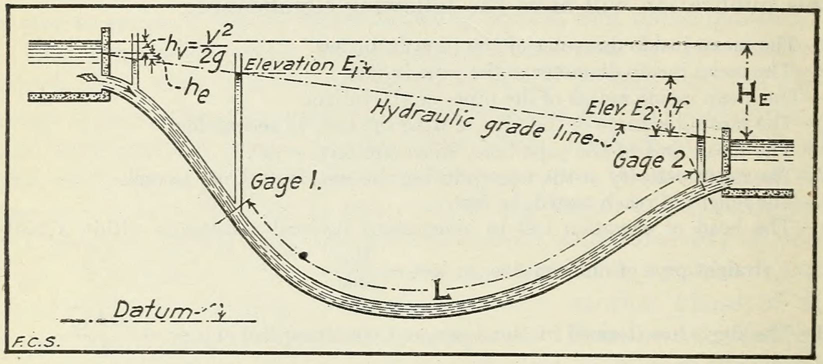


FIG. 1.—Hydraulic elements for loss of head in siphon pipe.

(fig. 1), between the surfaces of the water at the intake and outlet is the effective head through which the force of gravity acts. The effective or lost head is made up of several individual losses as follows (fig. 1):

$$\text{Velocity head} = h_v = \frac{V^2}{2g}. \tag{1}$$

This is the head absorbed in creating the mean velocity V, at which the water is conveyed through the pipe. This loss occurs at the intake.

As a rule, little or none of this velocity head is recovered at the outlet of the pipe. The conditions under which recovery may be expected are discussed on page 61.

$$\text{Entry head, } h_e = \frac{h_v}{2} \text{ (approximately).} \tag{2}$$

The amount of loss at the entry, due to the effect of contraction eddies and other retarding influences, is variable and uncertain, but most authorities agree that it should be taken as half the velocity head unless the inlet structure is especially designed to minimize this loss. For further discussion see page 59.

Friction head, $h_f$, is that lost in overcoming the retarding influences within a reasonably straight pipe. In pipes of great length, the amount of this loss so far exceeds the two losses first mentioned that they may often be neglected, especially in small pipes. This is the loss upon which the experiments described in this paper were concentrated. Apart from all other losses of head it must be found in order to permit solution of the various formulas for the flow of water in pipes with the view to securing additional values for the factor representing the retarding influences designated as friction.

In addition to the above losses, there may be others, such as those due to bends and valves or other obstructions; but, as a general thing, these items do not enter the design of wood-stave pipes, especially for irrigation purposes. In this use the pipe is laid on such gentle curves, both horizontal and vertical, that such losses need not be considered. Valves are seldom set across the line of the pipe, although there are often one or more valves of various sizes leading from the pipe. The loss in the main line due to these valves is also negligible compared with the friction and velocity head losses.

In 1775, Chezy, a French engineer, offered his now well-known formula for the flow of water in both open channels and closed conduits:

$$V = C\sqrt{Rs}. \tag{3}$$

Here C is a coefficient, originally thought to be constant, but now known to vary with functions of the slope, the hydraulic radius, the velocity, and with some factor representing the retarding influences in the channel. Many of the formulas used in this country for the design of pipes have accepted the Chezy formula as a basis and made only such modifications as experience dictated, some of them merely assigning definite values to the coefficient C for definite conditions of velocity, roughness, and size of pipe.

Since the hydraulic elements secured in the field experiments furnish the necessary data for the determination of the factor representing the retarding influences in all the formulas most used in this country, this publication will show this factor as developed by field tests for several formulas as follows:

(*a*) The Chezy formula, 3,

$$V = C\sqrt{Rs} = CR^{0.5}s^{0.5} \tag{4}$$

(*b*) The Kutter modification of the Chezy formula,

$$V=\left\{\frac{\frac{1.811}{n}+41.66+\frac{0.00281}{s}}{1+\left(41.66+\frac{0.00281}{s}\right)\frac{n}{\sqrt{R}}}\right\}\sqrt{Rs} \qquad (5)$$

in which C is elaborated so that it takes into consideration the influence of the hydraulic grade and of the mean hydraulic radius and introduces a new variable, *n*, which is supposed to represent all the retarding influences.

(*c*) The Weisbach formula,

$$h_f=f\frac{LV^2}{2Dg} \qquad (6)$$

From the same field data comparison is made between the following formulas:

(*d*) The Tutton [1] formula for flow in wood-stave pipes,

$$V=C_1R^{0.66}s^{0.51} \text{ with } C_1=129 \qquad (7)$$

$C_1$ in this formula is not to be confused with C in the Chezy formula.

(*e*) The Williams-Hazen general formula [2] for many kinds of pipes

$$V=C_wR^{0.63}s^{0.54}\ 0.001^{-0.04} \qquad (8)$$

which may be arranged in the same form as formulas 9 and 12 for comparison, becoming, with $C_w=120$,

$$H=\frac{.427\ V^{1.852}}{D^{1.167}} \qquad (8a)$$

For wood-stave pipe a value for $C_w$ of 120 is recommended by Williams and Hazen. This recommendation is based on their study of pipes Nos. 20, 41, 44, 47, and 48, Tables 2 and 3. The exponents of the formula "were selected as representing as nearly as possible average conditions, as deduced from the best available records of experiments upon the flow of water in such pipes and channels as most frequently occur in waterworks practice."

(*f*) The Moritz formulas:[3]

$$H=\frac{8.6\ V^{1.8}}{d^{1.26}}=\frac{0.38\ V^{1.8}}{D^{1.26}} \qquad (9)$$

$$V=1.72\ D^{0.7}\ H^{0.555} \qquad (10)$$

$$Q=1.35\ D^{2.7}\ H^{0.555} \qquad (11)$$

These three formulas express the same values from different points of view. Unlike formulas 4, 5, and 6, they were developed

[1] Tutton, C. H. Journal Assoc. Engin. Socs., 23 (1899), p. 151.
[2] Hydraulic Tables, Williams and Hazen, 2d ed. New York, 1909.
[3] Flow of water in pipes, E. A. Moritz, Eng. Rec., 68, No. 24, p. 667.

from an extensive series of experiments on wood-stave pipe from 4 to 55¾ inches in diameter and were offered for use on wood-stave pipe only either jointed or continuous.[1]

In the development of formulas 9, 10, and 11 Moritz used only his own experiments on the pipes as indicated on Plate VII, rejecting all prior tests by other experimenters.

(*g*) A new set of formulas is offered by the writer, based on all experiments on round stave pipe known to him from description in engineering literature, and supplemented by an extensive set of experiments in which he was aided by Ernest C. Fortier. The method used in developing these formulas is explained on page 50. Hereafter any one of this set of formulas will be referred to as the new formula. Arranged in the same order as the Moritz formulas for comparison:

$$H=\frac{7.68\ V^{1.8}}{d^{1.17}}=\frac{0.419\ V^{1.8}}{D^{1.17}} \qquad (12)$$

$$V=1.62\ D^{0.65}\ H^{0.555} \qquad (13)$$

$$Q=1.272\ D^{2.65}\ H^{0.555} \qquad (14)$$

It is to be noted that the exponent of V in formulas 9 and 12 is the same, as is also the exponent of H in formulas 10–11 and 13–14. The difference in the formulas is caused by the wide divergence in the intercept curves shown in figure 4 (p. 56). As indicated in these curves, the difference becomes greater as the larger pipes are approached, for the reason that all weight for large pipes in the Moritz formulas came from his tests on the 55¾-inch Mabton pressure pipe (Nos. 45 and 46), and the position of the points representing the intercepts for this pipe, in figure 4, indicates that this pipe was abnormally smooth.

Referring to formula 8a, it will be seen that the exponent of D in the new formula is almost identical with the exponent of D in the converted Williams-Hazen formula and that it follows the suggestion of Schoder:[2] "If the attempt is made to lump all pipes except the very smooth ones and the small tuberculated ones, giving thereby more weight to large rough pipes and ordinary lap-riveted pipes, then m will be found to vary inversely about as $D^{1.15}$ to $D^{1.20}$."

## TREND OF ENGINEERING THOUGHT REGARDING THE CARRYING CAPACITY OF WOOD-STAVE PIPES.

The ideas of the engineering profession concerning the carrying capacity of wood pipe, expressed as direct statements or as formulas, have varied widely during the past 20 years. Wood-stave pipe enters into direct competition with iron and steel pipe. The claim

[1] For details of these experiments see Trans. Amer. Soc. Civ. Engin., 74 (1911), p. 411.

[2] Friction Head Hydraulics and Pipe Flow Diagrams, Ernest W. Schoder, Cornell Civil Engineer, May, 1910.

has persisted that there is less friction in wood pipe than in metal pipe. It has often been insisted that new wood pipe not only has a higher carrying capacity than new metal pipe but that the wood pipe becomes smoother with age, while it is a well-known fact that metal pipe becomes rougher. (See discussion, p. 72.)

While the analysis of all the tests on wood pipe now available bears out the above claims in a general way (excepting that wood pipe is not shown to become smoother with age), yet the consideration of tests on individual pipes led to hasty conclusions presently shown to be greatly at variance with facts. The following ideas of hydraulicians have been extracted by the writer from all the literature on the subject known to him:

The experiments of Darcy and Bazin in 1857 and 1859 (Nos. 22 and 33) and of Clarke in 1884 (No. 49) were considered but little in later discussions for the reason that they were made on rectangular rather than on round pipe. Smith's test (No. 1), made in 1877, has also not been considered in the discussion of wood pipe, as the test was made on a bored pipe of very small caliber; yet these four series supplied the data upon which Tutton based his formula. (See p. 50.)

Although none of the 81 tests considered by Kutter and his colleague in developing the Kutter formula had been made on closed channels running full, yet nearly all of the experimenters on wood-stave pipe have determined for their tests the value of $n$ in this formula. Kutter's formula has undoubtedly been used a great deal in estimating the capacity of wood pipes, but the writer will endeavor to show (p. 56) the fallacy of employing a constant value of $n$ in this formula and the advantages lying in a formula of the exponential type.

The first experiment of public record was mentioned by the late J. D. Schuyler [1] in speaking of a test (No. 34) on the newly installed 30-inch pipe for Denver, but unfortunately he did not give sufficient details by which the test might be weighed. Mr. Schuyler states that "as low a coefficient of $n$ as 0.0096 can be used." This appeared reasonable, as the pipe was made of planed lumber and all lists of proper values of $n$ then published recommended a value of 0.009 for such material. The earlier designers adopted a value of 0.010 "in order to be conservative."

The next tests were made by A. L. Adams [2] on the Astoria, Oreg., 18-inch pipe (No. 23). Here, too, a low value of $n$ was found, 0.00985, which led Adams to observe "that the value of 0.010 for $n$ used by many engineers in dealing with stave pipe, is here found to be practically correct." The low value of the friction factor found in this

[1] Trans. Amer. Soc. Civ. Engin., 31 (1894), p. 144.
[2] Trans. Amer. Soc. Civ. Engin., 36 (1896), p. 26.

test is the more remarkable in view of the fact that there are "in addition to a succession of sweeping horizontal and vertical curves, 27 cast-iron bends with a radius of curvature of 5 feet, and with an average central angle of about 31°." (See Pl. XIV, fig. 1.)

The next test (No. 32), spoken of by F. B. Gutelius,[1] was conducted by D. C. Henny[2] on the Butte, Mont., 24-inch pipe in 1892. In this test the value of $n$ was found to be 0.0103. Here again was a value so close to 0.010 that it tended to establish the fact that 0.010 was, closely, the proper value. After these three tests by three different experimenters an extensive series of tests would naturally be required to convince the profession that a higher value of $n$ should be used. Attention may here be directed to the fact, however, that in the three last-mentioned tests but one or two runs of water, with little or no variation in velocity, had been observed.

In 1897 Profs. Marx, Wing, and Hoskins[3] of Leland Stanford Junior University, made a careful and vastly more extensive series of tests than any previously carried through (No. 47). The values of $n$ varied inconsistently between 0.010 and 0.0204. (See Table 2, column 10.) Of the 22 runs in this series, all but one showed a value of $n$ above 0.0123, and most of them showed it above 0.013.

The experimenters did not publish their results as values of $n$, merely stating:[4]

In regard to the applicability of Kutter's formula it is to be said that the experiments on the wooden pipe herein described give values of $n$ ranging from 0.012 to 0.015, an average value being perhaps 0.013. The difference between this value and those given for the Denver and Butte city conduits can hardly be attributed to the greater roughness of the Ogden pipe. It is rather to be supposed that the Kutter formula is defective. (See p. 56.)

In correspondence relating to these tests T. A. Noble offers the values of $n$ for the various observations.[5] These have been checked by the writer and are found in Table 2, column 10. In the same correspondence (p. 544) A. L. Adams offers his tests on the West Los Angeles pipe (No. 20) where the values of $n$ range from 0.0105 to 0.0111. Mr. Adams voices the following warning:

These values * * * do not indicate 0.01 as being a safe assumed value for $n$ as have all previous experiments.

Various arguments were brought forward to furnish a reason for the unprecedentedly high values of $n$ in the Ogden pipe. These included the following: That Kutter's formula did not apply to pipes as large as 6 feet in diameter; that sediment had deposited in the pipe; that the nominal area was not the true area; that a constant reduction factor should not be used in computing the equivalent water column from the mercury column.

[1] Journal Assoc. Engin. Socs., 12 (1893), p. 219.
[2] Journal Assoc. Engin. Socs., 21 (1898), p. 250.
[3] Trans. Amer. Soc. Civ. Engin., 40 (1898), p. 471.
[4] Id., p. 516.
[5] Id., p. 547.

In 1899 the same experimenters made additional tests (No. 48) upon the same pipe with improved apparatus.[1] Their experiments were centered on a longer reach of pipe and a consistent set of values of $n$ was obtained, ranging from 0.0130 to 0.0133.

The trend of the discussion of the second Ogden tests shows that a general belief existed to the effect that the difference in the values of $n$, when compared with $n$ for smaller pipes, was due to defects in the Kutter formula.

A graphic presentation of the data then available was made on ordinary squared cross-section paper. In the discussion a method was offered for testing the correctness of experimental data by the use of this paper, "if the loss of head varies as the square of the velocity."[2] Although as long ago as 1808, Dr. Thomas Young[3] suggested that the loss of head was in proportion to the 1.8 power of the velocity, rather than the second power, many still insisted that loss of head must vary as the square of the velocity. It is interesting to note that 1.8 is the exact exponent found by both Moritz and the writer, while Williams and Hazen use an exponent of 1.85 in their general formula for flow in many kinds of pipes.

In 1901 T. A. Noble[4] contributed greatly to the available knowledge by making tests on 44½-inch and 54-inch pipes (Nos. 41 and 44), thus bridging the gap between 30-inch and 72-inch pipes. For both these pipes the values of $n$ ranged from 0.0120 to 0.0136, with the higher values in the smaller pipe, although the same water flowed through both pipes and they were constructed at the same time. Also, strange to say, the pipe with the lower value of $n$ contained more curvature and growths of *Spongilla* which were not present in the smaller pipe. Noble says:[5]

> The writer can offer no suggestion as to why the value of C should be less and $n$ greater in the 44-inch than in the 54-inch pipe, when, to conform to the results of other experiments, it should be the reverse.

In discussing the available data on this subject,[6] E. W. Schoder of Cornell University suggests the possibilities of an exponential formula derived from a study of the straight-line curves resulting when the losses of head are platted on logarithmic paper as ordinates and the velocities as abscissas. This was the method used later by Moritz in deriving his formula, and also by the writer as being the best known form by which to study the now extensive number of tests upon wood pipe.

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[1] Trans. Amer. Soc. Civ. Engin., 44 (1900), p. 34.
[2] Id., p. 73.
[3] Philosophical Trans., Royal Society of London (1808).
[4] Trans. Amer. Soc. Civ. Engin., 49 (1902), p. 112.
[5] Id., p. 143.
[6] Id., p. 145.

Gardner S. Williams[1] says:

One of the most interesting features of the investigation is the light it throws upon the inapplicability of the long-honored law that loss of head varies as the square of the velocity.

He offers the deductions, based on the study of more than 80 series of tests by 13 observers, that the exponent increases from 1.80 to 2 in pipes ordinarily used by engineers; that it increases as the roughness increases; that it decreases as curvature increases, and that it is different for different materials, being lowest for tin and brass.

After the Noble tests nothing was offered in engineering literature until J. L. Campbell[2] made tests on the El Paso & Southwestern Railway pipe (Nos. 15 and 21). The values of $n$ were so low that the results were seized upon by some wood pipe manufacturers and given out broadcast as the values of $n$ to apply to wood pipe. These values showed an enormously greater carrying capacity for wood than for iron or steel pipe. The results are unquestionably too low for the following reasons: In the discussion G. E. P. Smith[3] asks, "Was the first appearance or the average time of appearance, accepted for computing the velocity of flow?" to which Campbell replies (p. 188), "Referring to Mr. Smith's question about the velocity measurements by bran, the *first* appearance of the bran and the colors was taken because the intervals of time given thereby were in close accord among themselves and with the weir measurements." (Italics are the writer's.)

In the opinion of the writer, who used color for many of his experiments (see p. 23), the mean of the first and last appearance of color comes quite close to the true mean. (See also the article by E. W. Schoder in the Cornell Civil Engineer, December, 1911.) If the first indication of color is taken, then the maximum thread of velocity is used; or, if diffusion in addition to mechanical mixing occurs, a velocity in excess of the true maximum is indicated. No one would suggest accepting as the average the velocity of a float down the maximum current in an open channel without applying a coefficient which varies from about 0.55 to 0.95. The fact mentioned by Mr. Campbell, that the "intervals * * * were in close accord among themselves," proves nothing but consistency. Regarding the agreement with the weir it should be remembered that this device gives discharge; color and bran tests give velocity. To permit comparison with the results of weir tests the velocity must be multiplied by the area of the bore. If the velocity as determined by the colors were taken too high and the assumed area of the bore too low,

[1] Trans. Amer. Soc. Civ. Engin., 49 (1902), p. 155.

[2] Engin. News, 60 (1908), p. 225. Trans. Amer. Soc. Civ. Engin., 70 (1910), p. 178.

[3] Trans. Amer. Soc. Civ. Engin., 70, p. 186.

the results might still agree with a weir test quite closely and yet include an error as to the velocity.

The writer dwells on this discussion for the reason that he has before him three catalogues of prominent pipe makers, each of which claims a very high efficiency for wood pipe (to the consequent disparagement of iron and steel pipe), basing this claim on one questionable series of tests and ignoring the other tests mentioned above for the probable reason that the most of the latter show the capacities of wood and new iron pipe to be more nearly the same.

In 1911 E. A. Moritz[1] offered the results of experiments which were quite complete between pipes 4 inches and 22 inches in diameter, with a gap then to one pipe 55¾ inches in diameter. He used much the same methods (in fact, much of the same equipment) which were used on the Ogden tests.

Rejecting all previous experiments and his own series on the 22-inch pipe (No. 28), Moritz developed the formulas given on page 6. This left a very complete set of experiments between 4 and 18 inches but with a gap from 18 to 55¾ inches. The positions of platted points for the 55¾-inch pipe (Nos. 45 and 46) shown on Plates VI and VII, when compared with corresponding points for other pipes, all indicate that this pipe was exceptionally smooth. So much weight was given the tests on this pipe, being the only tests on large pipe which were accepted, that the formulas derived from the experiments indicate a greater carrying capacity for wood pipe generally and large diameter wood pipe particularly than a study of all tests shows to be warranted.

In the discussion of Moritz's article, R. G. Dieck writes:

> The use of the Kutter formula in pipe design has always been questionable, even though its ease of application, in default of a more convenient formula, has commended it * * *. It is evident from the Sunnyside experiments that an adjustment in the ideas of hydraulicians on this point is bound to come. * * * When the discharge varies, all other conditions being the same, the value of $n$ also varies; hence in its present form, the Kutter formula can not be considered a true statement of conditions.[2]

In the same discussion[3] Rudolph Hering states that he "recognized as well as did Mr. Kutter himself, almost at the outset, that $n$ was not to be considered a precise and unvarying constant." The writer will take up the comparison between the Kutter and the new exponential formula later (p. 56).

In the same discussion Gardner S. Williams objects to the inconsistency of the profession in introducing inches into a formula otherwise expressed in feet and decimals. The writer agrees in this, but the manufacture of iron, steel, clay, and wood pipe has been so long

[1] Trans. Amer. Soc. Civ. Engin., 74 (1911), p. 411. [2] Id., p. 452. [3] Id., p. 459.

conducted on these units that it appears best to construct separate formulas with terms in both inches and feet.

Also in the same discussion[1] J. S. Moore, who aided in the experiments and computation of the Moritz data, offers tests on 48¾ and 31-inch pipes (Nos. 43 and 36). The 48¾-inch pipe appears to have been very smooth and the tests confirm the Moritz formulas. However, it must be borne in mind that this pipe is part of the same siphon and subject to the same conditions as those affecting the 55¾-inch pipe which contributed so largely to the data from which the Moritz formulas were derived. Advocating the use of all previous data accepted as criteria, Moore suggests the intercept line for the exponential formula as shown by the dash line in figure 4. This line approaches the position of the intercept line for the new formula which considers all reliable data.

## RECAPITULATION.

The above outline indicates that 25 years ago Kutter's formula, with a value of $n$ of 0.010, was accepted as accurate in the design of wood pipes. As tests were made on larger sizes of pipe, higher values of $n$ were found. These results were not accepted unreservedly, however; rather were the experiments discredited by some designers on the grounds that conditions in the pipes were not properly ascertained or that methods of making observations were erroneous. The experimenters themselves suggest that perhaps a constant value of $n$ should not be used; that is, that Kutter's formula does not apply if a constant value of $n$ is to be taken. The data were too meager to develop the variation in $n$ with the diverse elements.

As data accumulated authorities suggested interpreting results by exponential formulas; but not being well known this method was not extensively accepted until used by Moritz in interpreting his own results. He attempted to compare his formulas with the results of other experimenters but found this "a difficult and discouraging problem." This was true because all previous data on large pipes showed a much smaller relative capacity than the *one* pipe contributing so largely to his formulas. Though but tentatively offered by Moritz, his formulas appeared to be the best available and have been extensively accepted, in spite of the fact that Moore, who was perfectly familiar with the Moritz tests, suggests a formula that more nearly fits all previous observations.

In the following pages of this publication, particularly beginning on page 28, the writer will endeavor to show analytically the following:

1. That an exponential formula most nearly applies to the flow of water in wood-stave pipes.

[1] Trans. Amer. Soc. Civ. Engin., 74 (1911), p. 463.

2. That the mean of all reliable observations on carrying capacity of wood-stave pipes agrees with the exponential formulas in the following order and per cent (see Table 9):

| | Per cent. |
|---|---|
| 1. Scobey | +0.19 |
| 2. Williams-Hazen [1] | +4.7 |
| 3. Tutton | +3.6 |
| 4. Moritz | −9.4 |

3. That the mean of the capacities of the several pipes agrees with the exponential formulas in the following order and per cent (see Table 3):

| | Per cent. |
|---|---|
| 1. Scobey | +1.29 |
| 2. Williams-Hazen | +4.96 |
| 3. Tutton | +7.25 |
| 4. Moritz | −7.72 |

4. That Kutter's formula with a constant value of $n$ does not apply to flow in wood-stave pipes running full.

5. That $n$ decreases with an increase in velocity in a given size of pipe and increases with the size of pipe for a given velocity, varying from less than 0.010 for small pipes at high velocities to more than 0.014 in large pipes.

6. That this variation in $n$ is so marked and complicated as to render the use of Kutter's formula inadvisable.

7. That the Ogden experiments showed the capacity of the 72-inch pipe (Nos. 47 and 48) to be within from 5 to 8 per cent of the average.

8. That the Sunnyside experiments showed the 55¾-inch pipe (Nos. 45 and 46) to be abnormally smooth by 18 per cent.

## NECESSARY FIELD DATA FOR DETERMINING THE RETARDATION ELEMENTS OF VARIOUS FORMULAS.

A glance at pages 5 to 7 shows that for study of the various formulas the same hydraulic elements must be determined by field tests. These are:

1. The mean velocity, V, of water in the pipe.

2. The loss of head, $h_f$, due to retardation in a section of pipe of uniform size, within a known distance.

3. The internal size of pipe, D or d.

The above data having been secured, the observed velocity for any particular observation may be compared with the computed velocity for the same-sized pipe with the observed loss of head, for any of the formulas.

### MEAN VELOCITY OF WATER.

The velocity of the water flowing in a section of wood-stave pipe may be measured in two general ways:

[1] Using coefficient of 120 in Williams-Hazen formula.

1. Directly, by timing a given volume of water through a known distance.

2. Indirectly, by measuring the discharge of the pipe, thus determining the quantity, Q, and solving the equation $V = \frac{Q}{A}$.

Where the velocity is tested by the direct method the error is smaller than where the indirect method is used.

### LOSS OF HEAD DUE TO RETARDATION.

Most of the recent experiments on the flow of water in pipes of uniform size have been made with piezometer columns. This was the method used by the writer. If a piezometer (fig. 1) be properly attached to the pipe, the pressure in the latter will support a column of water whose surface is at elevation $E_1$ on the hydraulic grade line. In the same way the pressure at gauge No. 2 will lift a column to elevation $E_2$. The difference between these elevations is the head lost, $h_f$, due to the retarding influences.

### INTERNAL SIZE OF PIPE.

It was not practicable to secure inside measurements of any of the pipe tested in the experiments conducted by the writer. The method used in ascertaining the inside cross-sectional area of the pipe is recounted in the description of each test. In some cases several joints of pipe, remaining from construction, were measured and their mean inside cross-sectional areas accepted as the internal sizes of the operated pipes. In other cases the external circumferences of the reaches tested were measured in several places and the mean inside cross-sectional areas computed, the thickness of the staves being known. This thickness runs very uniformly, being determined at time of manufacture by the use of the same templet.

In still other cases, especially on pipes of small diameter, the nominal diameter of the pipe was accepted. As the pipe runs very close to nominal size the writer believes that no appreciable error is introduced in accepting these areas, provided the conditions are such that the pipe is not liable to be more or less clogged with rocks, sand, or other débris.

### SCOPE OF THE EXPERIMENTS.

The writer conducted 64 tests on 16 separate pipes, 13 of which ranged from 8 inches to 4 feet in diameter; one was 6½ feet; one, 12 feet; and one, 13½ feet in diameter. Six pipes were of the machine-banded type, put together in lengths, and 10 were of the continuous-stave type. Mean velocities ranged from less than 1 foot per second to more than 8 feet per second.

From other sources, listed in summary Table 3, and briefly described in the appendix commencing on page 74, descriptions of experiments on pipes up to 6 feet in diameter were abstracted, but no other than the writer's records are available for pipes between 6 and 12 feet in diameter.

## EQUIPMENT AND METHODS EMPLOYED FOR COLLECTING AND INTERPRETING FIELD DATA.

In order to correctly weigh any new data bearing on hydraulic formulas it is necessary to know in detail the equipment used and the steps pursued in both the field and office. Consequently these features are described in some detail.

### EQUIPMENT.

*Tapes.*—High-grade steel tapes, graduated in feet and hundredths, were used in the determination of diameters, circumferences, etc. For distance chaining the tape was graduated to tenths.

*Level.*—An 18-inch Berger engineer's wye level, equipped with a bubble whose sensibility was rated at 10 seconds of arc for 1 division of scale equal to one-tenth of an inch was used. The bubble vial was 6.5 inches long; the telescope power was 35 diameters. The instrument was kept in excellent adjustment.

With one exception the levels in these tests were closed within the limits suggested by the U. S. Geological Survey, the allowable error in feet being $0.017\sqrt{\text{distance in miles.}}$[1] The exception noted occurred in connection with the tests on pipe No. 37, where the levels were run in high wind, over deep sand. Several trials were made, but the best closure was to 0.023 foot, while to conform to the formula it should have been to 0.012 foot, the distance being about 2,500 feet.

*Rod.*—A new Philadelphia rod, in three sections, equipped with rod level and vernier reading to thousandths of a foot was used in the determination of the elevations of gauge zeros with regard to an assumed datum.

*Thermometers.*—Temperatures of air and water were taken with all-glass laboratory thermometers, graduated to degrees and fifths, Centigrade scale. The range covered in the graduations was only that liable to be encountered in the tests, so that each degree was represented by about three-sixteenths inch.

*Hydrometer.*—Specific gravity of water in the pipes was tested by means of a laboratory hydrometer simultaneously with a like determination of the temperature of the water. The hydrometer was afterwards tested by the U. S. Bureau of Standards. The proper corrections were thereafter applied to readings before computation was undertaken.

*Current meter.*—A small Price cup current meter of the combination type was used. This meter had been carefully rated by the U. S.

[1] Precise Leveling, in Topographic Instructions of the U. S. Geological Survey, 1913, p. 100.

Bureau of Standards the year previous, but had been used only a few times, and then as a standard. Its rating curve was checked by the writer and his assistant in the channel of the hydraulic laboratory at Cornell University, just prior to these tests. No change was found necessary.

*Fluorescein.*[1]—Direct measurements of velocity of water in a pipe were made by injecting solutions of fluorescein and timing the passage of the resultant green-colored water through the reach tested.

*Weirs.*—Where weirs had been installed to measure the quantity of water from pipes the writer made use of them. Each is described in the report of the test in which it was used.

*Hook gauge.*—A small hook gauge of the Boyden type, with vernier reading to thousandths of a foot, was used to determine surface fluctuations for head on a weir. (See Pl. 1, fig. 1.)

*Piezometers.*—Two types were used:

Water column: This was employed where the pressure in the pipe was low. A simple glass manometer-tube, engine-divided to tenths and hundredths of a foot, was connected to the tap in the wood pipe by a piece of rubber pressure tubing. (See Pl. II, fig. 1.)

Mercury manometer: Where otherwise the pressure would have compelled the use of a long water column, a mercury manometer of the U-tube pattern was selected. Two of these U-tube mercury gauges, as shown in figure 3, were provided. They consisted of wrought-iron U tubes with unequal legs. The short leg was a glass manometer tube surmounted by a tee connection provided with the necessary cocks for manipulation. The long leg was formed of 2-foot units of one-eighth inch wrought-iron pipe until a length had been attained which permitted the top of the high mercury column to show in another glass tube.

These glass tubes were engine-divided into tenths and hundredths of a foot, the tenths and half-tenths lines extending completely around the tube and the other lines but half way around. By sighting through the tube across the front and back of any one line, all tendency toward parallax was removed and the mercury column could be correctly read to thousandths of a foot. The relative vertical positions of the two sets of graduations were of immaterial consequence as the graduations on each gauge glass were brought into the general scheme of levels above an assumed datum, as shown in figure 2.

All abutting pipes screwed against fiber gaskets. The ends of the gauge glasses were permanently set into sleeved couplings with sealing

[1] The writer is indebted to R. B. Dole, of the U. S. Geological Survey, for suggesting the use of this wonderful coloring matter. See "Use of Fluorescein in the study of underground waters," R. B. Dole, Water Supply Paper No. 160, U. S. Geological Survey.

wax. Both the couplings and attendant follow nuts were recessed at an angle of 45° in order to effectively bind rubber gaskets. Joints between ends of iron pipe units were made in the same way. A cement made of equal parts of beeswax and turpentine softened the rubber gaskets and gummed the pipe threads so that the joints were mercury-tight. This was doubly assured by winding sewing thread into the wax in the pipe threads.

The inside of all metal pipes and connections was japanned three coats thick in order to prevent amalgamation with the mercury.

*Color injector.*—The only practicable method of measuring the velocity of water in some of the pipes tested was by timing the passage of some color or chemical. After various tests fluorescein appeared to offer the best results. In order to inject the color into the pipe at the upstream gauge the "fluorescein gun" was developed (fig. 3). This is connected to the nipple C through the T connection D. At the downstream manometer the nipple C connects directly to the cock E.

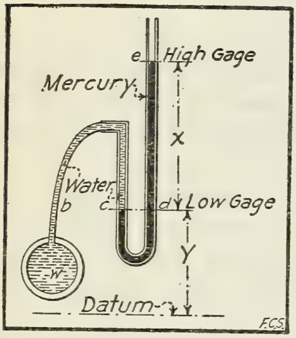

FIG. 2.—Hydraulic principles of mercury manometer of U-tube type.

*Mercury container.*—The usual lead torpedo weights for the current meter were dispensed with and a combination mercury bottle and meter weight was constructed (fig. 3). The details are evident in the illustration with the possible exception of the surge walls which divided the bottle into small compartments so that the mercury gave no trouble by surging when the bottle was used as a meter weight. Likewise the small holes in the walls at the top of the weight offered small chance of losing all the mercury in case of accident.

## FIELD METHODS.

### CHOOSING A REACH TO BE TESTED.

In order to be considered adaptable for field tests, a pipe must be practically water-tight (or the leaks measured) and of such length, without bends or obstructions, that the effect of errors is minimized—the longer the better. Gentle curves, both vertical and horizontal, were thought desirable, as their effect must be considered in the design of practically all wood-stave pipes. No distinct bend in any pipe was included in the reaches tested. Such a bend would cause an appreciable loss of head aside from friction loss. Some method of determining the mean velocity in the pipe must be available.

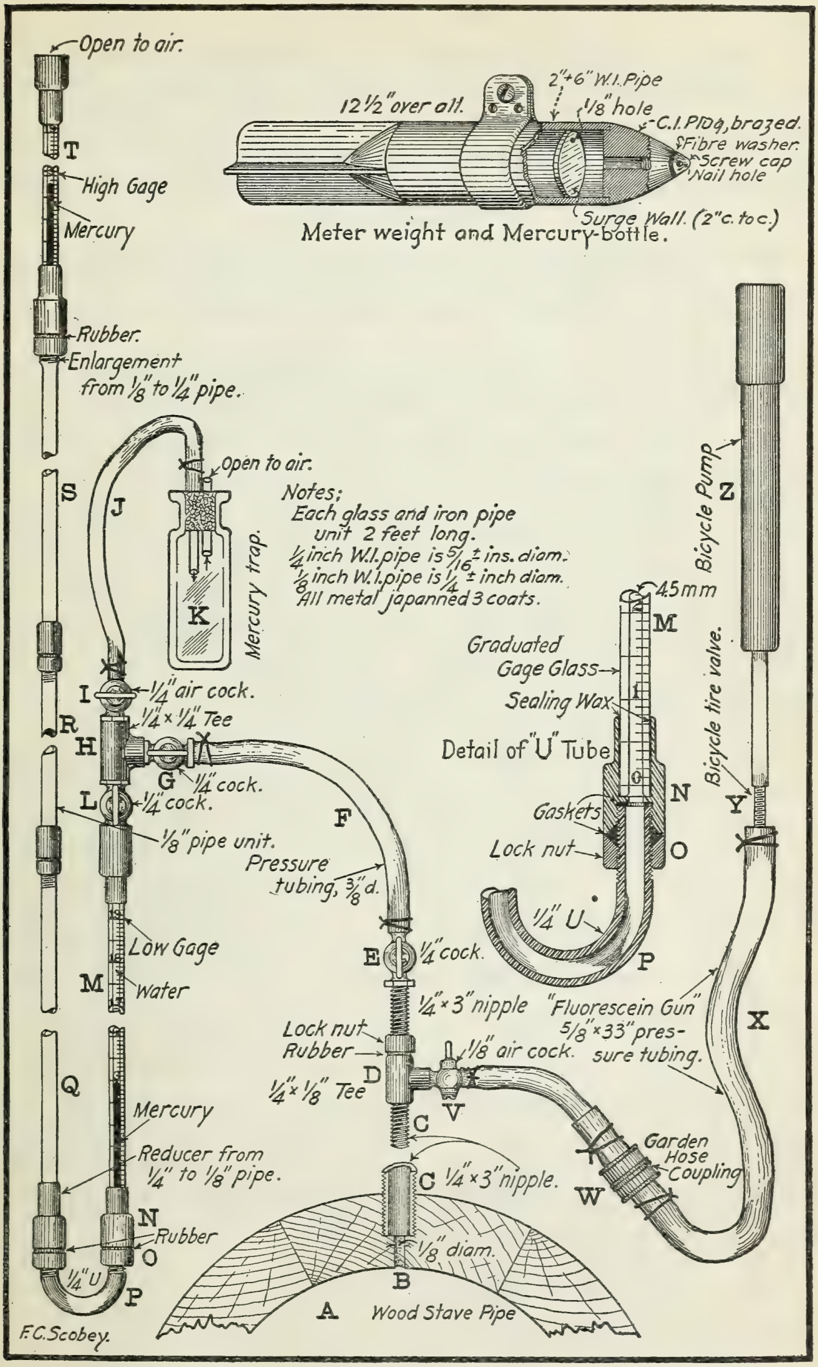


FIG. 3.—Method of attaching mercury manometers to wood-stave pipes. Details of manometers, fluorescein gun, and combined current meter weight and mercury bottle.

## ATTACHMENT OF PIEZOMETERS.

As it is not often practicable to secure permission to make several holes at each manometer in a wood pipe used commercially, the writer accepted the discussion of Profs. Marx, Wing, and Hoskins concerning the position of the point of attachment to the pipe and whether different results will be given by multiple attachment than by attachment at a single point.[1] Their first conclusion is:

> When the pressure in the given cross section of the pipe everywhere exceeds that of the atmosphere an open piezometer will stand at the same height at whatever point of the cross section it be attached, and whether it communicates with the pipe at one point or at several.

As a rule taps were not made on the top of the pipe, as the writer judged that more air bubbles would be in the water at this part of the pipe than at some lower point. Care was exercised in choosing the reach, so that guages could be set at each end of it, where the positions of the two taps would be such that the same relationship to velocity would hold. All taps were made on tangents. The position on the circumference was chosen in the neutral zone where the influence of curves would be a minimum. For instance, if the pipe was straight in horizontal alignment, but curved vertically, the taps were made in the side of the pipe. In experiments on pipe No. 52, where the pipe followed a chosen gradient but was curved horizontally, taps were made near the top of the pipe. (Pl. V, fig. 3.)

The essential requirement in a piezometer connection is to exclude all positive or negative influence of velocity head. The hole through the pipe must be normal to the pipe and as clean cut as possible on the inside. If splinters are pushed off the inner surface, then either positive or negative influence from the velocity head must act on the column in the gauge, whereas the pressure head alone is desired.

The gauges were attached to the pipe in a manner slightly modified from that used by Noble[2] and later by Moritz.[3] They bored a hole for the nipple with a wood bit until the tip of the bit pierced the inner surface. In the experiments described in this paper a seven-sixteenth-inch wood bit was used to make a hole about 1 inch deep. Then a twist drill one-eighth inch in diameter was twisted by hand until the inner surface of the pipe was cleanly pierced (fig. 3). Experiments made with both systems showed the holes made by the last method to be more nearly free from splinters which might affect the gauge tube by velocity head.

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[1] Trans. Amer. Soc. Civ. Engin., 40 (1898), p. 526.
[2] Id., 49 (1902), p. 119.
[3] Id., 74 (1911), p. 411.

### OPERATION OF GAUGES.

From observations on the ground or study of the profile, the pressure in the pipe was known roughly. In assembling the gauge the proper number of iron-pipe units was installed in the long leg of the U so that the two ends of the mercury column balancing the pressure in the pipe would appear near the mid-point of the glass gauge tubes.

The gauge, as assembled in figure 3, was set up beside the tapped pipe, the glass tubes being made truly vertical by means of a plumb bob. Shade was always provided for the gauges.

With the cocks I and L open and G closed, mercury was filtered into the tube T. A paper-lined glass funnel was inserted at the top of T. The mercury filtering through a pin hole at the bottom of the paper funnel was thus cleansed at each experiment and the meniscus in each tube was made bright and clear. Mercury filtered into a tube of small diameter in this manner will fill up without air bubbles, but if it is poured into such a tube air bubbles will occupy long reaches of pipe and may not be found if they occur in the iron-pipe sections. When both legs of the gauge were filled to near the top of the lower glass, I was closed and G opened until the mercury column in M was pressed well down in the gauge, when G was again closed. Mercury was then added and G was opened from time to time until it might be allowed to remain open, the pressure holding the mercury column in sight on both glass gage legs.

At this time there was probably a mixture of air and water above the mercury in M, but the air was driven out by alternately closing G and opening I for an instant. In using the gauges L was closed and G and I opened every few minutes, so that water and any accumulated air bubbles might be blown out of the pressure tube between the gauge and the wood pipe.

Because of the use of unequal legs on the gauge there was danger of blowing mercury out of the gauge at I unless the cocks L and G were operated most carefully. To catch the mercury in the event of such an accident, the tube J was discharged into the bottle K which included a glass tube open to the air so that water was freely discharged but the mercury caught.

Pulsations were nearly always present and as simultaneous readings of both low and high gauges were necessary in order to determine the length of the mercury column, readings were made in the following manner:

Pulsation effect was reduced by partially closing either L or G until the mercury was barely "alive." This assured an average length of column. The cock was then completely closed, leaving a "dead" mercury column of the proper length. Both low and high gauges were carefully read to thousandths after which the cock was opened. This process was repeated every 10 minutes. All other readings were taken by alternately reading high and low gauges with the mercury just alive, the corresponding reading for the other gauge being computed from the dead readings as described above. Since the only change in the total length of mercury thread was due to temperature changes, and since the gauges, which were made of the highest grade of manometer tubing, were practically uniform in diameter, no error was introduced by reading but one leg at a time, alternately.

### DETERMINATION OF LOST HEAD.

The exact amount of $h_f$ (fig. 1) must be determined. Where a water column is used, say at gauge No. 2, the elevation $E_2$ is the gauge reading added to the elevation of the gauge zero above an assumed datum, with proper corrections (see p. 23). Where a mercury manometer of the U-tube pattern is used, the reasoning is as follows: It is desired to know the elevation $E_1$ (fig. 1) for a water column which is the equivalent of a mercury column in a U-tube placed as for gauge No. 1. Referring to figure 2, the mercury in the two legs of the U-tube below c–d will be seen to balance. Therefore the pressure of the water at c is just balanced by the column of mercury X. But the pressure at c equals that at d. If the mercury X were replaced with water it would reach an elevation sX above d, where s is the specific gravity of the particular mercury in the gauge, compared with the particular water in the pipe. But the elevation to which this water column would reach is the desired elevation, $E_1$. Therefore the elevation $E_1 = sX + y$ above the assumed datum. As applied to these experiments, referring to figures 1 and 2, the difference in elevation between the readings of the low gauge and the high gauge multiplied by the specific gravity of the mercury and added to the elevation of the low-gauge reading gave the elevation of the equivalent water column when the proper corrections had been applied.

### CORRECTIONS.

Although quite numerous, the principles involved in all of the necessary corrections have been the subjects of such thorough investigation that appreciable errors are not liable to result from their use.

*Temperature.*—Corrections are necessary for the temperature changes in both air and water. A temperature of 15° C. was adopted as standard and the specific gravity of the mercury used in the tests was referred to that temperature, being compared to distilled water at the same temperature.

The mercury column balances the pressure of the water in the pipe, but this water may be either heavier or lighter than distilled water. Hydrometer tests of the water at the time of the experiment showed the specific gravity of the water for that temperature. A table was computed showing the proper specific gravity factor to apply to convert the mercury column to the equivalent water column for any observed specific gravity of water.[1] No additional correction is necessary for the temperature of the water as the hydrometer takes this into consideration.

The pressure in the pipe (fig. 2) supports the mercury column X and in addition the water column from the pipe to the elevation of c. If this water is of a different temperature from that in the pipe a correction is necessary, but in these experiments the water was kept at about the same temperature by frequently blowing off the water in the rubber pressure tube. The length of this water column in a mercury gauge at no time was more than 1 or 2 feet.

However, in a water column manometer the difference in temperature must be considered. The temperature of the water in the tube was taken as that of the air adjoining, while the temperature of the water in the pipe was determined at the same time that its specific gravity was tested. Water columns were not blown off but air bubbles were driven to the glass tube by striking the rubber tubing sharply with a stick. Siphons in the pressure tubing were carefully prevented.

*Capillarity.*—Water rises by capillarity in a small tube and mercury is depressed. Two sets of glass tubes were used for water columns. For one, with inside diameter of 4.5 mm., water rises 0.017 foot, while in the other set, with diameter of 5.6 mm., the water rises 0.01 foot.

### MEASUREMENT OF MEAN VELOCITY.

As a rule, each pipe tested presented its own problem as to the method to be adopted to determine the mean velocity of the water, and in case this method digressed from one of the following standard methods it is described.

*Current meter.*—Where the water entered or left the pipe in an open channel the discharge was determined with a current meter, and the velocity in the pipe was secured by dividing this discharge by the area of the pipe. The two-tenths and eight-tenths depth method was used, as the results obtained in this way, when compared with the discharge found by the multiple-point method, generally agree with it to about 1 per cent.

*Fluorescein.*—About 1 teaspoonful of fluorescein (in the form of red powder) dissolved in about a pint of water gave sufficient solution

[1] The mercury used in experiments conducted by the writer was tested for specific gravity in the laboratory of Nutrition Investigations, U. S. Department of Agriculture. The specific gravity was found to be 13.575 at 15° C., compared with distilled water at 15° C. These were the temperatures adopted as basic for the computation of results.

for four injections of color in a pipe carrying up to 60 second-feet, while in the $13\frac{1}{2}$-foot pipe (No. 52) the total contents of the "fluorescein gun" (fig. 3) were injected at one time, and for the volume of water carried in this pipe (the maximum was 871 second-feet) a saturate solution was used. Though not measured, this consisted of about 4 teaspoonsful of the powder for each "shot" of about one-third pint. The powder dissolved readily in cold water.

In making a test the coupling W is opened and the solution poured into the pressure tube X. The gun is again connected with the apparatus by the coupling W. With E closed V is opened. Pressure in the wood pipe enters the gun, making pressures in both gun and pipe equal. In order to inject the color into the pipe the only thing necessary is to increase the now existing pressure in the gun. After V has been closed the gun is pumped up like a bicycle tire. While noting the time to a second the operator opens the cock V. By the hissing sound, it is probable that the jet passes well across the diameter of a medium-sized pipe. If the contents of the gun are to cover three or four injections V is opened and almost immediately closed. If all the contents are to be used a few quick strokes of the pump, after V has been opened, will clear the gun in a very few seconds, the mean time being accepted in later computations.

The observer at the outlet, provided with a watch agreeing to the second with that used in timing the start of the color, notes to the second the first and last appearance of the color. The color is extended by the variation in the velocity throughout the section of the pipe. This extension covers about 8 per cent of the total time the color spends in the pipe. Comparison with carefully constructed weirs shows that the color method is correct within about 3 per cent. Wherever possible, a comparison between color and current meter was also made. To secure comparative results the time the color spent in the pipe is taken as from the moment of injection to the mean between first and last sight at the outlet. These comparative tests are shown in Table 1.

TABLE 1.—*Velocities by color (fluorescein) compared with velocities by weir and current meter.*

| Reference No. | Pipe diameter. | Crest length of weir. | Meter method. | Velocity per second by color. $V_c$ | Velocity per second by meter. $V_m$ | Velocity per second by weir. $V_w$ | $\frac{V_c-V_m}{V_c}$ | $\frac{V_c-V_w}{V_c}$ |
|---|---|---|---|---|---|---|---|---|
| | *Inches.* | *Feet.* | | *Feet.* | *Feet.* | *Feet.* | *Per cent.* | *Per cent.* |
| 60 | 8 | 1.05 Cip.[1] | | 1.251 | | 1.295 | | −3.5 |
| 61 | 8 | ....do | | 1.736 | | 1.735 | | +0.1 |
| 62 | 8 | 2.84 Rect.[2] | | 2.048 | | 2.09 | | −2.0 |
| 63 | 8 | ....do | | 3.043 | | 2.97 | | +2.4 |
| 64 | 8 | ....do | | 3.294 | | 3.37 | | −2.3 |
| 132 | 18 | | 6-tenths[3] | 2.08 | 1.99 | | +4.3 | |
| ([4]) | 36 | 10.0 Cip.[1] | Int.[5] | 3.48 | 3.48 | 3.47 | 0.0 | +0.3 |
| ([6]) | 36 | ....do | 6-tenths[3] | 3.48 | 3.55 | 3.47 | −2.0 | +0.3 |
| 192 | 48 | | 2+8[7] | 3.14 | 3.05 | | +2.9 | |
| 193 | 48 | | ....do | 3.75 | 3.71 | | +1.1 | |
| 194 | 48 | | ....do | 4.75 | 4.73 | | +0.4 | |
| 263 | 78 | | Curve[8] | 0.911 | 0.928 | | −1.9 | |
| 264 | 78 | | ....do | 0.963 | 0.974 | | −1.1 | |
| 265 | 78 | | ....do | 1.51 | 1.60 | | −6.0 | |
| 266 | 78 | | ....do | 2.063 | 2.08 | | −0.8 | |
| ([6]) | 78 | | ....do | 2.16 | 2.10 | | +2.8 | |
| 269 | 78 | | ....do | 2.40 | 2.37 | | +1.2 | |
| 270 | 78 | | ....do | 2.44 | 2.42 | | +0.8 | |
| 271 | 78 | | ....do | 2.59 | 2.51 | | +3.2 | |

[1] Cipolletti weir with good conditions of contraction and velocity. See p. 40.
[2] Rectangular weir with end contractions and sharp crest. See p. 40.
[3] Meter held in each vertical at 0.6 depth from surface.
[4] From tests on a concrete pipe, made in 1915.
[5] Velocity integrated by moving meter slowly from top to bottom and return.
[6] Excluded from Table 2 because gauge data lost for manometer No. 1.
[7] Meter held at 0.2 and 0.8 depths in each vertical; mean accepted for vertical. See p. 44.
[8] Rating curve developed by meter measurements. Velocity taken from curve. See p. 45

## FIELD PROCEDURE.

After the reach of pipe was selected, the manometers attached, and other equipment put in readiness the method for proceeding with the field test was in general carried out as described in the paragraphs following. Any necessary changes are noted in the text in connection with the description of the individual pipes tested.

The watches used at both ends of the reach were adjusted to agree to the second, and again compared at the end of the observation. Manometers were read every one or two minutes (depending on the amount of pulsation in the water) for a period of 30 minutes. If a weir was used to measure the discharge of water a hook gauge above the weir was read every two to five minutes, depending on the variation of discharge. If a current meter measurement was necessary to determine the discharge it was made either during or immediately following the series of manometer readings, the manometers being watched for appreciable variations of discharge. Where fluorescein was used to time the actual velocity of the water it was injected into the pipe at approximately known intervals, say, five minutes, throughout the time during which the manometers were read. Ordinarily the second gauge was near enough to the outlet of the pipe so that one observer could both read the manometer and watch for the appearance of the color. Sometimes a third observer was necessary.

### OFFICE EQUIPMENT AND METHODS.

Original multiplication, division, and addition were performed on mechanical devices. Checking was done by 20-inch slide rules and graphic methods. All percentage comparisons were made on 20-inch slide rules. Estimate diagrams were checked by proving random examples.

*Office procedure.*—Where water columns were used at both ends of the reach of pipe tested the loss of head in the pipe for the given velocity was the difference in elevation between the top of the mean water column at gauge No. 1 and the top of the mean column at gauge No. 2. Where a mercury manometer was used at one or both of the gauges the equivalent water column for each reading of the mercury column was computed. The mean of the elevations of the tops of the equivalent water columns was accepted as the elevation for that gauge. The loss of head was then computed as before. Standard methods were employed in computing current meter data or weir discharge. Where color was used in timing the velocity of the water the time was computed as from the instant of injection to the mean between first sight and last appearance of the color at the outlet.

## ELEMENTS OF FIELD TESTS TO DETERMINE FRICTION LOSSES AND COMPARISON OF OBSERVED VELOCITIES WITH VELOCITIES COMPUTED FROM VARIOUS FORMULAS.

In the following pages two tables are arranged (Tables 2 and 3). Table 2 gives the elements of nearly all known observations on wood pipes, either round or square. The various series are arranged in ascending sizes of pipe and within one series the observations are arranged in ascending order of velocities.

The tests of one experimenter are omitted from these tables as extraordinary friction values were found. The writer made an independent set of tests upon some of the same pipes and found them so choked with ravelings from the rock cuts above the siphons that erroneous values were obtained. In the omitted tests the error lay in making current meter measurements for Q and then accepting $V=\frac{Q}{A}$ where A was taken as the nominal area of the pipe when as a matter of fact the true value of A was about 90 per cent of the nominal A; therefore the true velocity was much higher than that found by the erroneous assumption of A.

### EXPLANATORY NOTES ON TABLE 2.

Column 1 gives the consecutive numbers of the pipes as followed in column 1, Table 3, also in the discussions in the following pages and in the appendix. The small letter *a* after the numbers refers to discussion in the appendix. Experiments conducted by this department are discussed in the text while the essential data secured from other sources are abstracted in the appendix.

Column 2 gives a consecutive reference number to each observation.

Column 3 shows the authority (see also column 3, Table 3), the series number where such was carried, together with the date of the test.

HS refers to Hamilton Smith.

EM refers to E. A. Moritz, engineer of the United States Reclamation Service.

C refers to J. L. Campbell.

A refers to the late A. L. Adams.

DB refers to Darcy and Bazin.

H refers to D. C. Henny.

JDS refers to the late J. D. Schuyler.

JM refers to J. S. Moore, assistant engineer, United States Reclamation Service.

N refers to T. A. Noble.

MWH refers to Professors Marx, Wing, and Hoskins, of Leland Stanford, Junior, University.

EC refers to E. C. Clarke.

S refers to the writer, Fred. C. Scobey, irrigation engineer, in charge of experiments on the flow of water in channels and pipes.

Column 4 gives the observation number as carried by the experimenter.

Column 10 shows the value of $n$ as computed from the observation.

Column 11 shows the value of $n$ for a normal pipe of the same size at the observed velocity. This value is taken by inspection of the $n$ curves in Plate VIII. The writer has termed this the normal value of $n$.

Columns 14 to 18, inclusive, show the velocities for the same size of pipe with the given loss of head (column 9) when computed by the various formulas.

Columns 19 to 23, inclusive, show the percentage comparison of observed velocities (column 8) to computed velocities (columns 14 to 18). This comparison is explained on page 55, in connection with the information in Plate VII. The grand algebraic means of all observations in the respective columns are given at the foot of the columns on page 37. These means are graphed in Plate VII and shown also on page 14. The other columns are self-explanatory.

### EXPLANATORY NOTES ON TABLE 3.

Column 1 gives the same consecutive numbers of pipes as column 1, Table 2. See discussion after "Column 1" on page 26.

Column 2 gives the inclusive reference numbers of observations on that particular pipe, which are the same as those in column 2, Table 2.

Columns 10 to 14, inclusive, give the weights assigned to the determination of the general value of the exponent of V in formula 12, page 7. The method of finding these weights is explained on page 52.

Column 15 gives the weights assigned the various series in determining the general equation for the intercept curve shown in figure 4.

Column 16 gives the revised values of the intercepts for individual pipes as explained on page 53. Note that these may be quite different from the value representing the intercept in the equations shown in column 17.

Column 17 gives the formulas of flow, as shown by the observations, for the individual pipes. Their derivation is explained on page 53.

Columns 18 to 22, inclusive, have the same general significance as columns 19 to 23, Table 2, respectively. For the series the figures given are the algebraic means of the percentages for the observations. The grand algebraic means for all pipes are shown at the foot of the columns on page 39. These means are graphed in Plate VII, and are also given on page 14.

The other columns are considered self-explanatory.

TABLE 2.—*Elements of experiments for the determination of friction losses in wood-stave pipes, with percentage comparison of observed velocities to formula velocities.*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Coefficients of retardation. | | | | Comparison, by various formulas, of observed to calculated velocities. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Velocities, by formulas, for given H, per second. | | | | | Column 8 compared to columns 14–18, inclusive. | | | | |
| | | | | | | | | | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| Pipe No. | Reference No. | Experimenter and year. | Observation. | d Diameter. | Name and description of pipe. | Q Discharge, per second. | V Mean velocity, per second. | H Loss of head, per 1,000 feet. | n Kutter, by observation. | n Kutter, normal. | C Chezy. | $C_w$ Williams-Hazen. | Scobey. | Williams-Hazen ($C_w=120$). | Moritz. | Tutton. | Weisbach. | Scobey. | Williams-Hazen ($C_w=120$). | Moritz. | Tutton. | Weisbach. |
| | | | | *Inches.* | | *Cu. ft.* | *Feet.* | *Feet.* | | | | | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* |
| 1a | 1 | HS-X,1877 | 339 | 1.26 | New Almaden, Cal. 8 joints of heart redwood, bored with a pipe auger. New and straight. | 0.014 | 1.653 | 24.19 | ...... | ...... | 65.5 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | − 6 | ...... |
| | 2 | | 338 | | | .021 | 2.469 | 50.94 | ...... | ...... | 67.5 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | − 4 | ...... |
| | 3 | | 337 | | | .026 | 3.008 | 76.10 | ...... | ...... | 67.2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | − 4.6 | ...... |
| | 4 | | 336 | | | .031 | 3.519 | 103.06 | ...... | ...... | 67.6 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | − 4.9 | ...... |
| | 5 | | 335 | | | .035 | 3.986 | 131.15 | ...... | ...... | 67.9 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | − 4.0 | ...... |
| 2a | 6 | EM, 1910 | 5 | 4.00 | Sunnyside project, Washington. Jointed straight pipe on continuous down slope. Growth at inlet. Condition unknown. | .037 | .425 | .464 | 0.0118 | 0.0107 | 68.6 | 96.8 | 0.519 | 0.527 | 0.520 | 0.502 | 0.520 | −18.1 | −19.4 | −18.4 | −15.4 | −18.3 |
| | 7 | | 7 | | | .067 | .770 | 1.259 | .0113 | .0101 | 75.2 | 102.2 | .902 | .904 | .906 | .836 | .901 | −14.6 | −14.8 | −15.0 | − 8.1 | −14.6 |
| | 8 | | 6 | | | .091 | 1.046 | 2.209 | .0112 | .0099 | 77.3 | 102.5 | 1.23 | 1.22 | 1.24 | 1.11 | 1.24 | −14.9 | −14.6 | −15.4 | − 6.0 | −15.9 |
| | 9 | | 4 | | | .126 | 1.448 | 3.688 | .0107 | .0097 | 82.8 | 107.6 | 1.64 | 1.62 | 1.64 | 1.45 | 1.64 | −11.6 | −10.4 | −11.8 | + 0.1 | −11.4 |
| | 10 | | 3 | | | .146 | 1.678 | 4.905 | .0106 | .0096 | 83.2 | 107.0 | 1.92 | 1.88 | 1.93 | 1.67 | 1.90 | −12.5 | −10.8 | −12.9 | + 0.2 | −11.7 |
| 3a | 11 | EM, 1910 | 2 | 4.00 | Another reach of pipe No. 2.. | .312 | 3.586 | 17.476 | .0098 | .0093 | 93.9 | 115.0 | 3.88 | 3.74 | 3.90 | 3.20 | 3.80 | − 7.6 | − 4.2 | − 8.1 | +12.1 | − 5.6 |
| | 12 | | 1 | | | .388 | 4.460 | 25.369 | .0096 | .0093 | 97.2 | 116.9 | 4.77 | 4.57 | 4.80 | 3.87 | 4.65 | − 6.5 | − 2.6 | − 7.0 | +15.3 | − 4.2 |
| 4a | 13 | EM, 1909 | 5 | 5.00 | Sunnyside project, Washington. Jointed inverted siphon. Straight in horizontal alignment. | .057 | .419 | .243 | .0104 | .0110 | 83.8 | 118.3 | .419 | .425 | .425 | .416 | .445 | 0.0 | − 1.4 | − 1.1 | + 0.7 | − 5.9 |
| | 14 | | 6 | | | .089 | .654 | .565 | .0107 | .0107 | 85.7 | 117.1 | .669 | .670 | .679 | .639 | .689 | − 2.2 | − 2.4 | − 3.6 | + 2.2 | − 5.2 |
| | 15 | | 7 | | | .111 | .816 | .837 | .0106 | .0104 | 87.8 | 118.1 | .830 | .827 | .844 | .781 | .848 | − 1.7 | − 1.5 | − 3.4 | + 4.4 | − 3.8 |
| | 16 | | 1 | | | .136 | 1.000 | 1.312 | .0108 | .0103 | 85.8 | 113.6 | 1.07 | 1.06 | 1.08 | .982 | 1.09 | − 6.6 | − 5.4 | − 7.6 | + 1.8 | − 8.0 |
| | 17 | | 2 | | | .179 | 1.316 | 2.165 | .0107 | .0100 | 87.2 | 114.0 | 1.41 | 1.38 | 1.43 | 1.27 | 1.42 | − 6.6 | − 5.0 | − 8.1 | + 3.8 | − 9.9 |
| | 18 | | 8 | | | .199 | 1.463 | 2.481 | .0104 | .0100 | 91.5 | 117.9 | 1.52 | 1.49 | 1.54 | 1.36 | 1.53 | − 3.9 | − 1.8 | − 5.2 | + 7.6 | − 4.5 |
| | 19 | | 4 | | | .311 | 2.287 | 6.099 | .0105 | .0097 | 91.2 | 113.3 | 2.50 | 2.42 | 2.54 | 2.15 | 2.47 | − 8.5 | − 5.6 | −10.0 | + 6.3 | − 7.4 |
| | 20 | | 3 | | | .313 | 2.301 | 6.292 | .0106 | .0097 | 90.4 | 112.3 | 2.56 | 2.46 | 2.58 | 2.18 | 2.51 | −10.1 | − 6.5 | −10.8 | + 5.3 | − 8.3 |

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5a | 21 | EM, 1909 | 1 | 6.00 | Sunnyside project, Washington. Jointed straight. pipe on continuous down slope. Total length 1,000 feet. | .098 | .499 | .250 | .0104 | .0112 | 89.3 | 123.7 | .480 | .484 | .490 | .476 | .504 | + 3.9 | + 3.0 | + 1.7 | + 4.8 | − 0.9 |
| | 22 | | 2 | | | .162 | .827 | .610 | .0103 | .0107 | 94.7 | 126.6 | .785 | .784 | .805 | .750 | .815 | + 5.3 | + 5.5 | + 2.8 | +10.2 | + 1.4 |
| | 23 | | 3 | | | .213 | 1.085 | .995 | .0102 | .0105 | 97.5 | 127.6 | 1.03 | 1.02 | 1.06 | .962 | 1.06 | + 5.3 | + 6.3 | + 2.9 | +12.6 | + 2.8 |
| | 24 | | 4 | | | .270 | 1.378 | 1.573 | .0102 | .0103 | 98.3 | 126.5 | 1.33 | 1.31 | 1.36 | 1.22 | 1.34 | + 3.6 | + 5.4 | + 1.3 | +13.4 | + 2.4 |
| | 25 | | 5 | | | .334 | 1.704 | 2.270 | .0101 | .0101 | 98.8 | 128.2 | 1.63 | 1.59 | 1.67 | 1.47 | 1.64 | + 4.5 | + 7.1 | + 2.1 | +16.2 | + 3.8 |
| 6a | 26 | EM, 1910 | 5 | 6.00 | Sunnyside project, Washington. Jointed inverted siphon. Curvature and profile similar to those discussed under pipe No. 11. | .079 | .403 | .160 | .0100 | .0113 | 90.2 | 127.1 | .374 | .380 | .383 | .380 | .397 | + 7.8 | + 5.9 | + 5.1 | + 6.4 | + 1.5 |
| | 27 | | 4 | | | .096 | .490 | .240 | .0103 | .0112 | 89.1 | 124.1 | .468 | .474 | .479 | .466 | .495 | + 4.6 | + 3.4 | + 2.2 | + 5.1 | − 1.0 |
| | 28 | | 3 | | | .121 | .617 | .370 | .0104 | .0110 | 90.7 | 123.7 | .595 | .598 | .610 | .581 | .617 | + 3.6 | + 3.2 | + 1.2 | + 6.2 | + 0.1 |
| | 29 | | 1 | | | .159 | .811 | .606 | .0104 | .0107 | 93.3 | 124.6 | .783 | .781 | .802 | .747 | .806 | + 3.6 | + 3.7 | + 1.2 | + 8.6 | + 0.6 |
| | 30 | | 2 | | | .194 | .990 | .930 | .0106 | .0106 | 91.9 | 120.7 | .990 | .986 | 1.[illegible]2 | .930 | 1.07 | 0.0 | + 0.6 | − 2.8 | + 6.2 | − 7.6 |
| | 31 | | 6 | | | .251 | 1.281 | 1.391 | .0103 | .0103 | 97.2 | 125.6 | 1.24 | 1.22 | 1.27 | 1.14 | 1.26 | + 3.3 | + 4.6 | + 0.6 | +12.4 | + 1.7 |
| 7a | 32 | EM, 1910 | 7 | 6.00 | Sunnyside project, Washington. Same pipe as Nos. 6, 8. | .299 | 1.526 | 1.973 | .0103 | .0103 | 98.4 | 123.9 | 1.50 | 1.48 | 1.54 | 1.37 | 1.52 | + 1.7 | + 3.2 | − 1.0 | +11.6 | + 0.5 |
| | 33 | | 9 | | | .456 | 2.327 | 4.295 | .0101 | .0100 | 100.5 | 124.1 | 2.32 | 2.25 | 2.38 | 2.03 | 2.31 | + 0.3 | + 3.2 | − 2.1 | +14.6 | + 0.9 |
| 8a | 34 | EM, 1910 | 8 | 6.00 | Sunnyside project, Washington. | .588 | 3.000 | 6.889 | .0100 | .0098 | 102.2 | 124.0 | 3.01 | 2.90 | 3.09 | 2.58 | 2.97 | − 0.3 | + 3.3 | − 2.8 | +16.1 | + 1.1 |
| 9a | 35 | EM, 1909 | 2 | 8.00 | Sunnyside project, Washington. Jointed inverted siphon. One bend in horizontal alignment. Same pipe covered by Nos. 10, 11, and 12. | .366 | 1.049 | .847 | .0116 | .0110 | 88.2 | 112.1 | 1.14 | 1.12 | 1.18 | 1.07 | 1.15 | − 7.8 | − 6.6 | −11.1 | − 2.1 | − 8.8 |
| | 36 | | 3 | | | .469 | 1.344 | 1.304 | .0114 | .0108 | 91.1 | 113.9 | 1.44 | 1.42 | 1.50 | 1.34 | 1.44 | − 6.7 | − 5.1 | −10.5 | + 0.6 | − 7.0 |
| | 37 | | 4 | | | .573 | 1.642 | 1.853 | .0112 | .0107 | 93.3 | 115.0 | 1.75 | 1.71 | 1.82 | 1.60 | 1.74 | − 6.1 | − 4.2 | − 9.9 | + 2.7 | − 5.9 |
| | 38 | | 5 | | | .745 | 2.135 | 2.988 | .0111 | .0103 | 95.6 | 115.5 | 2.28 | 2.22 | 2.38 | 2.04 | 2.26 | − 6.4 | − 3.7 | −10.3 | + 4.7 | − 5.6 |
| | 39 | | 6 | | | .904 | 2.590 | 4.428 | .0111 | .0103 | 95.2 | 113.3 | 2.84 | 2.74 | 2.96 | 2.51 | 2.78 | − 8.7 | − 5.6 | −12.5 | + 3.2 | − 6.7 |
| | 40 | | 1 | | | .961 | 2.754 | 4.874 | .0110 | .0102 | 96.6 | 114.5 | 3.00 | 2.88 | 3.12 | 2.64 | 2.92 | − 8.1 | − 4.6 | −11.6 | + 4.1 | − 5.6 |
| | 41 | | 7 | | | 1.045 | 2.994 | 5.707 | .0110 | .0102 | 96.9 | 114.3 | 3.27 | 3.14 | 3.40 | 2.84 | 3.18 | − 8.4 | − 4.7 | −12.1 | + 5.6 | − 5.8 |
| | 42 | | 8 | | | 1.349 | 3.866 | 8.934 | .0107 | .0101 | 100.1 | 115.8 | 4.19 | 4.00 | 4.37 | 3.57 | 4.05 | − 7.7 | − 3.5 | −11.4 | + 8.3 | − 4.5 |
| | 43 | | 9 | | | 1.538 | 4.407 | 11.149 | .0106 | .0100 | 102.1 | 117.0 | 4.75 | 4.52 | 4.94 | 3.99 | 4.65 | − 7.2 | − 2.5 | −10.7 | +10.3 | − 5.2 |
| 10a | 44 | EM, 1909 | 10 | 8.00 | Sunnyside project, Washington. See Nos. 9, 11, and 12. | .433 | 1.241 | 1.114 | .0114 | .0108 | 90.8 | 114.5 | 1.32 | 1.30 | 1.38 | 1.23 | 1.33 | − 6.0 | − 4.6 | − 9.7 | + 0.6 | − 6.8 |
| | 45 | | 11 | | | .782 | 2.241 | 3.270 | .0110 | .0103 | 95.6 | 115.5 | 2.40 | 2.33 | 2.50 | 2.14 | 2.36 | − 6.6 | − 3.8 | −10.4 | + 5.0 | − 5.2 |
| 11a | 46 | EM, 1910 | 8 | 8.00 | Sunnyside project, Washington. See Nos. 9, 10, and 12. Note great divergence in results on same pipe in years 1909 and 1910. Moritz suggests this is due to air conditions, which varied. | .575 | 1.648 | 1.257 | .0096 | .0106 | 113.4 | 142.4 | 1.41 | 1.39 | 1.47 | 1.31 | 1.44 | +16.9 | +18.7 | +12.1 | +25.7 | +14.4 |
| | 47 | | 7 | | | .748 | 2.143 | 1.993 | .0094 | .0104 | 117.1 | 144.3 | 1.82 | 1.78 | 1.90 | 1.66 | 1.85 | +17.7 | +20.2 | +12.7 | +29.2 | +16.1 |
| | 48 | | 6 | | | .905 | 2.593 | 2.813 | .0093 | .0103 | 119.3 | 145.0 | 2.21 | 2.15 | 2.30 | 1.98 | 2.22 | +17.3 | +20.7 | +12.7 | +31.0 | +17.0 |
| | 49 | | 5 | | | 1.169 | 3.350 | 4.305 | .0090 | .0101 | 124.5 | 148.9 | 2.80 | 2.70 | 2.91 | 2.46 | 2.78 | +19.6 | +24.1 | +15.0 | +36.4 | +20.4 |
| | 50 | | 4 | | | 1.315 | 3.768 | 5.310 | .0090 | .0101 | 126.0 | 149.5 | 3.15 | 3.02 | 3.27 | 2.73 | 3.11 | +19.6 | +24.5 | +15.0 | +37.7 | +20.9 |
| | 51 | | 3 | | | 1.484 | 4.252 | 6.357 | .0088 | .0100 | 130.0 | 153.1 | 3.48 | 3.33 | 3.62 | 3.00 | 3.43 | +22.2 | +27.5 | +17.8 | +41.8 | +24.0 |
| | 52 | | 2 | | | 1.803 | 5.166 | 9.200 | .0087 | .0099 | 131.4 | 152.4 | 4.26 | 4.06 | 4.44 | 3.62 | 4.17 | +21.3 | +26.9 | +16.4 | +42.7 | +23.6 |
| | 53 | | 1 | | | 2.050 | 5.874 | 11.494 | .0086 | .0099 | 133.9 | 153.7 | 4.84 | 4.59 | 5.02 | 4.05 | 4.69 | +21.3 | +28.1 | +16.9 | +44.9 | +25.2 |
| 12a | 54 | EM, 1910 | 12 | 8.00 | Sunnyside project, Washington. See Nos. 9, 10, and 11. | .158 | .453 | .161 | .0109 | .0117 | 87.1 | 118.8 | .451 | .458 | .470 | .460 | .47 | + 0.4 | − 1.0 | − 3.6 | − 1.5 | − 3.6 |
| | 55 | | 11 | | | .182 | .522 | .206 | .0109 | .0116 | 88.8 | 119.8 | .518 | .523 | .539 | .521 | .535 | + 0.6 | 0.0 | − 3.1 | − 0.2 | − 2.4 |
| | 56 | | 10 | | | .332 | .951 | .527 | .0103 | .0111 | 101.0 | 131.4 | .873 | .870 | .908 | .842 | .90 | + 8.9 | + 9.3 | + 4.8 | +13.0 | + 5.7 |
| | 57 | | 9 | | | .423 | 1.212 | .782 | .0101 | .0109 | 105.8 | 135.3 | 1.09 | 1.07 | 1.13 | 1.03 | 1.11 | +11.1 | +12.7 | + 7.2 | +17.7 | + 9.0 |

TABLE 2.—*Elements of experiments for the determination of friction losses in wood-stave pipes, with percentage comparison of observed velocities to formula velocities*—Continued.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Coefficients of retardation. 10 | 11 | 12 | 13 | Comparison, by various formulas, of observed to calculated velocities. Velocities, by formulas, for given H, per second. 14 | 15 | 16 | 17 | 18 | Column 8 compared to columns 14–18, inclusive. 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pipe No. | Reference No. | Experimenter and year. | Observation. | d Diameter. | Name and description of pipe. | Q Discharge, per second. | V Mean velocity, per second. | H Loss of head, per 1,000 feet. | n Kutter, by observation. | n Kutter, normal. | C Chezy. | $C_w$ Williams-Hazen. | Scobey. | Williams-Hazen ($C_w$=120). | Moritz. | Tutton. | Weisbach. | Scobey. | Williams-Hazen ($C_w$=120). | Moritz. | Tutton. | Weisbach. |
| | | | | *Inches.* | | *Cu. ft.* | *Feet.* | *Feet.* | | | | | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* |
| 13 | 58 | S-12,1914 | 2 | 8.00 | French Bros. Jointed delivery pipe, laid on gentle grade upward. One bend in horizontal alignment. Interior condition unknown, but probably good as open canal clears water. | 0.104 | 0.316 | 0.116 | 0.0123 | 0.0121 | 71.7 | 98.7 | 0.378 | 0.384 | 0.392 | 0.390 | 0.419 | −16.4 | −17.7 | −19.3 | −18.8 | −24.5 |
| | 59 | | 3 | | | .327 | .936 | .840 | .0126 | .0111 | 79.1 | 100.6 | 1.13 | 1.12 | 1.18 | 1.07 | 1.15 | −17.2 | −16.2 | −20.4 | −12.4 | −18.6 |
| | 60 | | 5 | | | .453 | 1.251 | 1.035 | .0110 | .0109 | 95.2 | 120.0 | 1.27 | 1.25 | 1.32 | 1.19 | 1.30 | − 1.5 | 0.0 | − 5.2 | + 5.1 | − 3.2 |
| | 61 | | 4 | | | .606 | 1.736 | 1.827 | .0107 | .0106 | 99.5 | 122.6 | 1.75 | 1.70 | 1.80 | 1.59 | 1.75 | − 0.7 | + 2.1 | − 3.6 | + 9.2 | − 0.6 |
| | 62 | | 8 | | | .730 | 2.048 | 2.393 | .0105 | .0104 | 102.5 | 125.0 | 2.02 | 1.96 | 2.10 | 1.82 | 2.03 | + 1.4 | + 4.1 | − 2.6 | +12.6 | + 0.8 |
| | 63 | | 6 | | | 1.036 | 3.043 | 5.979 | .0110 | .0102 | 96.4 | 113.2 | 3.35 | 3.22 | 3.50 | 2.90 | 3.25 | − 9.1 | − 5.7 | −12.8 | + 4.8 | − 6.4 |
| | 64 | | 7 | | | 1.177 | 3.294 | 6.850 | .0109 | .0102 | 97.5 | 114.0 | 3.62 | 3.47 | 3.77 | 3.11 | 3.45 | − 8.9 | − 5.0 | −12.5 | + 5.7 | − 4.5 |
| | 65 | | 1 | | | 1.243 | 3.558 | 8.019 | .0110 | .0101 | 97.3 | 113.3 | 3.96 | 3.77 | 4.11 | 3.37 | 3.85 | −10.2 | − 5.6 | −13.5 | + 5.4 | − 7.5 |
| 14 | 66 | S-11,1914 | 5 | 10.00 | Congdon Orchards, Washington. Jointed straight pipe with slight dip between gauges. | 1.978 | 3.633 | 6.160 | .0111 | .0103 | 101.4 | 115.5 | 3.95 | 3.77 | 4.15 | 3.42 | 3.81 | − 8.0 | − 3.6 | −12.6 | + 6.2 | − 4.6 |
| | 67 | | 1 | | | 2.499 | 4.585 | 10.724 | .0115 | .0102 | 97.0 | 108.2 | 5.37 | 5.07 | 5.65 | 4.53 | 5.08 | −14.6 | − 9.8 | −18.8 | + 1.2 | − 9.6 |
| | 68 | | 4 | | | 2.540 | 4.66 | 9.635 | .0109 | .0102 | 104.0 | 116.5 | 5.04 | 4.83 | 5.33 | 4.29 | 4.82 | − 7.5 | − 3.5 | −12.7 | + 8.5 | − 3.4 |
| | 69 | | 3 | | | 2.572 | 4.72 | 9.961 | .0110 | .0102 | 103.6 | 115.9 | 5.14 | 4.88 | 5.42 | 4.36 | 4.90 | − 8.1 | − 3.4 | −12.9 | + 8.2 | − 3.6 |
| | 70 | | 2 | | | 2.769 | 5.08 | 11.950 | .0112 | .0101 | 101.8 | 113.1 | 5.68 | 5.39 | 6.00 | 4.79 | 5.44 | −10.5 | − 5.8 | −15.2 | + 6.1 | − 6.6 |
| 15a | 71 | C-1908 | 2 | 10.12 | Bonito pipe line, New Mexico. Not used by writer in deriving formula as maximum velocity is taken. | 5.42 | 9.705 | 33.38 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| | 72 | C-1908 | 1 | | | 5.44 | 9.74 | 33.38 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| | 73 | C-1909 | 3 | | | 5.98 | 10.71 | 33.38 | .0087 | ...... | 128.0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| | 74 | C-1911 | 4 | | | 6.19 | 11.07 | 33.38 | .0089 | ...... | 132.0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| 16a | 75 | EM, 1910 | 1 | 12.00 | Sunnyside project, Washington. Jointed, machine banded pipe. Dip in profile. Probably silted as | .360 | .459 | .139 | .0129 | .0124 | 78.0 | 100.9 | .542 | .546 | .575 | .557 | .572 | −15.4 | −15.8 | −20.0 | −17.6 | −19.8 |
| | 76 | | 2 | | | .469 | .597 | .222 | .0130 | .0122 | 80.2 | 102.0 | .703 | .702 | .745 | .707 | .733 | −15.1 | −15.0 | −19.8 | −15.6 | −18.5 |
| | 77 | | 3 | | | .581 | .740 | .349 | .0134 | .0120 | 79.2 | 99.0 | .905 | .897 | .959 | .891 | .927 | −17.8 | −17.5 | −22.8 | −16.9 | −20.2 |
| | 78 | | 4 | | | .698 | .889 | .459 | .0130 | .0118 | 82.9 | 102.6 | 1.05 | 1.04 | 1.12 | 1.02 | 1.08 | −15.3 | −14.6 | −20.3 | −13.2 | −17.5 |

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 79 | | 5 | | velocities are low in nor- | .998 | 1.271 | .819 | .0126 | .0114 | 88.9 | 107.3 | 1.45 | 1.42 | 1.54 | 1.38 | 1.46 | −12.0 | −10.6 | −17.4 | − 7.7 | −12.9 |
| | 80 | | 6 | | mal flow. Loss of head | 1.200 | 1.529 | 1.196 | .0127 | .0113 | 88.5 | 105.2 | 1.78 | 1.74 | 1.90 | 1.67 | 1.79 | −11.1 | −12.3 | −19.6 | − 8.5 | −14.5 |
| | 81 | | 7 | | abnormally high. | 1.415 | 1.803 | 1.548 | .0124 | .0112 | 91.7 | 107.9 | 2.06 | 2.01 | 2.19 | 1.90 | 2.05 | −12.5 | −10.1 | −17.8 | − 5.5 | −12.2 |
| 17a | 82 | EM, 1909 | 1 | 14.00 | Sunnyside project, Wash- | .529 | .495 | .106 | .0118 | .0126 | 89.1 | 114.4 | .515 | .519 | .551 | .537 | .560 | − 3.9 | − 4.6 | −10.2 | − 7.8 | −11.6 |
| | 83 | | 8 | | ington. Jointed, machine | .555 | .519 | .115 | .0118 | .0126 | 89.7 | 114.8 | .540 | .542 | .577 | .560 | .579 | − 3.8 | − 4.3 | −10.1 | − 7.2 | −10.3 |
| | 84 | | 7 | | banded fir pipe. Wavy | 1.050 | .982 | .300 | .0111 | .0119 | 105.1 | 129.4 | .920 | .911 | .982 | .913 | .962 | + 6.7 | + 7.8 | 0.0 | + 7.5 | + 2.1 |
| | 85 | | 6 | | alignment. No deposit or | 1.298 | 1.214 | .474 | .0114 | .0117 | 103.2 | 124.8 | 1.19 | 1.17 | 1.27 | 1.15 | 1.22 | + 2.0 | + 4.0 | − 4.2 | + 5.2 | − 0.6 |
| | 86 | | 5 | | growth. Same pipe as No. | 1.752 | 1.639 | .767 | .0110 | .0114 | 109.6 | 130.1 | 1.55 | 1.51 | 1.65 | 1.47 | 1.58 | + 5.8 | + 8.4 | − 0.8 | +11.3 | + 4.1 |
| | 87 | | 4 | | 18. | 2.224 | 2.080 | 1.237 | .0110 | .0113 | 109.8 | 127.6 | 2.01 | 1.96 | 2.16 | 1.88 | 2.02 | + 3.5 | + 6.3 | − 3.4 | +10.6 | + 2.8 |
| | 88 | | 3 | | | 2.820 | 2.638 | 1.909 | .0109 | .0110 | 111.9 | 128.0 | 2.56 | 2.47 | 2.74 | 2.34 | 2.55 | + 3.0 | + 6.7 | − 3.9 | +12.5 | + 3.5 |
| | 89 | | 2 | | | 3.493 | 3.267 | 2.570 | .0104 | .0108 | 119.4 | 135.0 | 3.02 | 2.90 | 3.24 | 2.73 | 3.03 | + 8.2 | +12.5 | + 0.9 | +19.6 | + 7.8 |
| 18a | 90 | EM, 1910 | 6 | 14.00 | Sunnyside project, Wash- | .612 | .572 | .104 | .0105 | .0124 | 103.8 | 133.6 | .510 | .514 | .546 | .532 | .553 | +12.1 | +11.3 | + 4.8 | + 7.5 | + 3.5 |
| | 91 | | 5 | | ington. Same reach in | .790 | .739 | .171 | .0108 | .0122 | 101.5 | 132.2 | .672 | .672 | .719 | .685 | .717 | + 9.9 | +10.2 | + 2.8 | + 7.7 | + 2.9 |
| | 92 | | 4 | | same pipe as No. 17. | 1.050 | .982 | .283 | .0108 | .0119 | 108.2 | 133.6 | .890 | .882 | .951 | .886 | .939 | +10.2 | +11.2 | + 3.1 | +10.8 | + 4.6 |
| | 93 | | 3 | | | 1.384 | 1.295 | .478 | .0108 | .0117 | 109.7 | 132.6 | 1.19 | 1.17 | 1.27 | 1.16 | 1.23 | + 8.8 | +10.4 | + 1.7 | +11.9 | + 5.5 |
| | 94 | | 2 | | | 1.761 | 1.647 | .754 | .0108 | .0114 | 111.2 | 131.9 | 1.53 | 1.50 | 1.64 | 1.46 | 1.56 | + 7.8 | +10.0 | + 0.3 | +12.5 | + 5.4 |
| | 95 | | 8 | | | 2.133 | 1.995 | 1.067 | .0108 | .0113 | 113.5 | 132.5 | 1.85 | 1.81 | 1.99 | 1.74 | 1.88 | + 7.7 | +10.4 | + 0.3 | +14.4 | + 6.3 |
| | 96 | | 1 | | | 2.144 | 2.006 | 1.101 | .0108 | .0113 | 111.8 | 131.0 | 1.89 | 1.84 | 2.02 | 1.77 | 1.91 | + 6.1 | + 9.2 | − 0.7 | +13.1 | + 4.9 |
| | 97 | | 7 | | | 2.822 | 2.640 | 1.814 | .0107 | .0110 | 114.7 | 131.6 | 2.49 | 2.41 | 2.67 | 2.28 | 2.48 | + 6.1 | + 9.6 | − 1.0 | +15.7 | + 6.5 |
| 19 | 98 | S-10, 1914 | 2 | 14.00 | Congdon Orchards, Wash- | 6.64 | 6.22 | 10.015 | .0107 | .0105 | 115.2 | 123.3 | 6.40 | 6.05 | 6.88 | 5.46 | 6.07 | − 2.8 | + 2.8 | − 9.6 | +13.9 | + 2.5 |
| | 99 | | 1 | | ington. Jointed, machine | 6.66 | 6.24 | 10.232 | .0107 | .0105 | 114.3 | 122.3 | 6.50 | 6.12 | 6.96 | 5.52 | 6.14 | − 4.0 | + 2.0 | −10.5 | +13.0 | + 1.6 |
| | 100 | | 3 | | banded pipe. Straight. | 6.66 | 6.24 | 10.407 | .0108 | .0105 | 113.6 | 121.2 | 6.55 | 6.18 | 7.03 | 5.57 | 6.19 | − 4.7 | + 1.0 | −11.2 | +12.1 | + 0.7 |
| 20a | 101 | A 1898. . | 1 | 14.11 | West Los Angeles Water Co.: | .76 | .691 | .145 | .0106 | .0123 | 105.0 | 134.1 | .617 | .618 | .660 | .634 | .660 | +11.9 | +11.8 | + 4.7 | + 8.9 | + 4.7 |
| | 102 | | 1 | 14.08 | California redwood stave | .74 | .691 | .161 | .0109 | .0123 | 101.0 | 126.9 | .653 | .653 | .698 | .668 | .694 | + 5.8 | + 5.8 | − 1.0 | + 3.4 | − 0.3 |
| | 103 | | 1 | 14.05 | pipe for municipal use. | .75 | .698 | .170 | .0111 | .0123 | 99.0 | 124.7 | .673 | .672 | .718 | .685 | .713 | + 3.8 | + 3.9 | − 2.8 | + 1.8 | − 2.1 |
| | 104 | | 1 | 14.05 | Various reaches on same | .81 | .751 | .178 | .0108 | .0122 | 104.0 | 130.8 | .691 | .689 | .737 | .702 | .733 | + 8.6 | + 9.0 | + 1.9 | + 7.0 | + 2.4 |
| | 105 | | 2 | 14.05 | pipe considered together. | 1.27 | 1.181 | .375 | .0105 | .0118 | 113.0 | 137.6 | 1.05 | 1.03 | 1.12 | 1.03 | 1.09 | +12.5 | +14.7 | + 5.9 | +15.1 | + 8.8 |
| | 106 | | 1 | 14.05 | | 1.26 | 1.167 | .391 | .0107 | .0117 | 109.0 | 132.9 | 1.07 | 1.05 | 1.14 | 1.05 | 1.11 | + 9.1 | +10.8 | + 2.2 | +11.2 | + 5.0 |
| | 107 | | 2 | 14.05 | | 1.65 | 1.531 | .638 | .0108 | .0115 | 112.0 | 132.7 | 1.40 | 1.37 | 1.50 | 1.34 | 1.43 | + 9.3 | +11.7 | + 2.2 | +13.9 | + 6.8 |
| 21a | 108 | C 1908. . . | 2 | 16.12 | Bonito pipe line, New Mex- | 5.39 | 3.791 | 3.062 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| | 109 | C 1908. . . | 1 | | ico. Not used by writer | 5.40 | 3.805 | 3.062 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| | 110 | C 1909. . . | 3 | | for deriving formula as | 5.93 | 4.183 | 3.062 | .0092 | .0108 | 130.4 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| | 111 | C 1911. . . | 4 | | maximum velocity is taken | 6.19 | 4.37 | 3.062 | .0094 | .0108 | 137.0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| 22a | 112 | DB-52 | 1 | ........ | Experimental pipe. Closely | 1.895 | 1.230 | .533 | .0124 | .0118 | 94.3 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | − 1.6 | ...... |
| | 113 | 1859 | 2 | | jointed. Rectangular; | 2.74 | 1.778 | 1.067 | .0124 | .0114 | 96.4 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | − 0.5 | ...... |
| | 114 | | 3 | | 1.574 feet by 0.984 feet. | 3.50 | 2.276 | 1.733 | .0123 | .0113 | 96.8 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | − 1.0 | ...... |
| | 115 | | 4 | | Used by Tutton in deriv- | 4.52 | 2.939 | 2.733 | .0121 | .0110 | 99.5 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | + 2.0 | ...... |
| | 116 | | 5 | | ing formula. Not used by | 5.43 | 3.529 | 3.867 | .0120 | .0109 | 100.5 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | + 2.3 | ...... |
| | 117 | | 6 | | other authorities. | 6.70 | 4.349 | 6.267 | .0124 | .0107 | 97.3 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | − 1.4 | ...... |
| | 118 | | 7 | | | 7.13 | 4.625 | 7.267 | .0125 | .0107 | 96.1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | − 2.0 | ...... |
| | 119 | | 8 | | | 8.17 | 5.307 | 8.800 | .0121 | .0106 | 100.2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | − 1.0 | ...... |
| 23a | 120 | A 1896. . | 1 | 18.00 | Astoria, Oreg. Continuous | 6.369 | 3.605 | 1.963 | .0098 | .0111 | 132.9 | 147.0 | 3.07 | 2.95 | 3.32 | 2.81 | 3.06 | +17.3 | +22.3 | + 8.5 | +27.6 | +17.8 |
| | 121 | | 2 | | stave fir. | 6.369 | 3.605 | 1.963 | .0098 | .0111 | 132.9 | 147.0 | 3.07 | 2.95 | 3.32 | 2.81 | 3.06 | +17.3 | +22.3 | + 8.5 | +27.6 | +17.8 |

TABLE 2.—*Elements of experiments for the determination of friction losses in wood-stave pipes, with percentage comparison of observed velocities to formula velocities*—Continued.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Coefficients of retardation. | | | | Comparison, by various formulas, of observed to calculated velocities. Velocities, by formulas, for given H, per second. | | | | | Column 8 compared to columns 14–18, inclusive. | | | | |
| Pipe No. | Reference No. | Experimenter and year. | Observation. | d Diameter. | Name and description of pipe. | Q Discharge, per second. | V Mean velocity, per second. | H Loss of head, per 1,000 feet. | n Kutter, by observation. | n Kutter, normal. | C Chezy. | $C_w$ Williams-Hazen. | Scobey. | Williams-Hazen ($C_w$=120). | Moritz. | Tutton. | Weisbach. | Scobey. | Williams-Hazen ($C_w$=120). | Moritz. | Tutton. | Weisbach. |
| | | | | *Inches.* | | *Cu. ft.* | *Feet.* | *Feet.* | | | | | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* |
| 24a | 122 | EM 1910 | 3 | 18.00 | Sunnyside project, Washington. Same pipe as No. 25. | 3.877 | 2.194 | 0.902 | 0.0108 | 0.0116 | 119.4 | 136.1 | 1.99 | 1.93 | 2.16 | 1.90 | 2.04 | +10.2 | +13.5 | + 1.7 | +15.8 | + 7.8 |
| | 123 | | 2 | | | 4.998 | 2.829 | 1.339 | .0103 | .0113 | 126.5 | 141.8 | 2.47 | 2.39 | 2.71 | 2.31 | 2.51 | +14.5 | +18.1 | + 4.4 | +22.4 | +12.7 |
| | 124 | | 1 | | | 6.040 | 3.418 | 1.901 | .0102 | .0111 | 127.9 | 141.8 | 3.02 | 2.89 | 3.27 | 2.76 | 3.26 | +13.2 | +18.1 | + 4.5 | +23.8 | + 4.9 |
| 25a | 125 | EM 1910 | 8 | 18.00 | Sunnyside project, Washington. Same pipe as No. 24. Jointed, machine banded pipe. One gentle curve, otherwise straight. | .958 | .542 | .074 | .0108 | .0129 | 103.0 | 129.7 | .500 | .501 | .539 | .528 | .549 | + 8.3 | + 8.0 | + 0.6 | + 2.6 | − 1.3 |
| | 126 | | 7 | | | 1.271 | .719 | .126 | .0112 | .0127 | 104.6 | 129.7 | .670 | .666 | .724 | .694 | .723 | + 7.2 | + 8.0 | − 0.7 | + 3.5 | − 0.6 |
| | 127 | | 6 | | | 1.462 | .827 | .155 | .0110 | .0125 | 108.5 | 132.7 | .750 | .748 | .820 | .770 | .809 | +10.3 | +10.6 | + 0.8 | + 7.3 | + 2.3 |
| | 128 | | 5 | | | 1.756 | .994 | .212 | .0109 | .0123 | 111.4 | 134.8 | .892 | .885 | .966 | .903 | .956 | +11.3 | +12.3 | + 2.9 | +10.0 | + 3.8 |
| | 129 | | 4 | | | 2.471 | 1.398 | .382 | .0108 | .0120 | 116.7 | 137.9 | 1.24 | 1.22 | 1.34 | 1.22 | 1.30 | +12.7 | +14.8 | + 4.3 | +14.6 | + 7.7 |
| 26 | 130 | S–13 1914 | 1 | 18.00 | Congdon ditch, Washington. Continuous stave. | 1.979 | 1.12 | .190 | .0094 | .0122 | 132.8 | 161.3 | .837 | .824 | .908 | .853 | .90 | +33.7 | +35.9 | +23.5 | +31.1 | +24.3 |
| | 131 | | 2 | | | 3.481 | 1.97 | .847 | .0114 | .0116 | 110.3 | 126.5 | 1.92 | 1.82 | 2.08 | 1.83 | 1.97 | + 2.4 | + 8.3 | − 5.4 | + 7.3 | + 0.1 |
| 27 | 132 | S–7 1914 | 1 | 18.00 | Burbank Co., Washington. Jointed, fir siphon. | 3.503 | 2.077 | 1.107 | .0122 | .0115 | 102.0 | 115.3 | 2.24 | 2.16 | 2.42 | 2.10 | 2.26 | − 7.3 | − 3.9 | −14.0 | − 0.9 | − 8.0 |
| | 133 | | 2 | | | 4.023 | 2.277 | 1.248 | .0120 | .0115 | 105.2 | 118.3 | 2.39 | 2.31 | 2.58 | 2.23 | 2.40 | − 4.7 | − 1.5 | −11.9 | + 1.8 | − 5.1 |
| 28a | 134 | EM 1910 | 7 | 22.00 | Sunnyside project, Washington. Jointed pipe. Machine banded, reach tested is two tangents intersecting at angle about 5 degrees. Some unusual condition here. | 1.813 | .687 | .070 | .0099 | .0130 | 121.1 | 149.3 | .548 | .552 | .601 | .586 | .614 | +25.3 | +24.5 | +14.4 | +17.2 | +11.8 |
| | 135 | | 6 | | | 2.753 | 1.043 | .174 | .0108 | .0125 | 116.9 | 138.7 | .92 | .903 | .996 | .932 | .991 | +13.3 | +15.5 | + 4.7 | +11.8 | + 5.3 |
| | 136 | | 5 | | | 3.585 | 1.358 | .348 | .0119 | .0122 | 107.5 | 124.2 | 1.34 | 1.31 | 1.46 | 1.33 | 1.41 | + 1.4 | + 3.6 | − 7.1 | + 2.2 | − 3.8 |
| | 137 | | 3 | | | 4.569 | 1.731 | .492 | .0114 | .0121 | 115.4 | 131.8 | 1.62 | 1.59 | 1.77 | 1.49 | 1.69 | + 6.8 | + 8.9 | − 2.4 | +16.0 | + 2.4 |
| | 138 | | 4 | | | 4.709 | 1.784 | .616 | .0122 | .0121 | 106.1 | 119.8 | 1.84 | 1.79 | 2.01 | 1.78 | 1.89 | − 3.2 | − 0.2 | −11.2 | + 0.4 | − 5.7 |
| | 139 | | 1 | | | 7.803 | 2.956 | 1.786 | .0126 | .0117 | 103.4 | 111.7 | 3.32 | 3.18 | 3.63 | 3.06 | 3.28 | −10.9 | − 6.8 | −18.4 | − 3.3 | − 9.9 |
| | 140 | | 2 | | | 8.259 | 3.128 | 2.017 | .0127 | .0115 | 102.7 | 110.8 | 3.54 | 3.39 | 3.88 | 3.25 | 3.49 | −11.6 | − 7.6 | −19.4 | − 3.9 | −10.4 |

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29 | 141 | S-2 1914. | 4 | 24.06 | Butler Water Works, Pennsylvania. Jointed white-pine pipe on continuous down slope. Wire-wound. | 2.690 | .854 | .128 | .0117 | .0128 | 106.6 | 126.8 | .815 | .809 | .894 | .845 | .903 | + 4.8 | + 5.6 | − 4.4 | + 1.0 | − 5.4 |
| | 142 | | 2 | | | 2.824 | .897 | .196 | .0137 | .0128 | 90.5 | 105.5 | 1.03 | 1.02 | 1.13 | 1.05 | 1.13 | −12.8 | −12.1 | −20.6 | −14.8 | −20.5 |
| | 143 | | 3 | | | 2.886 | .916 | .202 | .0136 | .0127 | 91.1 | 106.4 | 1.04 | 1.03 | 1.15 | 1.06 | 1.15 | −12.3 | −11.2 | −20.2 | −13.9 | −20.2 |
| | 144 | | 1 | | | 3.570 | 1.13 | .239 | .0124 | .0126 | 103.3 | 119.9 | 1.15 | 1.13 | 1.26 | 1.16 | 1.26 | − 1.7 | − 0.1 | −10.3 | − 2.6 | −10.3 |
| 30 | 145 | S-1 1914. | 1 | 22.8 | Norfolk County Water Co., Virginia. Jointed pipe. | 2.608 | .918 | .135 | .0110 | .0127 | 114.4 | 136.6 | .81 | .807 | .887 | .840 | .905 | +13.3 | +13.8 | + 3.5 | + 9.1 | + 1.3 |
| | 146 | | 2 | | | 2.615 | .926 | .156 | .0116 | .0127 | 107.6 | 127.8 | .87 | .871 | .960 | .903 | .968 | + 6.4 | + 6.4 | − 3.5 | + 2.6 | − 4.3 |
| 31 | 147 | S-15 1914 | 2 | 24.00 | Ogden Water Works, Utah. Continuous stave. | 9.872 | 3.142 | 1.429 | .0115 | .0116 | 117.5 | 126.8 | 3.10 | 2.98 | 3.41 | 2.89 | 3.40 | + 1.3 | + 5.6 | − 7.8 | + 8.7 | − 7.6 |
| | 148 | | 1 | | | 9.907 | 3.153 | 1.375 | .0113 | .0116 | 120.2 | 130.1 | 3.02 | 2.91 | 3.33 | 2.83 | 3.34 | + 4.3 | + 8.4 | − 5.2 | +11.3 | − 5.7 |
| 32a | 149 | H-1892 | 1 | 24.00 | Butte Water Works, Montana. | 3.6 | 1.147 | ...... | .0103 | .0125 | 127.0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| 33a | 150 | DB-51 1857 | 1 | ...... | Experimental pipe, closely jointed. Rectangular, 2.624 feet by 1.64 feet. | ...... | 1.666 | .475 | .0122 | .0122 | 107.6 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | + 0.6 | ...... |
| | 151 | | 2 | | | ...... | 2.519 | 1.076 | .0123 | .0117 | 108.1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| | 152 | | 3 | | | ...... | 3.372 | 1.899 | .0122 | .0115 | 108.9 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| | 153 | | 4 | | | ...... | 4.225 | 2.911 | .0122 | .0112 | 110.2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | + 1.0 | ...... |
| | 154 | | 5 | | | ...... | 5.068 | 4.272 | .0123 | .0111 | 109.1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| | 155 | | 6 | | | ...... | 5.527 | 5.063 | .0123 | .0110 | 109.3 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| | 156 | | 7 | | | ...... | 5.914 | 5.760 | .0123 | .0110 | 109.7 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| | 157 | | 8 | | | ...... | 6.373 | 6.614 | .0122 | .0109 | 110.3 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| 34a | 158 | JDS-1891 | 1 | 30.00 | Denver Water Works, Colorado. | ...... | ...... | ...... | .0096 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| 35a | 159 | JM-1911. | 14 | 31.00 | Sunnyside project, Washington. Continuous stave fir siphon pipe. See also pipe No. 36. Intake from open feed canal, with high velocity in earth section. | 3.05 | .582 | .063 | .0129 | .0133 | 91.4 | 107.8 | .645 | .647 | .720 | .695 | .744 | − 9.7 | −10.2 | −19.2 | −16.4 | −21.8 |
| | 160 | | 13 | | | 3.85 | .735 | .094 | .0134 | .0133 | 93.5 | 109.7 | .805 | .803 | .900 | .854 | .914 | − 8.7 | − 8.7 | −18.3 | −14.0 | −19.6 |
| | 161 | | 12 | | | 4.94 | .943 | .142 | .0138 | .0131 | 98.4 | 112.7 | 1.01 | 1.00 | 1.13 | 1.05 | 1.13 | − 6.6 | − 6.0 | −16.7 | −10.6 | −16.5 |
| | 162 | | 11 | | | 5.90 | 1.126 | .197 | .0133 | .0130 | 99.9 | 112.7 | 1.22 | 1.20 | 1.36 | 1.25 | 1.34 | − 7.7 | − 6.0 | −16.9 | − 9.6 | −15.9 |
| | 163 | | 10 | | | 6.87 | 1.311 | .267 | .0135 | .0128 | 99.9 | 111.4 | 1.44 | 1.41 | 1.61 | 1.46 | 1.56 | − 9.0 | − 7.2 | −18.7 | − 9.9 | −16.2 |
| | 164 | | 9 | | | 8.90 | 1.698 | .398 | .0129 | .0125 | 107.2 | 116.3 | 1.79 | 1.75 | 2.00 | 1.78 | 1.92 | − 5.2 | − 3.2 | −15.3 | − 4.8 | −11.7 |
| | 165 | | 1 | | | 21.32 | 4.068 | 1.621 | .0114 | .0115 | 125.7 | 130.5 | 3.91 | 3.74 | 4.37 | 3.65 | 3.97 | + 3.9 | + 8.6 | − 6.8 | +11.4 | + 2.3 |
| 36a | 166 | JM-1911. | 8 | 31.00 | Sunnyside project, Washington. This reach included in that covered by No. 35. Practically straight on continuous down grade. | 11.59 | 2.211 | .757 | .0137 | .0122 | 100.0 | 107.0 | 2.57 | 2.48 | 2.86 | 2.48 | 2.67 | −14.0 | −10.8 | −22.8 | −10.7 | −17.4 |
| | 167 | | 7 | | | 13.56 | 2.587 | .962 | .0133 | .0121 | 103.8 | 110.0 | 2.93 | 2.82 | 3.27 | 2.80 | 3.02 | −11.7 | − 8.3 | −20.9 | − 7.7 | −14.4 |
| | 168 | | 6 | | | 16.38 | 3.125 | 1.347 | .0131 | .0119 | 106.0 | 110.9 | 3.53 | 3.38 | 3.94 | 3.32 | 3.59 | −11.4 | − 7.6 | −20.6 | − 5.9 | −12.9 |
| | 169 | | 5 | | | 16.51 | 3.150 | 1.390 | .0132 | .0118 | 105.1 | 109.8 | 3.60 | 3.44 | 4.01 | 3.38 | 3.64 | −12.5 | − 8.6 | −21.4 | − 6.5 | −13.6 |
| | 170 | | 3 | | | 20.34 | 3.881 | 1.959 | .0128 | .0117 | 109.1 | 112.4 | 4.35 | 4.14 | 4.85 | 4.02 | 4.36 | −10.7 | − 6.4 | −20.0 | − 3.5 | −11.1 |
| | 171 | | 2 | | | 21.11 | 4.028 | 1.648 | .0115 | .0116 | 123.5 | 128.1 | 3.96 | 3.77 | 4.41 | 3.68 | 4.00 | + 1.7 | + 6.6 | − 8.6 | + 9.4 | + 0.5 |
| | 172 | | 4 | | | 24.05 | 4.589 | 2.661 | .0127 | 0.115 | 110.7 | 112.7 | 5.16 | 4.89 | 5.75 | 4.70 | 5.09 | −11.0 | − 6.0 | −20.2 | − 2.4 | − 9.8 |
| 37 | 173 | S-4 1914. | 2 | 36.00 | Pasco Reclamation Co., Washington. Continuous stave. | 11.69 | 1.653 | .360 | .0133 | .0127 | 100.7 | 109.0 | 1.87 | 1.82 | 2.11 | 1.87 | 2.04 | −11.5 | − 9.2 | −21.4 | −11.3 | −19.1 |
| | 174 | | 1 | | | 13.84 | 1.957 | .570 | .0147 | .0126 | 94.8 | 100.7 | 2.42 | 2.33 | 2.71 | 2.36 | 2.58 | −19.1 | −16.0 | −27.9 | −17.0 | −24.1 |
| 38 | 175 | S-5 1914. | 1 | 36.00 | Pasco Reclamation Co., Washington. Continuous stave. | 15.30 | 2.164 | .628 | .0141 | .0124 | 99.8 | 106.5 | 2.55 | 2.44 | 2.87 | 2.48 | 2.70 | −15.1 | −11.3 | −24.5 | −12.7 | −19.9 |
| | 176 | | 2 | | | 16.01 | 2.265 | .636 | .0136 | .0123 | 103.9 | 110.8 | 2.57 | 2.45 | 2.89 | 2.50 | 2.72 | −11.8 | − 7.7 | −21.5 | − 9.2 | −16.7 |
| 39 | 177 | S-8 1914. | 1 | 38.13 | Burbank Co., Washington. | 10.07 | 1.271 | .142 | .0117 | .0131 | 119.6 | 133.4 | 1.16 | 1.14 | 1.31 | 1.21 | 1.26 | + 9.7 | +11.2 | − 2.7 | + 5.3 | + 1.2 |

TABLE 2.—*Elements of experiments for the determination of friction losses in wood-stave pipes, with percentage comparison of observed velocities to formula velocities*—Continued.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Coefficients of retardation. | | | | Comparison, by various formulas, of observed to calculated velocities. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Velocities, by formulas, for given H, per second. | | | | | Column 8 compared to columns 14–18, inclusive. | | | | |
| | | | | | | | | | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| Pipe No. | Reference No. | Experimenter and year. | Observation. | Diameter. d | Name and description of pipe. | Discharge, per second. Q | Mean velocity, per second. V | Loss of head, per 1,000 feet. H | Kutter, by observation. n | Kutter, normal. n | Chezy. C | Williams-Hazen. $C_w$ | Scobey. | Williams-Hazen ($C_w$=120). | Moritz. | Tutton. | Weisbach. | Scobey. | Williams-Hazen ($C_w$=120). | Moritz. | Tutton. | Weisbach. |
| | | | | *Inches.* | | *Cu. ft.* | *Feet.* | *Feet.* | | | | | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* |
| 40 | 179 | S-6 1914. | 2 | 40.00 | Burbank Co., Washington. | 18.03 | 2.066 | 0.401 | 0.0128 | 0.0126 | 113.0 | 120.1 | 2.14 | 2.07 | 2.41 | 2.12 | 2.26 | − 3.4 | + 0.1 | −14.1 | − 2.4 | − 8.5 |
| | 180 | | 3 | | Continuous stave fir. | 18.56 | 2.126 | .339 | .0116 | .0125 | 126.6 | 135.4 | 1.94 | 1.88 | 2.19 | 1.94 | 2.06 | + 9.5 | +12.8 | − 3.0 | + 9.5 | + 3.1 |
| 41a | 181 | N 1901.. | 1 | 44.50 | Seattle Water Works, Washington. Continuous stave | 37.44 | 3.464 | 1.067 | .0134 | .0122 | 110.1 | 110.9 | 3.93 | 3.75 | 4.46 | 3.74 | 4.12 | −11.8 | − 7.6 | −22.2 | − 7.5 | −16.0 |
| | 182 | | 2 | | fir pipe. Practically | 38.06 | 3.522 | 1.134 | .0136 | .0121 | 108.6 | 109.1 | 4.07 | 3.87 | 4.62 | 3.86 | 4.31 | −13.4 | − 9.0 | −23.7 | − 8.8 | −18.2 |
| | 183 | | 3 | | straight. No interior | 39.82 | 3.685 | 1.191 | .0133 | .0121 | 110.9 | 111.2 | 4.18 | 3.98 | 4.74 | 3.96 | 4.35 | −11.8 | − 7.4 | −22.2 | − 6.9 | −15.3 |
| | 184 | | 4 | | growth. This reach downstream from No. 44. | 41.44 | 3.853 | 1.262 | .0132 | .0121 | 112.6 | 112.7 | 4.32 | 4.10 | 4.90 | 4.08 | 4.50 | −10.8 | − 6.0 | −21.3 | − 5.5 | −14.2 |
| | 185 | | 5 | | | 42.84 | 3.964 | 1.330 | .0131 | .0121 | 112.9 | 112.4 | 4.45 | 4.22 | 5.04 | 4.19 | 4.62 | −10.9 | − 6.3 | −21.4 | − 5.3 | −14.2 |
| | 186 | | 6 | | | 42.54 | 3.972 | 1.331 | .0131 | .0121 | 113.0 | 112.9 | 4.45 | 4.22 | 5.05 | 4.19 | 4.62 | −10.6 | − 5.9 | −21.2 | − 5.2 | −14.1 |
| | 187 | | 7 | | | 44.04 | 4.075 | 1.404 | .0131 | .0120 | 112.9 | 112.7 | 4.58 | 4.35 | 5.20 | 4.30 | 4.74 | −11.1 | − 6.0 | −21.6 | − 5.4 | −14.0 |
| | 188 | | 11 | | | 47.71 | 4.415 | 1.613 | .0131 | .0119 | 113.7 | 113.9 | 4.95 | 4.68 | 5.61 | 4.62 | 5.10 | −10.9 | − 5.0 | −21.4 | − 4.5 | −13.6 |
| | 189 | | 10 | | | 49.66 | 4.595 | 1.757 | .0130 | .0119 | 113.8 | 112.4 | 5.17 | 4.91 | 5.89 | 4.83 | 5.31 | −11.1 | − 6.3 | −21.9 | − 4.6 | −13.4 |
| | 190 | | 9 | | | 50.09 | 4.635 | 1.757 | .0129 | .0119 | 114.8 | 113.4 | 5.17 | 4.91 | 5.89 | 4.83 | 5.30 | −10.3 | − 5.5 | −21.2 | − 3.9 | −12.5 |
| | 191 | | 8 | | | 52.21 | 4.831 | 1.888 | .0129 | .0118 | 115.4 | 113.7 | 5.40 | 5.10 | 6.13 | 5.01 | 5.48 | −10.5 | − 5.1 | −21.1 | − 3.4 | −11.8 |
| 42 | 192 | S-9 1914. | 2 | 48.00 | Cowiche siphon, Washington. | 38.32 | 3.14 | .452 | .0105 | .0123 | 147.7 | 152.4 | 2.56 | 2.47 | 2.92 | 2.54 | 2.81 | +22.6 | +27.3 | + 7.5 | +23.6 | +11.5 |
| | 193 | | 5 | | New inverted siphon. | 46.62 | 3.75 | .649 | .0104 | .0122 | 147.2 | 149.7 | 3.13 | 3.01 | 3.57 | 3.05 | 3.52 | +19.8 | +24.4 | + 5.0 | +22.7 | + 6.6 |
| | 194 | | 3 | | Steep legs joined by verti- | 57.83 | 4.61 | 1.095 | .0110 | .0120 | 139.3 | 138.8 | 4.18 | 3.98 | 4.77 | 3.99 | 4.79 | +10.2 | +15.6 | − 3.4 | +15.6 | − 3.7 |
| | 195 | | 4 | | cal curve. High velocity | 59.43 | 4.75 | 1.143 | .0110 | .0119 | 140.5 | 139.7 | 4.30 | 4.08 | 4.89 | 4.08 | 4.87 | +10.5 | +16.5 | − 2.8 | +16.2 | − 2.5 |
| | 196 | | 1 | | prevents silt. | 59.09 | 4.84 | 1.174 | .0109 | .0118 | 141.3 | 140.2 | 4.36 | 4.14 | 4.96 | 4.13 | 4.94 | +10.8 | +16.9 | − 2.4 | +17.0 | − 2.1 |
| 43a | 197 | JM 1911. | 1 | 48.75 | Mabton pressure pipe. Sun- | 30.0 | 2.315 | .283 | .0111 | .0127 | 136.6 | 143.3 | 2.00 | 1.94 | 2.28 | 2.02 | 2.25 | +15.6 | +19.3 | + 1.7 | +14.5 | + 2.8 |
| | 198 | | 2 | | nyside project, Washing- | 36.4 | 2.809 | .335 | .0101 | .0124 | 152.3 | 158.8 | 2.18 | 2.12 | 2.50 | 2.20 | 2.46 | +28.9 | +32.3 | +12.3 | +27.5 | +14.2 |
| | 199 | | 3 | | ton. Continuous stave. | 46.2 | 3.565 | .608 | .0108 | .0122 | 143.4 | 146.1 | 3.06 | 2.93 | 3.48 | 2.98 | 3.32 | +16.3 | +21.8 | + 2.4 | +19.6 | + 7.4 |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 44a | 200 | N 1901. . | 2 | 54.19 | Seattle Water Works, Washington. Continuous stave fir pipe. Gentle curves. Some growths, Spongilla. On even gradient except one depression. Intake in low diversion dam from river. See No. 41. | 36.53 | 2.276 | .342 | .0131 | .0128 | 115.8 | 119.1 | 2.38 | 2.29 | 2.72 | 2.38 | 2.66 | − 4.6 | − 0.7 | −16.4 | − 4.8 | −14.5 |
| | 201 | | 1 | | | 36.62 | 2.282 | .342 | .0130 | .0128 | 116.1 | 119.3 | 2.38 | 2.29 | 2.72 | 2.38 | 2.68 | − 4.1 | − 0.6 | −16.2 | − 4.2 | −14.8 |
| | 202 | | 3 | | | 42.53 | 2.650 | .436 | .0127 | .0127 | 119.4 | 120.7 | 2.72 | 2.63 | 3.19 | 2.70 | 3.04 | − 2.6 | + 0.5 | −17.0 | − 1.8 | −12.8 |
| | 203 | | 5 | | | 48.87 | 3.045 | .557 | .0126 | .0125 | 121.4 | 122.4 | 3.12 | 2.99 | 3.57 | 3.06 | 3.42 | − 2.4 | + 2.0 | −14.8 | − 0.5 | −11.1 |
| | 204 | | 4 | | | 49.22 | 3.067 | .558 | .0125 | .0125 | 122.1 | 123.1 | 3.12 | 2.99 | 3.57 | 3.06 | 3.46 | − 1.6 | + 2.7 | −14.2 | + 0.1 | −11.2 |
| | 205 | | 6 | | | 54.69 | 3.408 | .672 | .0124 | .0124 | 123.7 | 123.8 | 3.47 | 3.31 | 3.97 | 3.37 | 3.76 | − 1.8 | + 3.2 | −14.5 | + 1.2 | − 9.2 |
| | 206 | | 7 | | | 59.77 | 3.724 | .783 | .0123 | .0122 | 125.2 | 124.5 | 3.78 | 3.59 | 4.32 | 3.64 | 4.08 | − 1.4 | + 3.7 | −13.7 | + 2.3 | − 8.6 |
| | 207 | | 8 | | | 62.98 | 3.924 | .856 | .0122 | .0121 | 126.2 | 125.0 | 3.97 | 3.77 | 4.53 | 3.81 | 4.26 | − 1.2 | + 4.2 | −13.3 | + 2.9 | − 7.8 |
| | 208 | | 9 | | | 67.66 | 4.215 | .983 | .0122 | .0121 | 126.5 | 124.7 | 4.28 | 4.06 | 4.90 | 4.09 | 4.56 | − 1.4 | + 4.0 | −13.7 | + 3.1 | − 7.6 |
| | 209 | | 10 | | | 70.92 | 4.419 | 1.076 | .0122 | .0120 | 126.7 | 124.5 | 4.48 | 4.26 | 5.15 | 4.28 | 4.77 | − 1.4 | + 3.7 | −14.2 | + 3.2 | − 7.2 |
| | 210 | | 11 | | | 75.24 | 4.688 | 1.162 | .0120 | .0120 | 129.2 | 126.6 | 4.70 | 4.44 | 5.37 | 4.45 | 4.96 | − 0.3 | + 5.3 | −12.7 | + 5.2 | − 5.5 |
| 45a | 211 | EM 1909. | 5 | 55.75 | Mabton pressure pipe. Continuous stave fir siphon pipe. This reach on continuous down slope. Intake from open canal. | 30.8 | 1.814 | .149 | .0111 | .0131 | 139.8 | 146.1 | 1.53 | 1.50 | 1.75 | 1.59 | 1.82 | +18.2 | +21.6 | + 3.6 | +14.5 | − 0.3 |
| | 212 | | 4 | | | 37.60 | 2.214 | .206 | .0108 | .0129 | 143.1 | 149.7 | 1.81 | 1.78 | 2.10 | 1.88 | 2.11 | +22.3 | +24.6 | + 5.6 | +17.8 | + 4.8 |
| | 213 | | 3 | | | 44.32 | 2.610 | .266 | .0105 | .0127 | 148.3 | 153.7 | 2.10 | 2.04 | 2.42 | 2.14 | 2.41 | +24.2 | +27.9 | + 8.0 | +22.0 | + 8.2 |
| | 214 | | 2 | | | 51.05 | 3.006 | .356 | .0106 | .0125 | 147.7 | 151.2 | 2.47 | 2.37 | 2.84 | 2.49 | 2.79 | +21.7 | +25.9 | + 5.8 | +20.6 | + 7.6 |
| | 215 | | 1 | | | 53.40 | 3.145 | .380 | .0105 | .0124 | 149.6 | 152.7 | 2.57 | 2.48 | 2.94 | 2.57 | 2.89 | +22.3 | +27.1 | + 6.8 | +22.4 | + 8.8 |
| 46a | 216 | EM 1910. | 9 | 55.75 | Mabton pressure pipe. Same reach as No. 45, one year later. This pipe rebuilt in 1915. Tests show this pipe far smoother than normal. Probably no sediment in this reach. See Nos. 43 and 45. | 21.46 | 1.246 | .086 | .0117 | .0135 | 124.6 | 135.0 | 1.12 | 1.11 | 1.29 | 1.21 | 1.34 | +12.9 | +12.3 | − 2.1 | + 3.0 | − 6.0 |
| | 217 | | 8 | | | 25.70 | 1.513 | .114 | .0115 | .0133 | 131.4 | 140.1 | 1.30 | 1.29 | 1.51 | 1.39 | 1.57 | +16.4 | +17.2 | + 0.2 | + 8.8 | − 3.3 |
| | 218 | | 7 | | | 31.44 | 1.852 | .163 | .0114 | .0131 | 134.6 | 142.1 | 1.60 | 1.57 | 1.84 | 1.67 | 1.88 | +15.7 | +18.2 | + 0.6 | +10.9 | − 1.5 |
| | 219 | | 5 | | | 40.90 | 2.409 | .259 | .0112 | .0127 | 138.6 | 143.9 | 2.07 | 2.01 | 2.38 | 2.12 | 2.38 | +16.3 | +19.7 | + 1.2 | +13.6 | + 1.3 |
| | 220 | | 6 | | | 48.82 | 2.875 | .350 | .0110 | .0126 | 142.5 | 146.0 | 2.45 | 2.37 | 2.82 | 2.47 | 2.77 | +17.4 | +21.5 | + 2.1 | +16.5 | + 3.7 |
| | 221 | | 1 | | | 52.10 | 3.068 | .397 | .0110 | .0125 | 142.7 | 145.5 | 2.63 | 2.53 | 3.02 | 2.62 | 2.96 | +16.6 | +21.1 | + 1.6 | +17.0 | + 3.7 |
| | 222 | | 4 | | | 57.98 | 3.415 | .483 | .0109 | .0123 | 144.1 | 145.7 | 2.93 | 2.82 | 3.36 | 2.91 | 3.26 | +16.6 | +21.2 | + 1.5 | +17.4 | + 4.8 |
| | 223 | | 3 | | | 64.32 | 3.788 | .583 | .0108 | .0122 | 145.4 | 146.0 | 3.25 | 3.12 | 3.74 | 3.20 | 3.59 | +16.5 | +21.5 | + 1.3 | +18.4 | + 5.4 |
| | 224 | | 2 | | | 66.85 | 3.937 | .602 | .0106 | .0122 | 148.7 | 149.1 | 3.31 | 3.17 | 3.80 | 3.25 | 3.65 | +19.0 | +23.7 | + 3.5 | +21.1 | + 7.7 |
| 47a | 225 | MWH 1897 | 35 | 72.5 | Pioneer Electric Power Co., Ogden, Utah. Continuous stave fir pipe. New. Both vertical and horizontal curves, maximum of latter 10 degrees. (R. 573 ft.) | 15.3 | .534 | .040 | .0204 | ...... | 69 | 74.0 | .872 | .867 | 1.02 | .969 | 1.11 | −38.7 | −38.4 | −47.4 | −44.8 | −51.8 |
| | 226 | | 47 | | | 15.6 | .544 | .025 | .0160 | ...... | 88 | 97.0 | .67 | .672 | .784 | .763 | .884 | −18.8 | −19.2 | −30.6 | −28.6 | −38.4 |
| | 227 | | 41 | | | 19.1 | .666 | .055 | .0199 | ...... | 73 | 77.6 | 1.04 | 1.03 | 1.21 | 1.14 | 1.31 | −36.0 | −35.3 | −40.5 | −41.6 | −49.2 |
| | 228 | | 30 | | | 23.4 | .816 | .020 | .0100 | ...... | 148 | 164.2 | .60 | .596 | .693 | .681 | .794 | +36.0 | +36.7 | +17.8 | +19.8 | + 2.8 |
| | 229 | | 48 | | | 34.9 | 1.217 | .095 | .0151 | .0137 | 101 | 105.6 | 1.41 | 1.38 | 1.64 | 1.51 | 1.73 | −13.6 | −12.0 | −25.9 | −19.2 | −29.6 |
| | 230 | | 36 | | | 35.2 | 1.228 | .100 | .0153 | .0136 | 100 | 103.2 | 1.45 | 1.42 | 1.69 | 1.55 | 1.77 | −15.3 | −13.6 | −27.3 | −20.5 | −30.6 |
| | 231 | | 37 | | | 35.6 | 1.242 | .095 | .0148 | .0136 | 104 | 107.9 | 1.41 | 1.38 | 1.64 | 1.51 | 1.73 | −11.9 | −10.1 | −24.3 | −17.6 | −28.3 |
| | 232 | | 42 | | | 38.2 | 1.332 | .106 | .0145 | .0136 | 106 | 109.1 | 1.49 | 1.46 | 1.74 | 1.59 | 1.83 | −10.6 | − 9.1 | −23.6 | −16.2 | −27.2 |
| | 233 | | 31 | | | 42.5 | 1.482 | .111 | .0135 | .0136 | 115 | 118.3 | 1.53 | 1.50 | 1.79 | 1.63 | 1.87 | − 3.1 | − 1.4 | −17.1 | − 9.0 | −20.8 |
| | 234 | | 49 | | | 53.8 | 1.876 | .181 | .0138 | .0134 | 114 | 115.2 | 2.01 | 1.95 | 2.35 | 2.09 | 2.40 | − 6.7 | − 4.3 | −20.0 | −10.3 | −21.8 |
| | 235 | | 43 | | | 56.7 | 1.978 | .211 | .0141 | .0133 | 111 | 111.8 | 2.19 | 2.12 | 2.55 | 2.26 | 2.59 | − 9.6 | − 6.8 | −22.5 | −12.4 | −23.6 |
| | 236 | | 32 | | | 61.3 | 2.138 | .211 | .0132 | .0133 | 120 | 122.3 | 2.19 | 2.12 | 2.55 | 2.26 | 2.59 | − 2.4 | + 1.7 | −16.2 | − 5.4 | −17.4 |
| | 237 | | 38 | | | 63.6 | 2.218 | .235 | .0135 | .0132 | 117 | 118.2 | 2.32 | 2.25 | 2.71 | 2.39 | 2.73 | − 4.5 | − 1.5 | −18.2 | − 7.1 | −18.8 |
| | 238 | | 50 | | | 72.7 | 2.536 | .300 | .0134 | .0130 | 119 | 118.4 | 2.67 | 2.57 | 3.12 | 2.71 | 3.10 | − 4.9 | − 1.3 | −18.7 | − 6.4 | −18.2 |
| | 239 | | 33 | | | 77.1 | 2.689 | .331 | .0133 | .0130 | 120 | 119.2 | 2.82 | 2.70 | 3.29 | 2.85 | 3.26 | − 4.6 | − 0.6 | −18.3 | − 5.6 | −17.5 |
| | 240 | | 39 | | | 79.8 | 2.783 | .361 | .0134 | .0129 | 119 | 117.8 | 2.96 | 2.83 | 3.46 | 2.97 | 3.40 | − 5.9 | − 1.7 | −19.6 | − 6.3 | −18.2 |
| | 241 | | 51 | | | 90.3 | 3.149 | .452 | .0132 | .0128 | 121 | 117.9 | 3.36 | 3.20 | 3.91 | 3.33 | 3.81 | − 6.2 | − 1.6 | −19.4 | − 5.4 | −17.3 |
| | 242 | | 34 | | | 99.0 | 3.453 | .517 | .0129 | .0127 | 124 | 120.2 | 3.62 | 3.44 | 4.22 | 3.57 | 4.18 | − 4.6 | + 0.2 | −18.2 | − 3.3 | −17.4 |
| | 243 | | 40 | | | 102.3 | 3.568 | .566 | .0132 | .0126 | 122 | 118.8 | 3.80 | 3.60 | 4.44 | 3.74 | 4.27 | − 6.1 | − 1.0 | −19.6 | − 4.6 | −16.4 |
| | 244 | | 46 | | | 103.7 | 3.617 | .501 | .0123 | .0125 | 131 | 127.8 | 3.56 | 3.40 | 4.17 | 3.53 | 4.03 | + 1.6 | + 6.1 | −13.2 | + 2.4 | −10.2 |
| | 245 | | 45 | | | 104.0 | 3.627 | .547 | .0127 | .0125 | 126 | 122.8 | 3.72 | 3.55 | 4.35 | 3.68 | 4.20 | − 2.4 | + 2.2 | −16.6 | − 1.4 | −13.6 |
| | 246 | | 44 | | | 104.5 | 3.645 | .576 | .0130 | .0125 | 123 | 120.3 | 3.84 | 3.64 | 4.48 | 3.77 | 4.30 | − 5.0 | − 0.2 | −18.6 | − 3.3 | −15.2 |

TABLE 2.—*Elements of experiments for the determination of friction losses in wood-stave pipes, with percentage comparison of observed velocities to formula velocities*—Continued.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Coefficients of retardation. | | | | Comparison, by various formulas, of observed to calculated velocities. Velocities, by formulas, for given H, per second. | | | | | Column 8 compared to columns 14–18, inclusive. | | | | |
| Pipe No. | Reference No. | Experimenter and year. | Observation. | d Diameter. | Name and description of pipe. | Q Discharge, per second. | V Mean velocity, per second. | H Loss of head, per 1,000 feet. | n Kutter, by observation. | n Kutter, normal. | C Chezy. | $C_w$ Williams-Hazen. | Scobey. | Williams-Hazen ($C_w$=120). | Moritz. | Tutton. | Weisbach. | Scobey. | Williams-Hazen ($C_w$=120). | Moritz. | Tutton. | Weisbach. |
| | | | | *Inches.* | | *Cu. ft.* | *Feet.* | *Feet.* | | | | | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* |
| 48a | 247 | MWH | J | 72.5 | Pioneer Electric Power Co., | 33.68 | 1.175 | 0.066 | 0.0130 | 0.0137 | 117.3 | 124.0 | 1.15 | 1.14 | 1.33 | 1.25 | 1.43 | + 2.1 | + 3.2 | −11.6 | − 5.9 | −17.7 |
| | 248 | 1899 | N | | Ogden, Utah. Longer | 35.66 | 1.244 | .074 | .0130 | .0136 | 117.7 | 124.6 | 1.23 | 1.20 | 1.42 | 1.32 | 1.52 | + 1.1 | + 3.7 | −12.4 | − 5.7 | −18.1 |
| | 249 | | L | | reach of same pipe as No. | 60.94 | 2.126 | .206 | .0130 | .0133 | 120.7 | 121.8 | 2.17 | 2.10 | 2.52 | 2.23 | 2.56 | − 2.0 | + 1.3 | −15.6 | − 4.6 | −16.9 |
| | 250 | | I | | 47. Two years interval | 61.41 | 2.144 | .213 | .0132 | .0132 | 119.5 | 120.8 | 2.21 | 2.13 | 2.57 | 2.27 | 2.60 | − 2.9 | + 0.7 | −16.4 | − 5.4 | −17.4 |
| | 251 | | Q | | between tests. Each let- | 83.72 | 2.920 | .378 | .0131 | .0129 | 122.2 | 120.7 | 3.04 | 2.91 | 3.54 | 3.05 | 3.48 | − 3.9 | + 0.6 | −17.4 | − 4.2 | −16.1 |
| | 252 | | 67 | | tered series the mean of | 85.63 | 2.987 | .396 | .0131 | .0129 | 122.2 | 120.2 | 3.12 | 2.98 | 3.64 | 3.12 | 3.56 | − 4.2 | + 0.2 | −17.8 | − 4.2 | −16.2 |
| | 253 | | K | | several observations. | 92.85 | 3.239 | .474 | .0132 | .0127 | 121.1 | 118.3 | 3.45 | 3.29 | 4.02 | 3.42 | 3.91 | − 6.1 | − 1.4 | −19.4 | − 5.2 | −17.2 |
| | 254 | | M | | | 95.28 | 3.324 | .498 | .0132 | .0127 | 121.2 | 118.4 | 3.54 | 3.37 | 4.13 | 3.50 | 4.00 | − 6.1 | − 1.3 | −19.4 | − 4.9 | −16.8 |
| | 255 | | 63 | | | 99.60 | 3.474 | .542 | .0132 | .0127 | 121.4 | 118.3 | 3.72 | 3.53 | 4.33 | 3.66 | 4.18 | − 6.6 | − 1.4 | −19.7 | − 5.1 | −16.8 |
| | 256 | | P | | | 101.10 | 3.527 | .557 | .0132 | .0126 | 121.7 | 118.4 | 3.78 | 3.57 | 4.39 | 3.71 | 4.24 | − 6.6 | − 1.3 | −19.6 | − 5.0 | −16.8 |
| | 257 | | 39 | | | 107.51 | 3.750 | .644 | .0133 | .0125 | 120.2 | 116.4 | 4.08 | 3.87 | 4.77 | 3.99 | 4.56 | − 8.0 | − 3.0 | −21.4 | − 6.0 | −17.7 |
| | 258 | | R | | | 127.26 | 4.439 | .889 | .0132 | .0123 | 121.2 | 116.0 | 4.87 | 4.60 | 5.70 | 4.70 | 5.37 | − 8.7 | − 3.2 | −22.1 | − 5.5 | −17.3 |
| | 259 | | U | | | 134.57 | 4.694 | .959 | .0131 | .0122 | 123.3 | 118.0 | 5.09 | 4.76 | 5.91 | 4.86 | 5.55 | − 7.8 | − 1.7 | −20.5 | − 3.4 | −15.4 |
| | 260 | | T | | | 138.89 | 4.845 | 1.027 | .0131 | .0121 | 123.0 | 117.0 | 5.28 | 4.97 | 6.19 | 5.06 | 5.78 | − 8.3 | − 2.4 | −21.8 | − 4.3 | −16.2 |
| | 261 | | S | | | 151.34 | 5.279 | 1.242 | .0132 | .0121 | 121.9 | 114.9 | 5.88 | 5.51 | 6.87 | 5.56 | 6.36 | −10.2 | − 4.2 | −23.2 | − 5.2 | −17.0 |
| 49a | 262 | EC–1884 | 1 | ........ | Moon Island Conduit....... | ....... | 4.8 | .843 | .0120 | .0122 | 135 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | + 5.0 | ...... |
| 50 | 263 | S–16, 1915 | 1 | 78.00 | Mohawk Hydro Electric Co., | 30.2 | .911 | .058 | .0165 | .0138 | 93.8 | 98.8 | 1.12 | 1.11 | 1.32 | 1.23 | 1.47 | −18.7 | −17.7 | −31.0 | −25.8 | −38.0 |
| | 264 | | 2 | | New York. Continuous | 31.95 | .963 | .069 | .0170 | .0138 | 90.9 | 95.6 | 1.24 | 1.21 | 1.45 | 1.34 | 1.62 | −22.0 | −20.4 | −33.6 | −28.2 | −40.6 |
| | 265 | | 3 | | stave fir pipe. Gentle | 50.00 | 1.506 | .115 | .0144 | .0136 | 110.1 | 113.2 | 1.64 | 1.60 | 1.93 | 1.74 | 2.09 | − 8.2 | − 5.6 | −22.0 | −13.5 | −27.9 |
| | 266 | | 4 | | curves, both horizontally | 68.5 | 2.063 | .194 | .0139 | .0134 | 116.1 | 116.4 | 2.20 | 2.12 | 2.57 | 2.28 | 2.74 | − 6.2 | − 3.1 | −19.8 | − 9.6 | −24.8 |
| | 267 | | 5 | | and vertically. Water | 72.4 | 2.18 | .215 | .0136 | .0134 | 116.6 | 117.1 | 2.32 | 2.23 | 2.72 | 2.39 | 2.87 | − 6.1 | − 2.4 | −19.8 | − 8.8 | −24.0 |
| | 268 | | 6 | | from reservoir. Pipe prob- | 77.3 | 2.33 | .244 | .0138 | .0131 | 117.0 | 117.0 | 2.50 | 2.39 | 2.91 | 2.55 | 3.06 | − 6.7 | − 2.4 | −19.8 | − 8.6 | −23.9 |

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 269 | | 7 | | ably free from sediment. | 79.6 | 2.40 | .243 | .0132 | .0131 | 120.6 | 120.2 | 2.49 | 2.39 | 2.91 | 2.55 | 3.06 | − 3.6 | + 0.2 | −17.5 | − 5.9 | −21.5 |
| | 270 | | 8 | | Trunk line for power plant. | 81.1 | 2.443 | .289 | .0143 | .0131 | 112.7 | 111.7 | 2.73 | 2.62 | 3.20 | 2.79 | 3.34 | −10.5 | − 6.9 | −23.7 | −12.4 | −26.8 |
| | 271 | | 9 | | | 85.9 | 2.59 | .287 | .0134 | .0131 | 119.8 | 118.9 | 2.72 | 2.61 | 3.20 | 2.78 | 3.34 | − 4.8 | − 0.9 | −19.1 | − 7.0 | −22.6 |
| 51 | 272 | S-3, 1914 | 8 | 144.00 | Salmon River Power Co., | 672 | 5.94 | .514 | .0118 | .0124 | 151.2 | 134.7 | 5.62 | 5.29 | 6.77 | 5.60 | | + 5.7 | +12.1 | −12.2 | − 6.0 | |
| | 273 | | 10 | | New York. Continuous | 693 | 6.13 | .643 | .0128 | .0124 | 139.5 | 123.1 | 6.36 | 5.97 | 7.66 | 6.27 | | − 3.6 | + 2.6 | −20.0 | − 2.2 | |
| | 274 | | 9 | | stave fir pipe. Gentle hori- | 700 | 6.19 | .615 | .0124 | .0123 | 144.0 | 127.4 | 6.20 | 5.83 | 7.48 | 6.14 | | − 0.1 | + 5.9 | −17.2 | + 0.8 | |
| | 275 | | 1 | | zontal and no vertical | 714 | 6.31 | .694 | .0129 | .0123 | 138.3 | 121.7 | 6.64 | 6.22 | 8.00 | 6.52 | | − 4.8 | + 1.3 | −21.0 | − 3.5 | |
| | 276 | | 6 | | curves. Water from reser- | 728 | 6.44 | .724 | .0130 | .0123 | 138.1 | 121.4 | 6.79 | 6.36 | 8.18 | 6.66 | | − 5.2 | + 1.0 | −21.3 | − 3.6 | |
| | 277 | | 5 | | voir. Probably free from | 737 | 6.52 | .716 | .0127 | .0123 | 140.6 | 123.6 | 6.75 | 6.33 | 8.13 | 6.63 | | − 6.4 | + 2.9 | −19.8 | − 1.6 | |
| | 278 | | 2 | | sediment. Trunk line for | 757 | 6.69 | .770 | .0128 | .0123 | 139.2 | 122.0 | 7.02 | 6.59 | 8.47 | 6.88 | | − 4.6 | + 1.6 | −20.9 | − 2.7 | |
| | 279 | | 3 | | power plant. | 775 | 6.85 | .749 | .0124 | .0123 | 144.5 | 126.6 | 6.91 | 6.49 | 8.35 | 6.79 | | − 0.8 | + 5.4 | −17.9 | + 0.8 | |
| | 280 | | 7 | | | 930 | 8.22 | 1.061 | .0123 | .0121 | 145.7 | 126.0 | 8.40 | 7.83 | 10.12 | 8.10 | | − 2.1 | + 5.0 | −18.7 | + 1.4 | |
| | 281 | | 4 | | | 930 | 8.22 | 1.092 | .0125 | .0121 | 143.7 | 124.2 | 8.52 | 7.95 | 10.28 | 8.22 | | − 3.4 | + 3.5 | −20.0 | + 0.1 | |
| 52 | 282 | S-14, 1914 | 3 | 162.00 | Northwestern Electric Co. | 501 | 3.50 | .148 | .0117 | .0133 | 156.6 | 144.9 | 3.04 | 2.90 | 3.71 | 3.19 | | +15.2 | +20.8 | − 5.6 | + 9.8 | |
| | 283 | | 1 | | (Condit Plant), Washing- | 560 | 3.92 | .155 | .0106 | .0130 | 171.6 | 158.2 | 3.12 | 2.98 | 3.81 | 3.28 | | +25.6 | +31.9 | + 2.8 | +19.6 | |
| | 284 | | 2 | | ton. Continuous stave fir | 578 | 4.05 | .197 | .0116 | .0129 | 156.9 | 143.1 | 3.57 | 3.40 | 4.36 | 3.71 | | +13.3 | +19.2 | − 7.2 | + 9.0 | |
| | 285 | | 5 | | pipe. Gentle horizontal | 676 | 4.73 | .256 | .0113 | .0128 | 161.1 | 145.3 | 4.12 | 3.91 | 5.04 | 4.24 | | +14.7 | +21.1 | − 6.1 | +11.7 | |
| | 286 | | 4 | | and no vertical curves. | 871 | 6.09 | .452 | .0116 | .0124 | 156.0 | 137.6 | 5.64 | 5.32 | 6.92 | 5.66 | | + 8.0 | +14.7 | −11.8 | + 7.6 | |
| | | | | | Total plus | | | | | | | | | | | | | 1,158.9 | 1,515.3 | 356.2 | 1,705.7 | 514.5 |
| | | | | | Total minus | | | | | | | | | | | | | 1,239.2 | 822.8 | 2,757.3 | 944.8 | 2,131.1 |
| | | | | | Net difference, plus | | | | | | | | | | | | | | +692.5 | | 760.9 | |
| | | | | | Net difference, minus | | | | | | | | | | | | | 80.3 | | 2,401.1 | | 1,616.6 |

NOTE.—See page 81 for additional tests. Net difference carried forward to Table 9, after additional tests.

TABLE 3.—*Summary of pipes.—Also weights used in finding general exponent of V, in new formula; values of m'; individual pipe formulas and comparison between observed and calculated velocities.*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Weights used in determining general exponent for V. | | | | | 15 | 16 | 17 | Means, by pipes, of percentages in columns 19 to 23, inclusive, Table 2. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 10 | 11 | 12 | 13 | 14 | | | | 18 | 19 | 20 | 21 | 22 |
| Pipe No. | Reference No. for observations. | Experimenter. | Age of pipe, years. | Diameter of bore. | Diameter of bore. | Length of reach tested. | Area of bore. | Range of velocities, per second. | Number of observations. | Distribution of observations. | Range of observations. | Range of velocities. | Total weight for exponent, X. | Weight for intercept. | Revised intercept, m'. | Individual pipe formulas; before revising value of intercept, m to m'. | Scobey. | Williams-Hazen ($C_w$=120). | Moritz. | Tutton. | Weisbach. |
| | | | | *Inches.* | *Feet.* | *Feet.* | *Sq. ft.* | *Feet.* | | | | | | | | | | | | | |
| 1a | 1- 5 | Hamilton Smith... | 0 | 1.26 | 0.11 | 62.1 | 0.009 | 1.653-3.986 | 5 | 0 | 0 | 0 | 0 | 0 | ...... | ........ | ...... | ...... | ...... | ...... | ...... |
| 2a | 6- 10 | E. A. Moritz...... | 3 | 4.00 | .33 | 603.0 | .087 | .425-1.678 | 5 | 7.5 | 11.9 | 2.8 | 1,000 | 3 | 2.006 | H=1.99 $V^{1.723}$ | } -12.3 | -11.0 | -12.7 | -00.3 | -11.7 |
| 3a | 11- 12 | .....do.......... | 3 | 4.00 | .33 | 1,109.5 | .087 | 3.586-4.460 | 2 | 0 | 0 | 0 | 0 | 1 | 1.715 | ........ | | | | | |
| 4a | 13- 20 | .....do.......... | 2 | 5.00 | .42 | 1,822.0 | .136 | .419-2.301 | 8 | 8.9 | 15.9 | 3.8 | 1,000 | 3 | 1.277 | H=1.27 $V^{1.895}$ | - 4.9 | - 3.7 | - 6.2 | + 4.0 | - 6.6 |
| 5a | 21- 25 | .....do.......... | .5 | 6.00 | .50 | 500.4 | .196 | .499-1.704 | 5 | 6.8 | 11.0 | 2.4 | 898 | 3 | .869 | H=0.869 $V^{1.808}$ | + 4.5 | + 5.4 | + 2.2 | +11.4 | + 1.9 |
| 6a | 26- 31 | .....do.......... | .3 | 6.00 | .50 | 1,801.0 | .196 | .403-1.281 | 6 | 6.6 | 10.6 | 1.8 | 755 | 3 | .882 | H=0.908 $V^{1.877}$ | + 3.8 | + 3.6 | + 1.3 | + 7.5 | + 1.0 |
| 7a | 32- 33 | .....do.......... | .3 | 6.00 | .50 | 1,892.0 | .196 | 1.526-2.327 | 2 | 0 | 0 | 0 | 0 | 1 | .929 | ........ | + 1.0 | + 3.2 | - 1.5 | +13.1 | + 0.7 |
| 8a | 34 | .....do.......... | .3 | 6.00 | .50 | 2,021.0 | .196 | 3.000 | 1 | 0 | 0 | 0 | 0 | 0 | ...... | ........ | - 0.3 | + 3.3 | - 2.8 | +16.1 | + 1.1 |
| 9a | 35- 43 | .....do.......... | .5 | 8.00 | .67 | 3,394.5 | .349 | 1.049-4.407 | 9 | 7.1 | 12.8 | 6.8 | 1,000 | 2 | .794 | H=0.745 $V^{1.847}$ | - 7.5 | - 4.5 | -11.1 | + 4.2 | - 6.1 |
| 10a | 44- 45 | .....do.......... | 5 | 8.00 | .67 | 2,002.0 | .349 | 1.241-2.241 | 2 | 0 | 0 | 0 | 0 | 2 | .759 | ........ | - 6.3 | - 4.2 | -10.0 | + 2.8 | - 6.0 |
| 11a | 46- 53 | .....do.......... | 1.5 | 8.00 | .67 | 3,515.2 | .349 | 1.648-5.874 | 8 | 5.4 | 11.1 | 8.4 | 1,000 | 2 | .488 | H=0.528 $V^{1.724}$ | +19.5 | +23.8 | +14.8 | +36.2 | +20.2 |
| 12a | 54- 57 | .....do.......... | 1.5 | 8.00 | .67 | 4,054.9 | .349 | .453-1.212 | 4 | 6.5 | 8.1 | 1.4 | 294 | 2 | .614 | H=0.576 $V^{1.590}$ | + 5.2 | + 5.3 | + 1.3 | + 7.2 | + 2.2 |
| 13 | 58- 65 | Fred. C. Scobey... | 7 | 8.00 | .67 | 1,503.0 | .349 | .316-3.558 | 8 | 10.4 | 19.2 | 6.6 | 1,000 | 3 | .782 | H=0.800 $V^{1.760}$ | - 7.8 | - 5.5 | -11.2 | + 1.4 | - 8.1 |
| 14 | 66- 70 | .....do.......... | 7 | 10.00 | .83 | 1,242.4 | .545 | 3.63 -5.08 | 4 | 0.7 | 3.6 | 3.0 | 30 | 3 | .612 | H=0.555 $V^{1.875}$ | - 9.7 | - 5.2 | -14.4 | + 6.0 | - 5.6 |
| 15a | 71- 74 | J. L. Campbell.... | 0-3 | 10.12 | .84 | 12,700 | .554 | 9.70 -11.7 | 4 | 0 | 0 | 0 | 0 | 0 | ...... | ........ | ...... | ...... | ...... | ...... | ...... |
| 16a | 75- 81 | E. A. Moritz...... | .3 | 12.00 | 1.00 | 2,022.0 | .785 | .459-1.803 | 7 | 7.3 | 12.0 | 2.8 | 1,000 | 3 | .560 | H=0.556 $V^{1.738}$ | -14.6 | -13.7 | -19.7 | -12.1 | -16.5 |
| 17a | 82- 89 | .....do.......... | 4 | 14.00 | 1.17 | 3,637.0 | 1.069 | .495-3.267 | 8 | 9.9 | 16.1 | 5.4 | 1,000 | 3 | .334 | H=0.341 $V^{1.730}$ | } + 5.6 | + 7.4 | - 1.3 | + 9.1 | + 2.3 |
| 18a | 90- 97 | .....do.......... | 5 | 14.00 | 1.17 | 3,637.0 | 1.069 | .572-2.64 | 7 | 8.0 | 14.0 | 4.4 | 1,000 | 3 | .305 | H=0.296 $V^{1.870}$ | | | | | |
| 19 | 98-100 | Fred. C. Scobey... | 5 | 14.00 | 1.17 | 1,251.7 | 1.069 | 6.22 -6.24 | 2 | 0 | 0 | 0 | 0 | 2 | .377 | ........ | - 3.8 | + 1.9 | -10.4 | +13.0 | + 1.6 |
| 20a | 101-107 | A. L. Adams...... | ...... | 14 | 1.17 | Various | 1.08 | .691-1.531 | 7 | 0 | 0 | 0 | 0 | 3 | .300 | ........ | + 8.7 | + 9.7 | + 1.9 | + 8.8 | + 3.6 |
| 21a | 108-111 | J. L. Campbell.... | 0-3 | 16.12 | 1.34 | 47,500 | 1.396 | 3.791-4.37 | 4 | 0 | 0 | 0 | 0 | 0 | ...... | ........ | ...... | ...... | ...... | ...... | ...... |
| 22a | 112-119 | Darcy and Bazin.. | ...... | ...... | ...... | 145.7 | 1.54 | 1.230-5.307 | 8 | 0 | 0 | 0 | 0 | 0 | ...... | H=0.348 $V^{1.933}$ | ...... | ...... | ...... | ...... | ...... |
| 23a | 120-121 | A. L. Adams...... | 1 | 18.00 | 1.50 | Text. | 1.767 | 3.605 | 2 | 0 | 0 | 0 | 0 | 1 | .194 | ........ | +17.3 | +22.3 | + 8.5 | +27.6 | +17.8 |
| 24a | 122-124 | E. A. Moritz...... | 2 | 18.00 | 1.50 | 2,802.5 | 1.767 | 2.194-3.418 | 3 | 0 | 0 | 0 | 0 | 3 | .210 | ........ | } +10.8 | +12.9 | + 3.6 | +12.4 | + 8.1 |
| 25a | 125-129 | .....do.......... | 2 | 18.00 | 1.50 | 2,774.2 | 1.767 | .542-1.398 | 5 | 4.6 | 8.2 | 1.8 | 340 | 3 | .218 | H=0.215 $V^{1.703}$ | | | | | |
| 26 | 130-131 | Fred. C. Scobey... | .5 | 18.00 | 1.50 | 1,787.5 | 1.767 | 1.12 -1.97 | 2 | 0 | 0 | 0 | 0 | 2 | .196 | ........ | +18.0 | +22.1 | + 9.0 | +19.2 | +12.2 |
| 27 | 132-133 | .....do.......... | 1 | 18.00 | 1.50 | 1,479.1 | 1.767 | 2.077-2.277 | 2 | 0 | 0 | 0 | 0 | 2 | .290 | ........ | - 6.0 | - 2.7 | -12.9 | + 0.4 | - 6.6 |
| 28a | 134-140 | E. A. Moritz...... | 4 | 22.00 | 1.83 | 2,087.0 | 2.640 | .687-3.128 | 7 | 9.7 | 16.1 | 4.8 | 1,000 | 2 | .197 | H=0.161 $V^{2.176}$ | + 3.0 | + 5.4 | - 5.6 | + 5.8 | - 1.5 |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29 | 141–144 | Fred. C. Scobey | 7 | 24.00 | 2.01 | 1,357.7 | 3.15 | .854– 1.13 | 2 | 0 | 0 | 0 | 0 | 2 | .207 | | – 5.5 | – 4.4 | –13.9 | – 7.6 | –14.1 |
| 30 | 145–146 | .....do | 2 | 22.8 | 1.90 | 1,077.5 | 2.831 | .918– .926 | 2 | 0 | 0 | 0 | 0 | 2 | .168 | | + 9.8 | +10.1 | 0.0 | + 5.8 | – 1.5 |
| 31 | 147–148 | .....do | 24 | 24.00 | 2.00 | 2,240.7 | 3.142 | 3.142– 3.153 | 2 | 0 | 0 | 0 | 0 | 2 | .177 | | + 2.8 | + 7.0 | – 6.5 | +10.0 | – 6.6 |
| 32a | 149 | D. C. Henny | 0 | 24.00 | 2.00 | 18,389.0 | 3.142 | 1.147 | 1 | 0 | 0 | 0 | 0 | 0 | | | | | | | |
| 33a | 150–157 | Darcy and Bazin | | | | 230.6 | 4.3 | 1.666– 6.373 | 8 | 0 | 0 | 0 | 0 | 0 | | $H=0.176\ V^{1.904}$ | | | | | |
| 34a | 158 | J. D. Schuyler | 0 | 30 | 2.5 | | | | 1 | 0 | 0 | 0 | 0 | 0 | | | | | | | |
| 35a | 159–165 | J. S. Moore | 0 | 31 | 2.58 | 7,354.0 | 5.241 | .582– 4.068 | 7 | 8.0 | 16.5 | 6.8 | 1,000 | 3 | .156 | $H=0.158\ V^{1.70}$ | – 6.1 | – 4.7 | –16.0 | – 7.7 | –14.2 |
| 36a | 166–172 | .....do | 0 | 31 | 2.58 | 4,513.5 | 5.241 | 2.211– 4.589 | 7 | 3.3 | 6.3 | 4.8 | 700 | 3 | .167 | $H=0.230\ V^{1.63}$ | – 9.9 | – 5.9 | –19.2 | – 3.9 | –11.2 |
| 37 | 173–174 | Fred. C. Scobey | 4 | 36.00 | 3.00 | 2,516.0 | 7.069 | 1.653– 1.957 | 2 | 0 | 0 | 0 | 0 | 2 | .158 | | –15.3 | –12.6 | –24.6 | –14.2 | –20.8 |
| 38 | 175–176 | .....do | 4 | 36.00 | 3.00 | 538.1 | 7.069 | 2.164– 2.265 | 2 | 0 | 0 | 0 | 0 | 2 | .151 | | –13.5 | – 9.5 | –23.0 | –10.9 | –18.3 |
| 39 | 177 | .....do | 1 | 38.13 | 3.18 | 5,965.9 | 7.922 | 1.271 | 1 | 0 | 0 | 0 | 0 | 1 | .092 | | + 9.7 | +11.2 | – 2.7 | + 5.3 | + 1.2 |
| 40 | 179–180 | .....do | 1.5 | 40.00 | 3.33 | 927.4 | 8.727 | 2.066– 2.126 | 2 | 0 | 0 | 0 | 0 | 2 | .097 | | + 3.0 | + 6.4 | – 8.5 | + 3.5 | – 2.7 |
| 41a | 181–191 | T. A. Noble | 1 | 44.5 | 3.71 | 4,041.0 | 10.81 | 3.464– 4.831 | 8 | 1.6 | 2.8 | 3.0 | 125 | 3 | .112 | $H=0.129\ V^{1.70}$ | –11.2 | – 6.4 | –21.7 | – 5.6 | –14.3 |
| 42 | 192–196 | Fred. C. Scobey | .5 | 48.00 | 4.00 | 887.4 | 12.57 | 3.14 – 4.84 | 4 | 2.1 | 4.6 | 3.4 | 150 | 3 | .065 | $H=0.032\ V^{2.31}$ | +14.8 | +20.2 | + 0.8 | +19.0 | + 2.0 |
| 43a | 197–199 | J. S. Moore | 2 | 48.75 | 4.06 | 1,341.0 | 12.96 | 2.315– 3.565 | 3 | 0 | 0 | 0 | 0 | 2 | .058 | | +19.6 | +24.5 | + 5.5 | +20.5 | + 8.1 |
| 44a | 200–210 | T. A. Noble | 1 | 54.19 | 4.52 | 2,446.7 | 16.05 | 2.276– 4.688 | 11 | 3.8 | 6.2 | 5.0 | 1,000 | 3 | .074 | $H=0.081\ V^{1.719}$ | – 2.1 | + 2.5 | –14.6 | + 0.6 | –10.0 |
| 45a | 211–215 | E. A. Moritz | .5 | 55.75 | 4.65 | 2,848.2 | 16.98 | 1.814– 3.145 | 5 | 3.2 | 4.7 | 2.6 | 196 | 3 | .049 | $H=0.052\ V^{1.696}$ | +18.3 | +21.7 | + 2.8 | +16.0 | + 3.2 |
| 46a | 216–224 | .....do | 1.5 | 55.75 | 4.65 | 2,848.2 | 16.98 | 1.246– 3.937 | 9 | 6.0 | 9.8 | 5.2 | 1,000 | 3 | .053 | $H=0.0555\ V^{1.747}$ | | | | | |
| 47a | 225–246 | Marx-Wing-Hoskins | 1 | 72.5 | 6.04 | 2,710.0 | 28.6 | .534– 3.645 | 17 | 8.9 | 16.2 | 6.2 | 1,000 | 2 | .060 | $H=0.067\ V^{1.618}$ | – 7.8 | – 5.1 | –20.8 | –11.2 | –22.7 |
| 48a | 247–261 | .....do | 3 | 72.5 | 6.04 | 22,672.0 | 28.6 | 1.175– 5.279 | 15 | 6.8 | 14.3 | 8.2 | 1,000 | 2 | .056 | $H=0.047\ V^{1.973}$ | – 5.2 | – 0.7 | –18.6 | – 5.0 | –16.9 |
| 49a | 262 | E. C. Clarke | | | | 2,486.5 | 36 | 4.8 | 1 | 0 | 0 | 0 | 0 | 0 | | | | | | | |
| 50 | 263–271 | Fred. C. Scobey | 5 | 78.00 | 6.5 | 2,650.0 | 33.18 | .911– 2.59 | 9 | 0 | 0 | 0 | 0 | 0 | | $H=0.056\ V^{1.690}$ | – 9.6 | – 6.5 | –22.9 | –13.3 | –27.8 |
| 51 | 272–281 | .....do | 1 | 144.00 | 12.0 | 2,169.3 | 113.1 | 5.94 – 8.22 | 8 | 1.7 | 3.6 | 4.5 | 220 | 2 | .024 | $H=0.020\ V^{1.891}$ | – 2.5 | + 4.3 | –18.9 | – 1.6 | |
| 52 | 282–286 | .....do | 1 | 162.00 | 13.5 | 2,378.9 | 142.9 | 3.50 – 6.10 | 5 | 3.4 | 5.5 | 5.1 | 477 | 2 | .016 | $H=0.010\ V^{2.143}$ | +15.4 | +21.5 | – 5.6 | +11.5 | |
| 53 | 287 | T. A. Noble and C. W. Harris. | | 4.00 | .33 | 717.7 | .0873 | 1.5 | | | | | | | | | + 2.4 | + 3.8 | + 2.1 | +17.2 | + 3.4 |
| | 288 | .....do | | 4.00 | .33 | 1,321.1 | .0873 | 2.1 | | | | | | | | | | | | | |
| 54 | 289 | R. E. Koon | 0 | 8.00 | .67 | 46,000.0 | .349 | 2.32 | | | | | | | | | + 0.4 | + 3.6 | – 3.4 | +12.3 | – 1.8 |
| 15 | 290–292 | J. L. Campbell | 0–3 | 10.12 | .84 | 12,700.0 | .554 | 10.3 –10.9 | | | | | | | | | + 4.8 | +12.5 | – 0.4 | +30.7 | +13.4 |
| 21 | 293–295 | .....do | 0–3 | 16.12 | 1.34 | 47,500.0 | 1.396 | 4.1 – 4.3 | | | | | | | | | +14.9 | +20.3 | + 6.7 | +28.0 | +16.7 |
| 55 | 296 | W. H. Taylor and N. Z. Ball. | 2 | 30.00 | 2.5 | 4,706.0 | 4.909 | 3.22 | | | | | | | | | +12.3 | +16.9 | + 0.9 | +18.0 | + 9.2 |
| 56 | 297 | .....do | 2 | 36.00 | 3.0 | 39,580.0 | 7.069 | 2.89 | | | | | | | | | +11.5 | +15.8 | – 0.7 | +14.8 | + 4.9 |
| 42 | 298 | Fred. C. Scobey | 9 | 48.00 | 4.0 | 887.4 | 12.57 | 5.095 | | | | | | | | | + 4.8 | +10.8 | – 7.8 | +11.6 | + 0.8 |
| 57 | 299–302 | J. D. Ross | 3 | 67.75 | 5.65 | 15,865.0 | 25.04 | 2.5 –10 | | | | | | | | $H=0.0402\ V^{1.962}$ | + 2.6 | + 8.8 | –11.3 | + 7.7 | – 6.7 |
| 58 | 303 | G. P. F. Boese and C. M. O'Neil. | 0 | 90.00 | 7.5 | 1,698.0 | 44.18 | 14.5 | | | | | | | | | – 4.4 | + 7.3 | –18.5 | + 7.3 | – 6.8 |
| 59 | 305 | Fred. C. Scobey | 2 | 96.00 | 8.0 | 1,239.1 | 50.26 | 6.18 | | | | | | | | | – 6.1 | + 0.2 | –20.5 | – 1.9 | –15.7 |
| 60 | 306–316 | A. C. Eaton and C. M. Allen. | 1 | 96.00 | 8.0 | 18,692.0 | 50.26 | 1.8 – 6.4 | | | | | | | | $H=0.0227\ V^{2.059}$ | + 6.6 | +12.2 | – 9.4 | + 6.7 | – 9.0 |
| 61 | 317–319 | Fred. C. Scobey | 16 | 120.00 | 10.00 | 6,698.0 | 78.54 | 3.2 – 7.8 | | | | | | | | $H=0.0337\ V^{1.760}$ | – 5.8 | 0.0 | –21.0 | – 4.5 | |
| 62 | 320–322 | .....do | 16 | 144.00 | 12.00 | 6,698.0 | 113.1 | 3.5 – 7.3 | | | | | | | | $H=0.0152\ V^{2.101}$ | – 4.5 | + 1.3 | –20.7 | – 4.5 | |
| | | Total plus | | | | | | | | | | | | | | | 251.1 | 369.2 | 61.4 | 452.7 | 135.6 |
| | | *Total minus | | | | | | | | | | | | | | | 182.7 | 106.3 | 471.0 | 104.3 | 289.8 |
| | | Net difference, plus | | | | | | | | | | | | | | | 68.4 | 262.9 | | 348.4 | |
| | | Net difference, minus | | | | | | | | | | | | | | | | | 409.6 | | 154.2 |
| | | Number of items | | | | | | | | | | | | | | | 53 | 53 | 53 | 53 | 49 |
| | | Average, per cent | | | | | | | | | | | | | | | +1.29 | +4.96 | –7.72 | +7.25 | –3.15 |

## DESCRIPTION OF PIPES.

The descriptions in the following pages are to be taken as supplementing Tables 2 and 3. The methods of determining the hydraulic elements necessary for each observation are described. The descriptions of pipes upon which previous experimenters have made observations are given in the appendix.

**No. 13, Expt. S–12, 8-inch Machine-Banded Douglas Fir Pipe, French Brothers' Orchard, North Yakima, Wash.**—From the lower end of the 10-inch pipe discussed as No. 14 a reach 1,751.5 feet long of 8-inch machine-banded pipe affords exceptional opportunity for investigation. This pipe conveys water to a high point in the orchard, from which it is distributed in open ditches. There are two taps in the line within the reach between the gauges. First is a 1¼-inch tap for lawn sprinkling; second, a 4-inch valve for irrigation purposes. These were closed tightly throughout the tests. Gauge No. 1, a mercury manometer, was placed 219 feet from the inlet valve. Gauge No. 2 was located 1,503 feet from gauge No. 1. For runs 1, 6, and 7 a water column was used. For runs 2, 3, 4, 5, and 8 a mercury manometer was used. An 8-inch control valve is located 17.5 feet downstream from gauge No. 2. A vertical iron pipe the same size as the wood pipe rises above the ground surface at this valve and discharges into a wooden division box. All but one ditch leading from this box were plugged with earth so that all the water was discharged at one end of the division box. This was equipped with a well-made Cipolletti weir 1.05 feet long. After run 3 this weir was removed and a rectangular weir, with end contractions suppressed, was built in its place. This weir was 2.84 feet long. Both weirs had clean-cut, sharp crests of galvanized iron. The change in weirs was necessary for the reason that it was desirable to run more water than could be accommodated through the Cipolletti weir and still maintain so-called standard conditions. The weirs were about 7 feet from the point where the water was turbulently discharged from the 8-inch pipe. From the place of impact to within about 2 feet of the weirs the box was filled with fresh-cut cottonwood branches and leaves. This mass formed an excellent screen from which the water emerged in good condition for weir measurement. A hook-gauge reading to thousandths of a foot was placed in the box above the weir. This permitted a direct comparison between the velocity in the pipe as determined with fluorescein and the velocity as determined by dividing the weir discharge by the nominal area of the pipe section. This comparison is shown in Table 1. The reach of pipe tested was without vertical curvature and had but one bend of about 20° about midway in its length. According to the best information available this pipe is about 7 years old and is used about 7 months of the year. It is buried about 3 feet below the surface and shows no signs of decay. The pipe capacity was approximately 8 per cent less than the discharge computed by the new formula.

**No. 14, Expt. S–11, 10-inch Jointed Machine-Banded Douglas Fir Pipe, Congdon Orchards, North Yakima, Wash.**—Irrigation water for the Congdon Orchards is conveyed from the main canal of the Yakima Valley Canal Co. in a 14-inch pipe (No. 19). From the lower end of this pipe a 10-inch pipe extends about one-half mile with a right angle bend about midway. A reach 1,297.4 feet long and without vertical or horizontal curvature was chosen at the lower end of the pipe, which was 7 years old at time of test and appeared to be free from leakage. The nominal size of the pipe was accepted as correct. Velocity was measured with fluorescein, the mean velocity shown by four batches of color for each run being accepted. The appearance of the color was awaited at a 6-inch hydrant 55 feet downstream from gauge No. 2. The color was injected at gauge No. 1. As the intake of this pipe line from the open canal is several miles from the river and the velocity in the pipe is rather high, it is improbable that there was any silt in the reach tested,

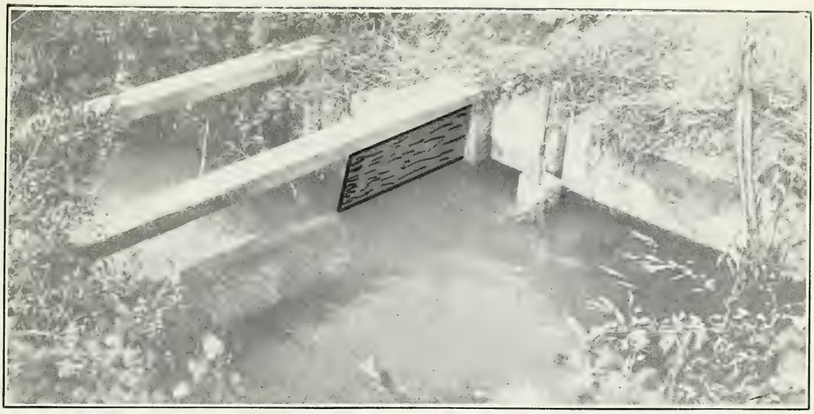


FIG. 1.—TYPICAL CIPOLLETTI WEIR, WITH HOOK GAUGE IN STILLING BOX.
Note brush screen in foreground to reduce velocity of approach.

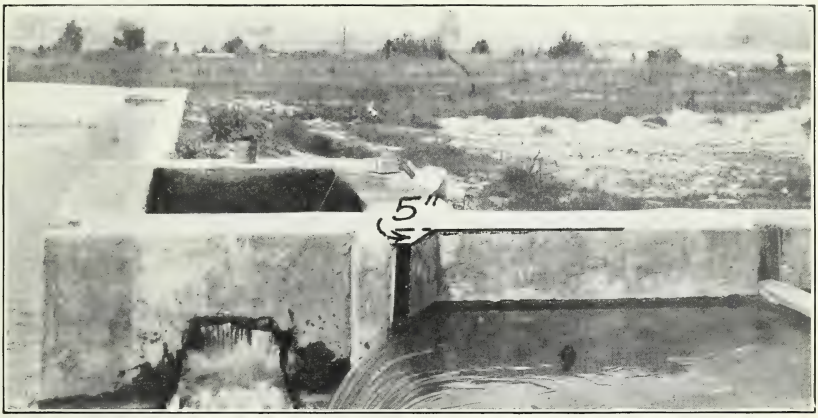



FIG. 2.—WEIR AT OUTLET OF PIPE NO. 30, NORFOLK COUNTY WATER CO., VIRGINIA.
The immediate bottom contraction similar to that shown at side, although water above weir wall is several feet deep.

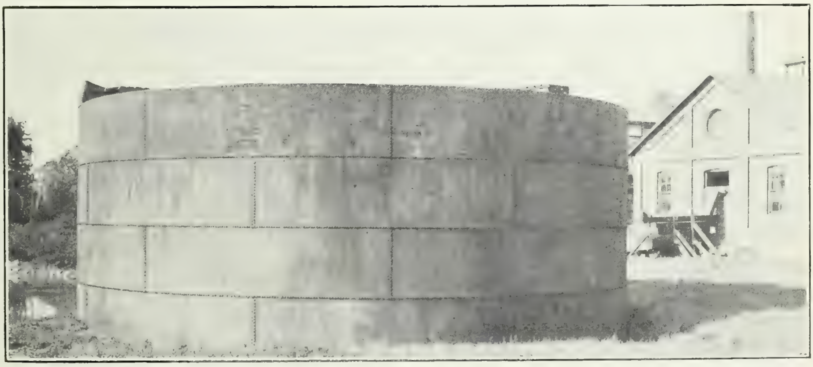


FIG. 3.—TANK OF BUTLER (PA.) WATER CO. USED IN MEASURING DISCHARGE OF PIPE NO. 29.

FIG. 1.—THUMB POINTS TO TOP OF PIEZOMETER COLUMN (GAUGE 2) SHOWING NEAR APPROACH OF PIPE LINE TO HYDRAULIC GRADIENT. (PIPE NO. 31.)

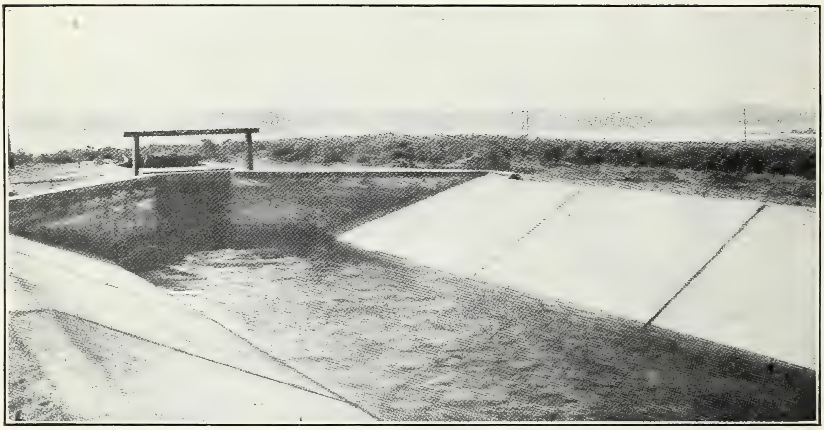


FIG. 2.—OUTLET STRUCTURE, PUMPING LINE OF PASCO RECLAMATION CO., WASHINGTON. (No. 38.) Discharge measured by rod floats in this concrete section.

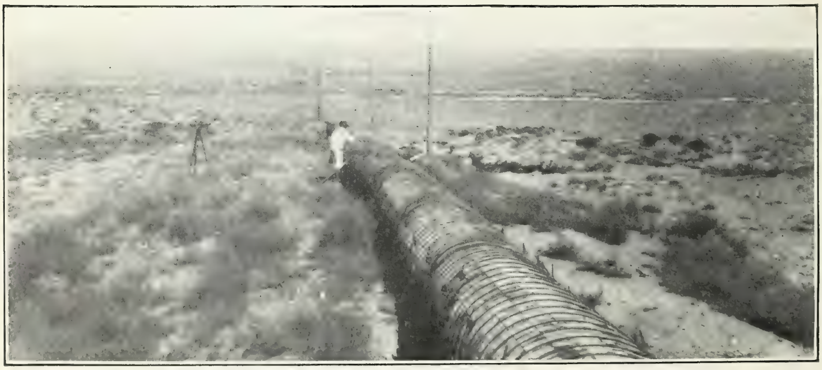


FIG. 3.—ALIGNMENT AND PROFILE OF SIPHON, BURBANK CO., WASHINGTON. (No. 39.)

although the observations show that the capacity of the pipe is 10 per cent below the discharge computed by the new formula.

**No. 19, Expt. S-10, 14-inch Jointed Machine-Banded Douglas Fir Pipe, Congdon Orchards, North Yakima, Wash.**—About 1 mile of 14-inch pipe conveys water from the Yakima Valley Canal to the Congdon Orchards. A reach 1,251.7 feet long was chosen near the lower end. A mercury manometer was used as gauge No. 1 and a water column as gauge No. 2. The velocity was determined with fluorescein. The color was injected at gauge No. 1 and appeared at a 4-inch hydrant about 100 feet below gauge No. 2. The capacity of this pipe is about 4 per cent less than as computed by the new formula.

**No. 26, Expt. S-13, 18-inch Continuous-Stave Redwood Siphon Pipe, Yakima Valley Canal Co., Washington.**—Irrigation water is conveyed across two depressions between open reaches of canal by means of a redwood siphon of the continuous-stave type, built in the winter of 1913–14. Thus the pipe had been in use but a few months at the time of the test. It is buried about 3 feet in sandy and gravelly soil. Blow-off valves are located at the low points, while a valve allows the escape of air at the one summit on the line. Gauge No. 1, a mercury manometer, was located 279.3 feet from the inlet. Gauge No. 2, a water column, was located 1,787.5 feet from gauge No. 1 and 19.7 feet from the outlet. The nominal size of the pipe was accepted. The velocity within the pipe was determined with fluorescein. It was not practicable to vary the velocities through the pipe, but so far as two observations can be accepted the capacity of the pipe is 18 per cent greater than the discharge computed by the new formula. Some excess is to be expected, as newly planed redwood is very smooth and the pipe was so new that material deposits of silt were unlikely.

**No. 27, Expt. S-7, 18-inch Jointed Machine-Banded Douglas Fir Siphon Pipe, Burbank Co., Washington.**—Irrigation water from Snake River is carried over a swale between open sections of a small ditch by means of an inverted siphon. This pipe was laid during February, 1913. The top of the pipe is about 18 inches below the surface of very gravelly, open soil. However, the pipe surface is protected with a heavy coating of asphalt, so that the wood appears to be perfectly sound. The maximum head is only about 14 feet. Water columns were used at both ends of the reach tested. Gauge No. 1 was located 67.1 feet from the inlet while gauge No. 2 was located 1,479.1 feet from gauge No. 1 and 7.6 feet from the outlet. The nominal size of the pipe was accepted as correct. For each run the velocity within the pipe was determined through fluorescein tests by taking the mean velocity of five batches of color. The pipe is straight in horizontal alignment and has no summits in the vertical plane. For all practical purposes it may be considered straight from the fact that the low point is but 14 feet below the hydraulic gradient, in a total distance of 1,553.8 feet. At no point was there any indication of leakage, but there was no way of determining the interior condition of the pipe. It is used for irrigation about seven months of the year, but is kept full all winter. This probably accounts for the absence of leakage. The water as pumped from Snake River contains some sand, but all of the heavier particles have settled to the bottom of the canal before reaching the siphon, which is some distance from the stream. For this reason there is small likelihood of a deposit at the low point of the siphon, although the two observations taken indicate that the capacity is 6 per cent below the discharge computed by the new formula.

**No. 29, Expt. S-2, 24-inch Jointed Machine-Banded White Pine Pipe, Butler Water Co., Butler, Pa.**—Municipal water for Butler, Pa., reaches a pumping plant near the city by gravity flow through a 24-inch pipe line laid in 1907. This pipe is 5 miles long from Boyds Town Reservoir to a settling tank. The maximum static head is about 67 feet. The last half mile is a cast-iron pipe, while the rest is a white pine machine-banded wood pipe. As there was considerable leakage throughout most of the wood pipe a straight reach of the latter 1,357.7 feet long was chosen well toward the juncture with the cast-iron pipe, which was considered tight. This fact permitted a close determination of the pipe's discharge by the rise of water in the settling tank (Pl. I, fig. 3), which is 50 feet in diameter, with vertical sides. Corrections were made for baffle walls and other displacement. The surface of the water in the tank was taken at 1-minute intervals with a plumb bob and steel tape. Mercury manometers were used at both ends of the reach. During any one run of water the mercury columns fluctuated but a few thousandths of a foot. The pipe is buried about 2 feet deep and is slightly elliptical. The mean of the areas of 10 pieces of pipe remaining from construction was taken as the area of the water section. Nothing is known regarding the interior of this pipe, but the observations indicate that the capacity is 5 per cent less than the discharge computed by the new formula.

**No. 30, Expt. S–1, 24-inch Jointed Machine-Banded White Pine Pipe, Norfolk County Water Co., Va.**—Water for domestic use in the territory in Norfolk County, Va., is pumped through 9 miles of 24-inch Canadian white pine machine-banded pipe from the Cadillac Pumping Plant to the plant in Princess Anne County. The pipe was laid during 1912 in lengths of from 3 to 12 feet. It is buried from 18 inches to 4 feet in sandy soil. The wood where bored for the manometers was sound, but the superintendent of the plant stated that there were several leaks in the line. This pipe is in use throughout the year. The reach tested is free from either horizontal or vertical curvature. It is 1,077.5 feet long, beginning about 100 feet below a gentle curve and extending to a point near the second pumping plant, where the pipe discharges over a rectangular weir into a concrete reservoir. The absence of moist ground indicated that there were no leaks on the reach tested, but the interior of the pipe was partly choked by a spongy growth. The velocity of water in the pipe was found by fluorescein tests. The discharge was determined by hook gauge readings for head on the weir shown in Plate I, figure 2. No correction is necessary for velocity of approach toward the weir, but the conditions of contraction are not quite standard. Mechanically the weir is well constructed and the discharge was not more than 2 per cent in error, in the estimation of the writer. The mean cross-sectional area of the interior of the pipe was determined by dividing the discharge as found above by the velocity as shown by the color. This area was 2.831 square feet, while the nominal area of a 24-inch pipe is 3.142 square feet. Loss of area was for the most part caused by the dense blanket of spongy growth adhering to the lower third of the circumference. As near as the writer could determine from the outlet end of the pipe, the rest of the perimeter of the pipe was smooth. With the above assumptions as to the true area of the pipe, the capacity is indicated by the observations to be 7 per cent greater than the discharge computed by the new formula, but if the presence of the growth were not known and the nominal size of the pipe accepted as the true size, then the capacity would be considered equal to the discharge computed by the new formula.

**No. 31, Expt. S–15, 24-inch Continuous-Stave Redwood Pipe, Ogden, Utah.**—Water for municipal uses is conveyed through Ogden Canyon to a reservoir near the city in a 24-inch redwood pipe, originally laid in 1890. The use to which this pipe is subjected, of course, requires it to be wet throughout the year, which is a more favorable condition than that usually encountered in irrigation practice, where a pipe is used but six to eight months. On the other hand this pipe practically reaches the hydraulic grade line at some of the summits. (During tests by the writer the water column at gauge No. 2 extended but 1 foot above the top of the pipe.) Thus there is not sufficient head for thorough saturation, yet the pipe appears to be in fairly good condition. The very rugged topography of this canyon precludes the use of long tangents in either horizontal or vertical alignment. The reach chosen for test commenced at the pipe bridge over Ogden River near "The Hermitage," where a mercury manometer was located as gauge No. 1. Gauge No. 2, a water column (Pl. II, fig. 1), was placed 2,240.7 feet from gauge No. 1. Douglas fir staves had been used in replacing some deteriorated redwood staves, and both gauges had been attached to the pipe through these because the harder fir appeared to give a tighter repair when plugs were inserted in the tap holes after the gauges had been removed. However, according to the superintendent of the line, that part of the pipe between the gauges was of redwood. The nominal size of the pipe was accepted as correct. The velocity was determined by injecting fluorescein at gauge No. 1 and timing its travel to an auxiliary tap on the same circumferential ring with gauge No. 2. Although the pipe was 24 years old the two observations at commercial velocities indicate its capacity to be 3 per cent greater than that computed by the new formula.

**No. 37, Expt. S-4, 36-inch Continuous-Stave Douglas Fir Pipe Line, Pasco Reclamation Co., Washington.**—The rolling ground in the vicinity of Pasco, Wash., does not furnish adequate support for an open canal. For this reason, and because of the sandy nature of the soil, water for irrigation is conveyed in pipes after settling in a reach of open canal where it has a very low velocity. Tests for loss of head were made on the 36-inch pipe shown in Plate IV, figure 2. Gauge No. 1 was placed about 800 feet from the intake and gauge No. 2 was located 2,516 feet farther on. The line abounds in gentle curves, both horizontal and vertical. Mercury manometers were used for both gauges. The nominal diameter of the pipe was accepted as correct. As all the water flowing in the canal entered this pipe, it was only necessary to measure this flow for discharge. This was done by weighted rod floats of such lengths that any one float just cleared the bottom throughout the reach on which it was used. This pipe was laid in the winter of 1909 and 1910. For the most part it is buried from 1 to 3 feet in light sandy soil. Exterior decay of the pipe indicated that it would have been better to place the pipe on the surface of the ground. The two observations taken at commercial velocities indicate that the capacity of this pipe is 15 per cent less than that computed by the new formula. The writer can not account for this. Velocities are so low in the feed canal that all sediment should precipitate before reaching the pipe.

**No. 38, Expt. S-5, 36-inch Continuous-Stave Douglas Fir Discharge Pipe, Pasco Reclamation Co., Washington.**—Water for domestic and irrigation use is lifted 107.2 feet vertically from Snake River to the canal-reservoir shown in Plate II, figure 2. All of the pumps feed one continuous-stave wood pipe 36 inches in diameter. This pipe, 893 feet in length, was built in 1909. Though at a rather sharp incline, the pipe is practically straight. Gauge No. 1, a mercury manometer, was located 335 feet from the pumps, while gauge No. 2, a water column, was located but 20 feet from the outlet shown in the plate and 538.1 feet from gauge No. 1. The pulsation due to the pumps was evident in the mercury columns, but at gauge No. 2 their effect was hardly noticeable, even in the water column. The nominal diameter of the pipe was accepted as correct. The discharge was measured with weighted rod floats in the concrete section of open canal shown in the plate. These were of such length that they barely cleared the bottom of the channel. It was not practicable to vary the discharges through this pipe. The two observations taken at the commercial velocities indicate that the capacity of this pipe is about 13 per cent below the discharge computed by the new formula.

**No. 39, Expt. S-8, 38.13-inch Continuous-Stave Douglas Fir Siphon Pipe, Burbank Co., Washington.**—Irrigation water from the Snake River is conveyed across a wide swale in section 16, township 8 north, range 31 east, by means of a continuous-stave siphon 6,170.4 feet long, built in February, 1913 (Pl. II, fig. 3). This pipe is 38.13 inches in diameter, as determined by measurements of outer circumference throughout its length and by measurements of stave thickness. It is supported on cradles on the surface of the ground and appears to be in perfect condition. During the colder months water is withdrawn and the ends are plugged. Irrigation continues about seven months each year. The pipe is straight in horizontal alignment, while the vertical curves are so gentle that for all practical purposes they are straight. There is one summit, as shown by the view. The maximum head is 74 feet. Water columns were used for both gauges. Gauge No. 1 was located 88.8 feet from the inlet. Gauge No. 2 was located 5,965.9 feet from gauge No. 1 and 115.7 feet from the outlet. Velocity within the pipe was determined by fluorescein tests, the mean time of travel of five batches of color being accepted. Levels were determined by static head; that is, on one visit to the pipe it happened that no water was running, so simultaneous readings at both gauges, taken 10 seconds apart for 1 minute, gave a true water level. The extremely slow fall of the water surface throughout these readings indicated that the leakage was negligible, which fact was also apparent to the eye. As well as an examination of the pipe outlet would disclose, the pipe was clean and smooth on the interior, though an examination of the long, low stretch across the marshy bottom of the swale might have shown deposits. The writer does not believe this likely, however, for the reason that the water flows for about 6 miles in open channels at comparatively low velocities before reaching the intake, and in these channels the heavier sand would have precipitated, leaving the water little more than clouded. The one observation at the commercial velocity indicates the capacity of this pipe to be about 10 per cent greater than that computed by the new formula.

**No. 40, Expt. S-6, 40-inch Continuous-Stave Douglas Fir Siphon Pipe, Burbank Co., Washington.**—Irrigation water is conveyed across a depression between two sections of open channel by a continuous-stave siphon, built in December, 1912, along the west side of section 6, township 8 north, range 31 east. This pipe was constructed on the surface of the ground and supported on cradles. At the time of these experiments, therefore, it was in its second irrigation season. As shown by the profile in Plate III, figure 1, there is one summit on the reach tested, but as this is protected by a standpipe, there was probably no air accumulation at the summit at the time of this test. Although the pipe is about 2,900 feet long, a reach 927.4 feet long was chosen near the outlet end for the reason that there is a diversion from the lowest point of the pipe. Gauge No. 1, a mercury manometer, was located 1,049.6 feet above the outlet and gauge No. 2, a water column, was located 122.2 feet above the outlet. The water divided in the outlet structure, flowing in two directions, one stream continuing in an earth channel and the other in a concrete-lined channel. The discharge in the pipe was determined by the sum of the flows in these two channels, as measured by current meter. The nominal area of the pipe was accepted as correct. At velocities exceeding 2 feet per second, it was noticeable that sections of the pipe immediately following the sharpest vertical curves vibrate about 1 inch, vertically, upon the cradles. This emphasizes the necessity for securing anchorage at bends. The two observations taken at commercial velocities indicate the capacity of this pipe to be about 3 per cent greater than that computed by the new formula.

**No. 42, Expt. S-9, 48-inch Continuous-Stave Redwood Siphon Pipe, Cowiche Siphon, Yakima Valley Canal Co., Washington.**—Water for irrigation is conveyed across Cowiche Canyon, about 4 miles from North Yakima, Wash., in a redwood siphon built in January, 1914. (Pl. IV, fig. 1.) Gauge No. 1, a mercury manometer, was located 67.3 feet from the inlet (Pl. III, fig. 2), while gauge No. 2, a water column, was located but 7.6 feet from the outlet. The inlet to the pipe is at the bottom of a concrete well about 10 feet deep. Subsequent tests to determine entry losses showed that much air was entrained and carried into the pipe, but no influence of air was apparent at gauge No. 1, which was attached to the pipe at the mid-point of its left side. From the intake to gauge No. 1 the pipe is straight. This is likewise true of the pipe for about 100 feet before gauge No. 2 is reached. For the balance of the distance between gauges the pipe is virtually one long vertical curve, as it is under a maximum head of about 100 feet and the total length is but 962.3 feet. The pipe has but one gentle bend in horizontal alignment. For each of the several runs made with different velocities in this pipe fluorescein was timed from inlet to outlet, the

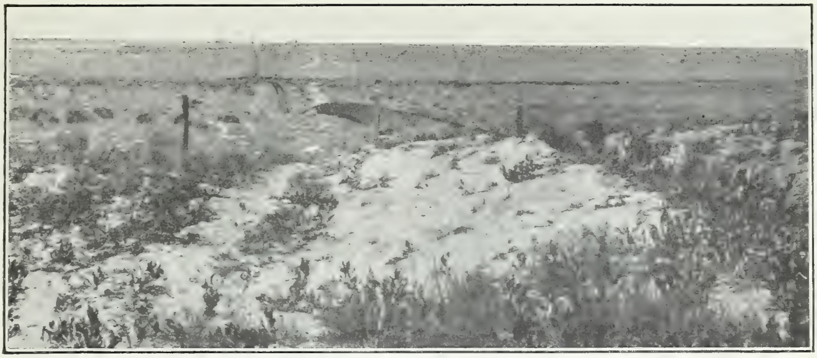


FIG. 1.—ALIGNMENT AND PROFILE OF SIPHON, BURBANK CO., WASHINGTON. (NO. 40.)

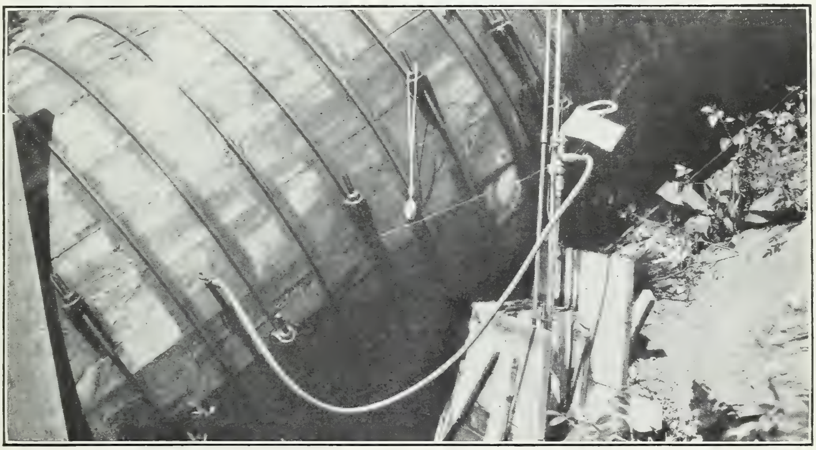


FIG. 2.—MERCURY MANOMETER (GAUGE 1) ATTACHED TO SIDE OF COWICHE SIPHON (NO. 42), YAKIMA VALLEY CANAL, WASHINGTON.

See note on figure 1, Plate IV.

FIG. 3.—CURRENT METER STATION BELOW OUTLET TO PIPE NO. 42.

A concrete slab, marked every 0.5 foot.

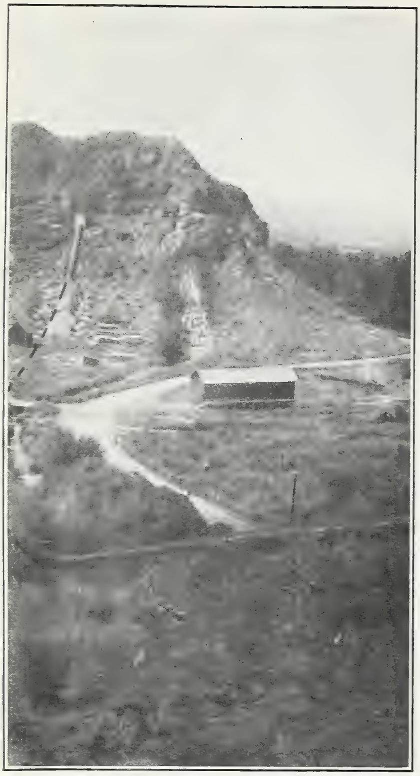


FIG. 1.—COWICHE SIPHON (NO. 42), YAKIMA VALLEY CANAL CO., WASHINGTON.

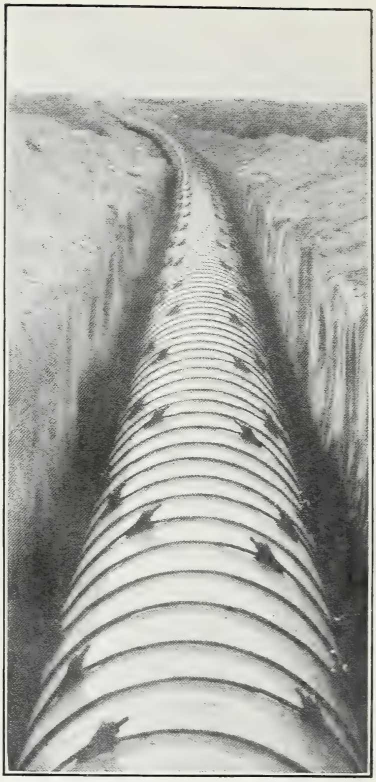


FIG. 2.—MAIN LINE, PASCO RECLAMATION CO., WASHINGTON (NO. 37). TYPICAL ALIGNMENT AND PROFILE.

FIG. 3.—TRUNK LINE, MOHAWK HYDRO-ELECTRIC CO., NEW YORK (NO. 50). TYPICAL ALIGNMENT AND PROFILE.

FIG. 1.—TRUNK LINE, SALMON RIVER POWER CO., NEW YORK. TAKEN ON REACH TESTED.
Typical alignment. Straight in profile. (No. 51.) See figure 2.

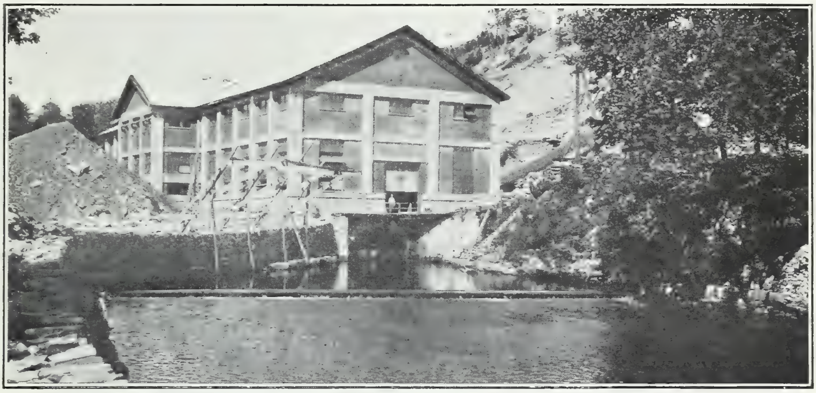


FIG. 2.—SUBMERGED WEIR BELOW POWER HOUSE, SALMON RIVER POWER CO. NEW YORK.
Discharge measured by calibrating weir. (No. 51.) See figure 1.

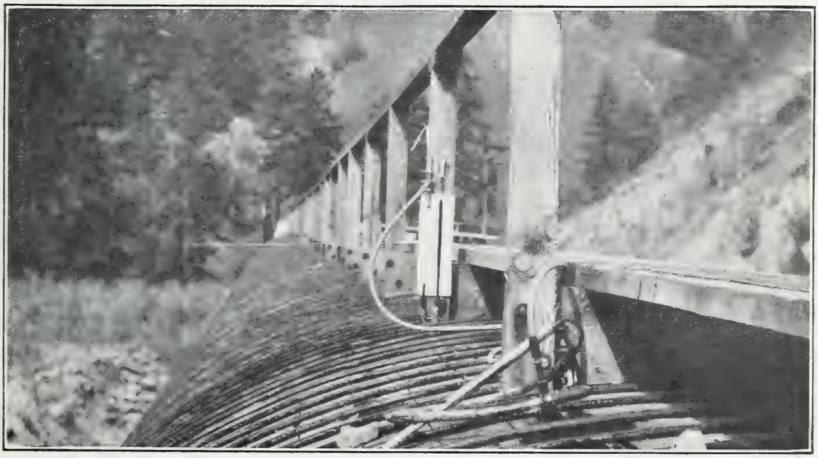


FIG. 3.—MERCURY MANOMETER AND FLUORESCEIN GUN (GAUGE 1) ON 13½-FOOT PIPE OF NORTHWESTERN ELECTRIC CO., WASHINGTON. (No. 52.)

mean velocity of four or five batches of color being accepted as the mean velocity of the water within the pipe for that particular run. Many of these color tests were checked by current meter measurements made by the two-tenths and eight-tenths depth method at the meter station shown in Plate III, figure 3. This station is in the concrete flume about 70 feet below the outlet from the siphon. The agreement between the two methods is shown in Table 1. As this pipe had been in use but a few months the interior was probably in excellent condition. The maximum discharge of the pipe necessitates a mean velocity of about 5.5 feet per second, so that it is probably scoured quite clean and smooth at all times. The capacity of the pipe was about 15 per cent greater than that computed by the new formula.

**No. 50, Expt. S-16, 78-inch Continuous-Stave Douglas Fir Pipe,[1] Mohawk Hydro-Electric Co., Ephratah, N. Y.**—The power house of the Mohawk Hydro-Electric Co., near Ephratah, is supplied with water by a trunk line of about 2½ miles of 78-inch stave pipe from the reservoir, Peck Lake, to the surge tank. (Pl. IV, fig. 3.) From the tank a stave pipe 96 inches in diameter extends to a point 1,460 feet distant, where the pressure head is 160 feet. It here joins a steel pipe of the same diameter, which completes the additional distance of a few hundred feet to the turbines. The writer conducted a series of tests on a reach of the 78-inch pipe 2,650 feet long. The lower end of this reach was about 1,000 feet above the surge tank. The whole line abounds in gentle curves, both horizontal and vertical. The pipe, built in 1910, was 5 years old at time of test. It is full of water throughout the year and is not protected against freezing, being so placed that some portions are completely buried and some completely exposed. Although extremely cold weather is experienced in this part of New York, the wood appears to furnish sufficient insulation. The peak load demands a velocity in this 78-inch pipe of less than 7 feet per second. This velocity and the fact that water comes from a reservoir that should act as a settling basin probably guarantees a pipe free from sediment. Several minor leaks were found on the reach tested. These are mostly at ends of staves where no additional bands were placed, and the pressure has bent outward the end of the stave farthest from the support of a band, the bend, of course, occurring under the last band. Whether the elastic limit of the wood had been exceeded and the fiber torn could not be ascertained, but the condition was such as to emphasize the desirability of confining all the joints in a stave pipe to a zone a few feet in length and placing extra bands throughout this zone. This of course does not apply to pipes under light pressures, say, 30 or 40 foot heads. Velocities within the pipes were determined directly with fluorescein for observations 1, 2, 3, 4, 7, 8, 9, and indirectly by comparison with the rating curve of the concrete channel forming the tailrace, for observations 5 and 6. The tailrace was calibrated by means of six careful current-meter gaugings, and a rating curve was plotted showing the comparison between gauge heights in the tailrace and velocities in the 78-inch pipe. The comparison between color tests and meter tests is shown in Table 1. The agreement between the two methods is closer than is usually expected by experienced hydrographers. Mercury manometers were used at both gauges. Some trouble was experienced from freezing temperatures (tests were made the first week in April, 1915), but no trouble occurred from air in the pipe, as the intake is deeply submerged. The color was injected at gauge No. 1 and observed at a secondary tap in the pipe 1 foot downstream from gauge No. 2, the water flowing into a white-lined pan which reflected greenish color. The same general procedure was followed here as on the Altmar tests (No. 51). That is, simultaneous readings were made over a long period of time, on both manometers and on a hook gauge in the tailrace. When the records were brought together, periods of slight fluctuation might be selected and each of these called an observation. Some such method as this must be chosen when a power plant in commercial operation is tested, as no one knows just when the changes in load, and consequent changes in velocity

[1] Engin. Rec., Vol. 64, No. 22, Nov. 25, 1911, p. 627.

within the pipe, are to occur. The capacity of this pipe was 9 per cent less than the discharge computed by the new formula. From the fact that the inlet is from a reservoir, and because the curves are very gentle, experience indicates that this pipe should have a greater capacity for a given loss of head than the new formula would indicate, although it is true that the interior condition of the pipe was not known. Two air valves at summits and one blow-off at a low point occur within the reach tested. The air valves are boxed to prevent freezing.

**No. 51, Expt. S-3, 144-inch Continous-Stave Douglas Fir Power Pipe Line,[1] Salmon River Power Co., New York.**—About 4 miles from Altmar, N. Y., on the bank of the Salmon River, is located an hydroelectric plant, constructed in 1913 and 1914 to carry a portion of the load formerly served by one of the big plants at Niagara Falls. Stillwater Reservoir is formed by a dam across the main channel of Salmon River about 2 miles above the power plant. A tunnel 600 feet long conveys water from the reservoir to the upper end of a continuous-stave Douglas fir pipe line 144 inches (12 feet) in diameter. (Pl. V, fig. 1.) At the end of 3,450 feet a taper transition section about 50 feet long leads into a similar pipe 132 inches (11 feet) in diameter. Tests were made on the 12-foot pipe. The portion of the pipe tested is without vertical curves, being laid on an even gradient Practically the lower third of the pipe is buried. No leaks worthy of notice occurred throughout the pipe. The line had been in operation but a few months, and since the velocities were high (up to more than 8 feet per second), it probably was in perfect condition on the inside, although it was not feasible to ascertain this. The staves are 4 inches thick. Taps for the nipples were made by a $\frac{7}{16}$-inch wood bit until the tip of the bit punctured the inside surface of the pipe. The nominal area of the pipe was accepted as its true area. After making these tests the writer made careful measurements of a still larger pipe built by the same company and found the true area extremely close to nominal area. The discharge of the pipe, from which the velocity within the pipe was obtained, was determined in the following manner: As shown in Plate V, figure 2, after the water passes through the turbines it falls over a submerged weir into a tail-race channel which in turn discharges into Salmon River about a quarter of a mile below the power house. A good meter rating could be obtained, as the mean velocity for the greatest discharge was but 3.25 feet per second. This velocity did not cause a turbulent condition in the channel, since the latter had a hard, flat rock bottom. The form of the weir and the conditions of velocity of approach are such that the writer did not feel justified in accepting the discharge as computed from any known weir formula. The velocity of approach, in particular, is an uncertain quantity, since the bottom of the channel slopes up from 20 feet deep at the power house to a mean of but 1.234 feet deep immediately above the weir crest, within a horizontal distance of 220 feet. The weir is 79.6 feet long with end contractions approximately suppressed. It is a concrete wall 18 inches thick, rounded over on top. It is not designed as a measuring weir but for the sole purpose of drowning the draft tubes for all discharges. This weir was calibrated by making four careful current-meter measurements with as many discharges from a bridge across the tailrace below the weir; and meanwhile reading a hook gauge in a stilling box 8 feet above the weir and a tape gauge 3 feet below the weir. The latter gauge reading had no bearing on the calibration but was taken for the purpose of securing more information concerning submerged weirs. The results of these measurements follow. The elevations are based on a bench mark with an assumed elevation of 10.000 feet.

[1] Eng. Rec., vol. 69, No. 24, June 13, 1914, p. 671.

TABLE 4.—*Simultaneous discharge, elevation of water surface above weir, elevation of water surface below weir, and head on weir.*

| No. | Discharge. | Elevation above weir. | Elevation below weir. | Head on weir. |
|---|---|---|---|---|
| | *Second-feet.* | *Feet.* | *Feet.* | *Feet.* |
| 1 | 106.6 | 8.752 | 7.77 | 0.515 |
| 2 | 446.1 | 9.539 | (not taken) | 1.302 |
| 3 | 724.9 | 10.123 | 9.62 | 1.888 |
| 4 | 749.6 | 10.172 | 9.62 | 1.937 |

The mean elevation of the weir crest, 8.237 feet, was based on readings with level and rod taken every 5 feet throughout its length. During measurement No. 1 the hook gauge remained constant. During No. 2 water rose 0.142 feet on the weir. During No. 3 water fell 0.020 feet on the weir. During No. 4 water fell 0.049 feet on the weir. The mean gauge reading was accepted where fluctuation occurred. Current-meter measurements were made by the two and eight-tenths depth method. As the load carried (and consequently the discharge of water at a power house) varies throughout the day, and since the discharge is controlled by the load (by means of governors), the following method of testing the 12-foot pipe for loss of head was adopted: The mercury manometers and the hook and tape gauges were read continuously throughout the morning and afternoon. A synchronous profile was then platted showing all gauge readings. From this profile periods of comparatively uniform flow were chosen and each of these periods was designated as an observation. These would necessarily vary in length of time. From the calibration curve of the weir the discharge for each reading of the hook gauge was taken and the mean of these discharges was assumed as the discharge which held throughout the observation. The capacity of this pipe was 2.5 per cent less than that computed by the new formula. Since the pipe was new, joints smooth, and the curvature gentle, the writer would estimate the capacity of this pipe to be greater than that computed by the new formula. Tests by all experimenters show similar cases where the observations indicate far different results than the conditions appear to warrant.

**No. 52, Expt. S–14, 162-inch Continuous-Stave Douglas Fir Power Line, Northwestern Electric Co., Condit Plant [1] on White Salmon River, Washington.**—About 2 miles above the mouth of White Salmon River is located the Condit Plant of the Northwestern Electric Co. Some 6,000 feet upstream a high diversion dam raises the water above the intake to the supply pipe line. This, said to be the largest wood-stave pipe in the world, 162 inches or 13½ feet in diameter, is used to convey the waters of White Salmon River from the diversion dam to the surge tank, a distance of 1 mile. Within the surge tank is a structure that divides the water from the 13½-foot pipe between two 9-foot pipes with very little loss of head. Each of the 9-foot pipes serves 1 electrical unit in the power house. (Pl. XI, fig. 1.) About midway of the large pipe, upon which tests were made, is a bend of 83° with a radius of but 40 feet (less than 3 diameters). In the opinion of the writer, such a bend would cause an appreciable loss of head independent of the friction loss, and for this reason a reach of pipe was chosen between this bend and the surge tank. Mercury manometers were used for both gauges, the equivalent water column being just too high to be feasible. (Pl. V, fig. 3.) Gauge No. 1 was located on the zone of neutral velocities 209.9 feet from the bend. Gauge No. 2 was located 2,378.9 feet from gauge No. 1 and about 40 feet above the dividing tongue in the surge tank. During all of the runs the load carried by the unit served by the right-hand 9-foot pipe was held constant, all the fluctuation being thrown to the other 9-foot pipe. The time necessary for fluroescein to travel from gauge No. 2 through the constant-velocity pipe was determined by

[1] Eng. Rec., Oct. 11, 1913; Eng. News., vol. 70, No. 15, p. 685.

accepting the mean time of four batches of color traveling from that gauge to the outlet of this particular pipe in the tailrace at the power house. For each of the tests for loss of head for differing velocities, color was injected at gauge No. 1 and timed to the outlet of the constant-velocity 9-foot pipe. To determine the time necessary for the color to travel between gauges for any particular run the time it spent in the 9-foot pipe was deducted from the total. For each run of water two batches of color were timed immediately before and after the gauge readings, and the mean time obtained was accepted.

## A NEW SET OF FORMULAS FOR THE FLOW OF WATER IN WOOD-STAVE PIPE.

So far as the writer has been able to ascertain, there have been two suggested modifications of existing formulas and three sets of formulas which were intended solely for use in the design of wood-stave pipes.

With the experiments before them, which have been underscored in Plate VII, Williams and Hazen in 1903 suggested the coefficient 120 in their general formula [1] given on page 6.

In 1915 Andrew Swickard,[2] after writing, "It is quite apparent that $n$ [in Kutter's formula] is not a constant for wooden pipe but a variable that varies directly with the size of the pipe," offered the following formula representing this variation of $n$,

$$n = \frac{d}{30{,}000} + 0.0105 \tag{15}$$

This formula ascribes all variation in $n$ to the change in diameter of the pipe, while the present paper shows quite clearly in column 10 of Table 2 and in Plate VI that this variation is also a function of the velocity. This latter fact has also been noted by Moritz and by Williams.

The first formula proposed for sole use in design of wood-stave pipe (see p. 6) was offered by C. H. Tutton [3] in 1899. Although not given wide publicity in this country and apparently not used to any extent here, Parker regards it with much favor, stating [4] in regard to general formulas for the flow of water in pipes that "the most useful formula seems to be the one given by Tutton."

In this work Parker unfortunately misquotes Tutton's data from that journal, giving as Tutton's formula for flow in wood pipes, $V = 140\ R^{0.59}s^{0.58}$, instead of $V = 129\ R^{0.66}s^{0.51}$. (See p. 6.)

In October, 1910, T. A. Noble published his own formula,[5]

$$Q = 1.28\ D^{2.58}\ H^{0.585} \tag{16}$$

which may be compared with formulas 11 and 14, pages 6 and 7. This formula was not given the publicity it deserved and does not appear

[1] Hydraulic Tables, Williams and Hazen, New York, 2d ed., 1909, p. 8.
[2] The Design of Wooden Stave Pipe, Engin. and Contracting, Vol. XLIII, No. 1, p. 10.
[3] Journal Assoc. Engin. Socs., 23 (1899), p. 151.
[4] The Control of Water, P. à M. Parker, New York, 1913, p. 427.
[5] Wood Pipe, T. A. Noble, Pro. Pac. Northwest Soc. Engin., Vol. IX, No. 1, Oct., 1910.

to have been used to any great extent, probably for the reason that it was based on tests covering only a few pipes, namely, a 4-inch pipe tested by Noble and Harris, Adams's 14-inch and 18-inch pipes, Noble's 44 and 54-inch pipes, and the Ogden tests of 1899 on the 72-inch pipe (Nos. 20, 23, 41, 44, and 48, Tables 2 and 3, and Pl. VII).

In 1911 E. A. Moritz proposed the fourth set of formulas[1] (see p. 6) with the following qualification: "This formula is not recommended for adoption until more data are available and some of the uncertain points have been cleared up."

A fifth set of formulas is now offered by the writer, who has fully appreciated the inadvisability of extending the number of formulas already existing except as must be required by continued investigation. His own experiments, especially those on large pipes, when studied in connection with all previous data, would seem to supply convincing proof that a new formula is needed.

With the exception of formula 15 all of the formulas referred to are of the exponential type; that is, they are based on the fact that for any particular series of observations, if losses of head are plotted logarithmically as one set of ordinates and velocities as the other, the resulting points will lie more or less along a straight line. Such a straight line on logarithmic paper represents an equation of the form

$$H = m\ V^{z} \tag{17}$$

which, expressed for logarithmic study, may be stated

$$\log H = \log m + z \log V \tag{18}$$

where m is the intercept on the axis of H, for $V = 1$ foot per second and z measures the inclination of the line, being the tangent of the angle which it makes with the axis of V.

For a series of pipes of the same general characteristics but of varying diameters the values of m follow the general equation

$$m = K\ d^{x} \tag{19}$$

Substituting in formula (17)

$$H = K\ d^{x} V^{z} \tag{20}$$

This expressed logarithmically becomes

$$\log H = \log K + x \log d + z \log V \tag{21}$$

Smith's tests (No. 1) were made on a pipe too small for any irrigation usage and the graphic representation of the results, while

[1] Trans. Amer. Soc. Civ. Engin., 74 (1911), p. 442.

adding no significant information, would have required a far larger diagram than that presented here. With the exception of these tests, therefore, data were plotted for all known observations where records were sufficiently complete. The writer agrees with J. S. Moore[1] that—

> In preparing a tentative formula for general use all complete data, which can be accepted as criteria for the loss of head in wood pipe, should be recognized in arriving at a conclusion.

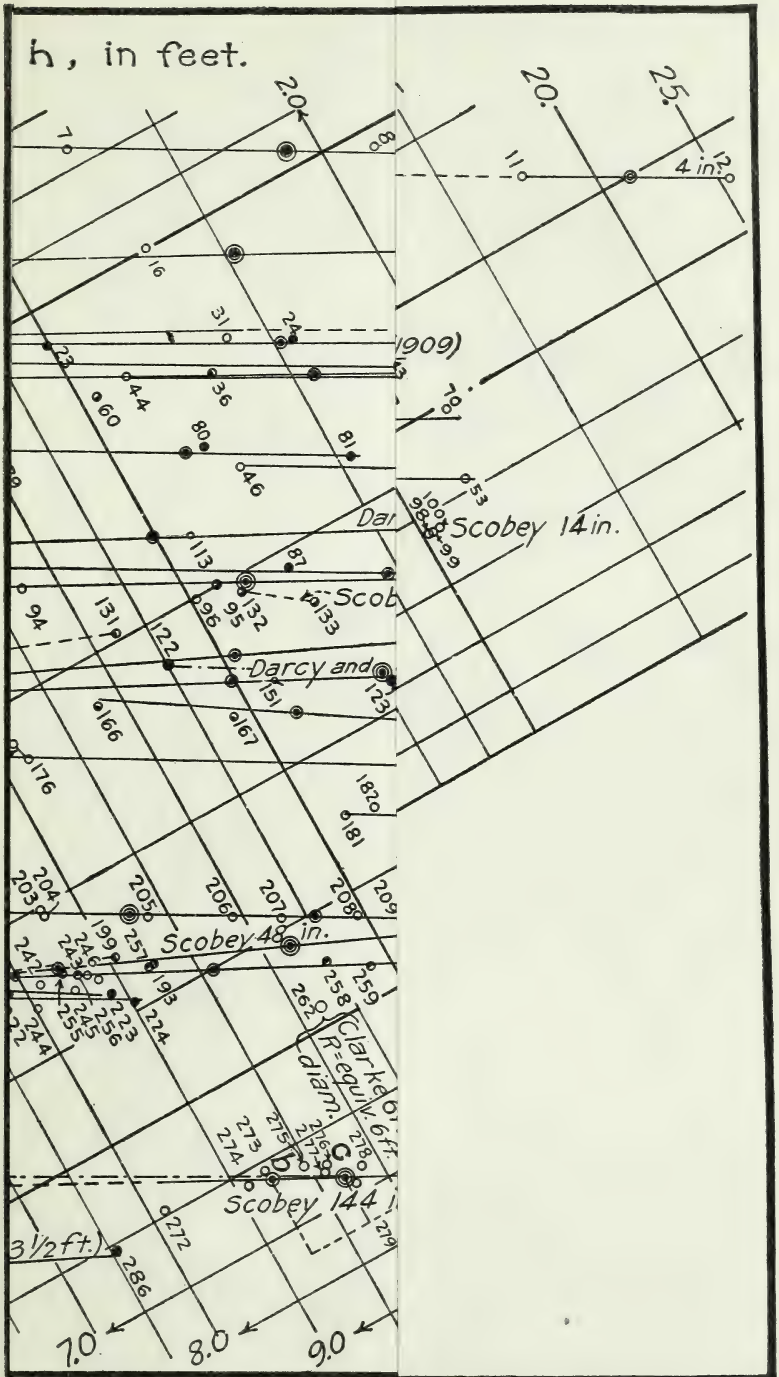
However, in deriving the new formula, tests made on round wood-stave pipe only were considered, in view of the proposed use of such a formula. The comparatively close agreement between results by use of the new formula and by the Tutton formula, as shown by Tables 2 and 3, indicates that had the excluded tests been used they would not have materially changed the new formula, inasmuch as Tutton used only four series, all of which were excluded by the writer because they were on other than wood-stave pipes. The close application of Tutton's formula to stave pipe, as shown by the consistent agreement in pipes all the way from 4 inches to 144 inches in diameter, is a remarkable coincidence, since his base data included no stave pipes whatever and but one round pipe.

In deriving the new formula the following methods were used: After the observations had been plotted the diagram was used merely as a sketch, all slopes and intercepts being determined analytically. Where the test on any one reach of pipe included several observations the procedure observed was that used in the following example:

Take the writer's series 3 (Nos. 272–281, inclusive) on the 144-inch Altmar pipe. The center of gravity of all the points was first determined. The antilogarithm of the mean value of the logarithms of the respective velocities gave the velocity ordinate of the center of gravity. The slope ordinate of the center of gravity was found similarly. This point, c, shown by a dot within two circles (Pl. VI), divides all the plotted observations into two parts. The center of gravity of each of these parts was found by using only the observations within the zone of the part. These points, a and b, are shown by dots within single circles. Thus three points are found, all of which lie on the straight line representing the equation for that particular reach of pipe.

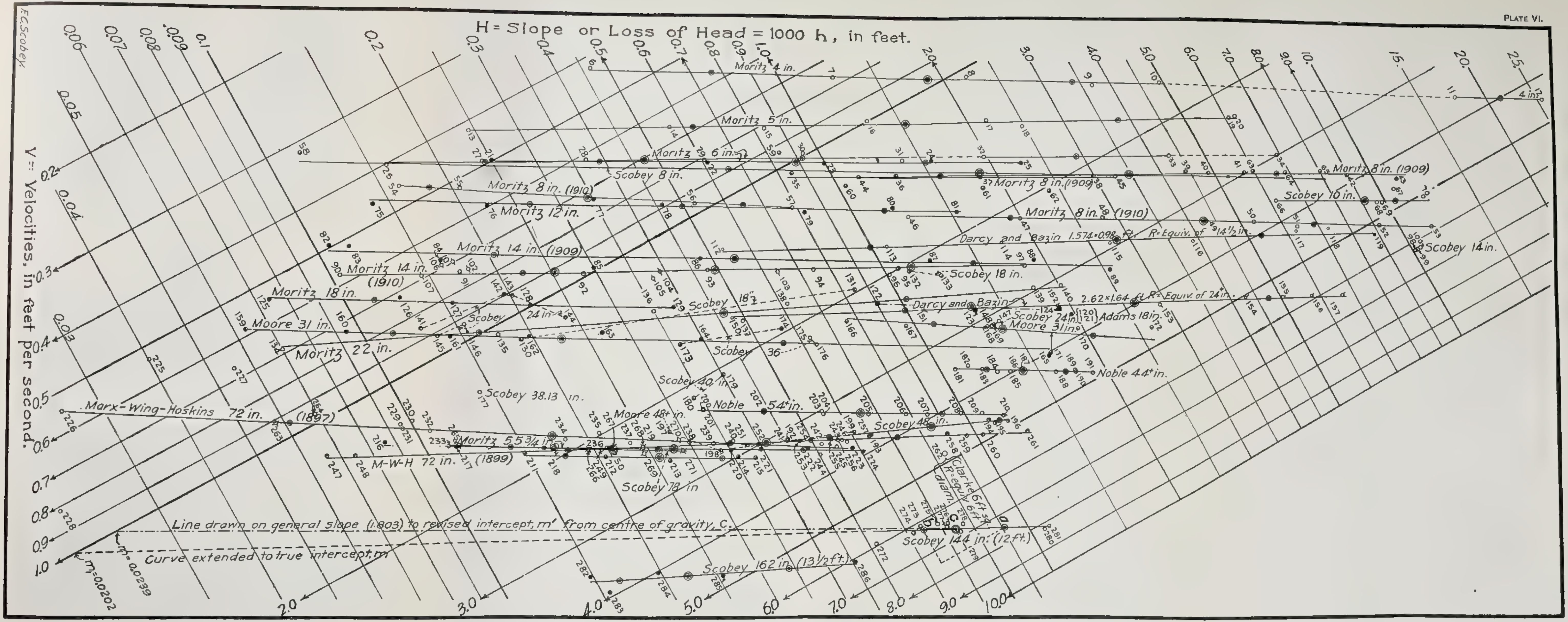
Let c = center of gravity of whole group; a = center of gravity of the part of the group above c; b = center of gravity of the part of the group below c; and let $c_V$, $a_V$, $b_V$, and $c_H$, $a_H$, $b_H$, be, respectively, the V and H coordinates of the above centers of gravity.

[1] Trans. Amer. Soc. Civ. Engin., 74 (1911), p. 470.




WOOD PIPES. NUMBERS CORRESPOND WI

PLATE VI.




LOGARITHMIC DIAGRAM SHOWING OBSERVATIONS FOR LOSS OF HEAD IN WOOD PIPES. NUMBERS CORRESPOND WITH COLUMN 2, TABLE 2.

| No. | V | H | log V | | log H | |
|---|---|---|---|---|---|---|
| 272 | 5.942 | 0.5144 | 0.7739 | | 9.7133 | |
| 273 | 6.127 | .6426 | .7873 | Sum=4.7756 | 9.8079 | Sum=58.8637 |
| 274 | 6.190 | .6154 | .7917 | Mean=.7959=$b_V$ | 9.7892 | Mean=9.8106=$b_H$ |
| 275 | 6.312 | .6938 | .8001 | Anti-log mean | 9.8412 | Anti-log mean |
| 276 | 6.436 | .7237 | .8086 | =6.250 | 9.8595 | =0.6466 |
| 277 | 6.516 | .7155 | .8140 | | 9.8546 | |
| 278 | 6.693 | .7700 | .8256 | Sum=3.4915 | 9.8865 | Sum=39.8249 |
| 279 | 6.852 | .7490 | .8358 | Mean=.8729=$a_V$ | 9.8745 | Mean=9.9562=$a_H$ |
| 280 | 8.222 | 1.061 | .9150 | Anti-log mean | 10.0257 | Anti-log mean |
| 281 | 8.223 | 1.092 | .9151 | =7.463 | 10.0382 | =0.9040 |

Sum=8.2671 — Sum=98.6886

Mean= .8267=$c_V$ — Mean= 9.8689=$c_H$

Anti-log mean=6.710 — Anti-log mean=0.7393

The center of gravity of the whole series thus comes at such a point that there are 4 points below and 6 points above c. Then

$$a_V - c_V = .0462, \text{ and } a_H - c_H = .0873;$$

$$c_V - b_V = .0308, \text{ and } c_H - b_H = .0583;$$

whence:

$$\frac{0.0462}{0.0308} = \frac{0.0873}{0.0583} = \frac{6}{4}$$

When the above ratios are in inverse proportion to the number of observations in the respective zones the three points found lie in the same straight line and approve the mathematical operations.

The exponent of V in formula 17 is the inclination of the line acb and is equal to the tangent of the angle formed by the curve and the axis of V. Thus

$$\frac{a_H - b_H}{a_V - b_V} = \frac{.1456}{.0770} = 1.891 = z. \quad \text{(See No. 51, column 17, Table 3.)}$$

The intercept m is found as follows: Since $\log m = \log H - z \log V$ (from formula 18, p. 49), by using the coordinates of the center of gravity c

$$\log m = 9.8689 - (1.891 \times 0.8267)$$
$$\log m = 8.3056, \text{ therefore } m = 0.02021$$

In the same manner the exponent of V for each of the pipes underscored in Plate VII was determined, being found to vary from 1.53 for No. 36 to 2.31 for No. 42. Any general law of variation in this exponent was not considered in their formulas by Moritz, Williams and Hazen, or the writer, although Hazen sees a tendency for the exponent to increase with the size of the pipe,[1] while Williams later offered the deductions mentioned on page 11. Simultaneous values of diameter and exponent were plotted on logarithmic paper.

[1] Trans. Amer. Soc. Civ. Engin., 51 (1903), p. 320.

As the exponent did not appear to vary in accordance with any particular law, but depended upon each individual pipe, the writer followed the authorities name above and derived one general value for this exponent. The method employed was as follows:

Obviously one observation on a particular pipe gave no data of value in determining the slope of a line. Two observations at about the same velocity contributed little more, but two observations at widely separated velocities gave enough information to indicate at least a tendency. Ten observations over a very short range of velocities did not give results as dependable as the same number over a greater range. Likewise ten observations, eight of which were close together and the other two well apart, did not contribute as much as the same number of observations evenly distributed throughout the range of velocities. With these general arguments and Plate VI as a basis, three men outlined a system for weighting the various exponents in the individual pipe formulas.

Four factors entered into this process: First, the number of observations; second, the distribution of the observations as shown by the distance between the centers of gravity of the upper and lower zones of observations; third, the extreme range of the observations on the chart; fourth, the actual range of the velocities. Usually the weight factor for the number of observations equaled the total number of observations, but some of the series showed an excessive evidence in restricted zones with fewer data in other zones. As an example of this, see No. 41. One observation within each half-second of velocity range received full weight. Each additional observation within the same half-second of range received an additional weight of half a unit. Thus the 11 observations in this series received a total rating of 8 for the number of observations. (See column 10, Table 3.)

The study of the data was made on 10-inch base logarithmic paper. Each inch of distance between centers of gravity of the upper and lower zones received a weight of 1 in the second factor. Thus, No. 41 was rated 1.6 in this factor. (See column 11, Table 3.)

Each inch of distance between the extreme observations also received a weight of 1 in the third factor. Thus, No. 41 was rated 2.8 in this factor. (See column 12, Table 3.)

Each one-half foot per second of velocity between the extreme observations also received a weight of 1 in the fourth factor. Thus No. 41 was rated 3 in this factor as the range of velocities extended from 3.5 to 4.8 feet per second, a difference of approximately 1.5 feet or the equivalent of $3 \times 0.5$ feet per second. The total weight for this pipe was the product of these four factors, the equivalent of

$$8 \times 1.6 \times 2.8 \times 3.5 = 125. \quad \text{(See column 14, Table 3.)}$$

No pipe was permitted a greater weight than 1,000 in determining the exponent of V. If the product of the four factors exceeded 1,000 no additional weight over the 1,000 was assigned.

The writer is aware of the arbitrary character of this method of determining the exponent, but it was obvious that some system of rating must be assigned and the one used appears to give about the right weight to the various pipes when Plate VI is studied. The proof of the relative accuracy of this method is shown in Tables 2 and 3 where the mean of all observations entering into the derivation of the general value of the exponent agrees with the formula to within $-0.33$ per cent. (See foot of column 19, Table 2). The mean value for all the pipes entering into the derivation of the exponent agrees with the formula to within $+0.66$ per cent. (See foot of column 18, Table 3.)

Letting $W_2$, $W_4$, $W_5$, etc., be the weights for Nos. 2, 4, 5, etc., in column 14, Table 3, and $E_2$, $E_4$, $E_5$, etc., be the exponents of V in formulas for Nos. 2, 4, 5, etc. (column 17, Table 3), then

$$\frac{W_2E_2+W_4E_4+W_5E_5+ \text{------} W_{52}E_{52}}{W_2+W_4+W_5+ \text{----------} W_{52}}=z=1.803$$

In deriving the values of the coefficient K and the exponent x, the writer has not pursued the usual practice. This is to plot and study logarithmically the various values of m (found in a similar manner to m on p. 51) and corresponding values of d as ordinates and abscissas, respectively.

The exponents of V in column 17, Table 3, vary within rather wide limits. The new general formula accepts a weighted mean value of this exponent, 1.803. Instead of using the values for m as taken from column 17, Table 3, the writer drew lines at the constant inclination 1.803 from the center of gravity of all the points in one series to the line where V equals 1 foot per second (the line for pipe No. 51 being shown in dot-dash in Pl. VI). This revised value of m for each series shown in Plate VI is found by the equation

$$\log m' = \log H - 1.803 \log V \qquad (22)$$

(substituting 1.803 for z and transposing equation 18).

Again, taking No. 51 as an example:

$$\log m' = 9.8689 - (1.803 \times 0.8267)$$
$$\log m' = 8.3784$$
$$m' = 0.0239$$

By the method usually employed the value of m (0.0202) shown in the formula for No. 51, column 17, Table 3, would have been used as derived on page 51. The reasoning which recommended revising the usual method follows:

In Plate VI the curves for the pipes of small diameters intersect the $V=1$ line. These intercepts give the values of m. Likewise, the lines drawn from the centers of gravity for these curves at the constant slope 1.803 give intercepts m′ not far, as a rule, from m. Thus not very much difference appears for the smaller pipes; but out in the zones of curves for the larger pipes the average velocities are so much higher, and consequently the centers of gravity are so far from $V=1$, that the difference between m and m′ is very marked. The revised method places all curves on the same footing; that is, the intercepts for the large pipes will have no more influence on the general formula than the intercepts for the small pipes. Using this method a line at the constant inclination 1.803 may be drawn through the point representing but one observation and a value of m′ found that is of weight in determining the general formula, whereas this same point contributes nothing toward the determination of the exponent 1.803.

The values of m′ for the various series are shown in column 16, Table 3. In order to derive the term $Kd^x$ (formula 19), figure 4 was platted logarithmically with values of m′ as ordinates and of d as abscissas.

The center of gravity of all the points is shown by the dot within two circles while the centers of gravity of the zones above and below this point are shown as dots within single circles. These three dots lie in the same straight line represented by the equation

$$m' = 7.68\, d^{-1.17} = 0.419\, D^{-1.17} \qquad (23)$$

where 7.68 is the intercept on the line $d=1$ and $-1.17$ is the inclination of the curve to the horizontal axis.

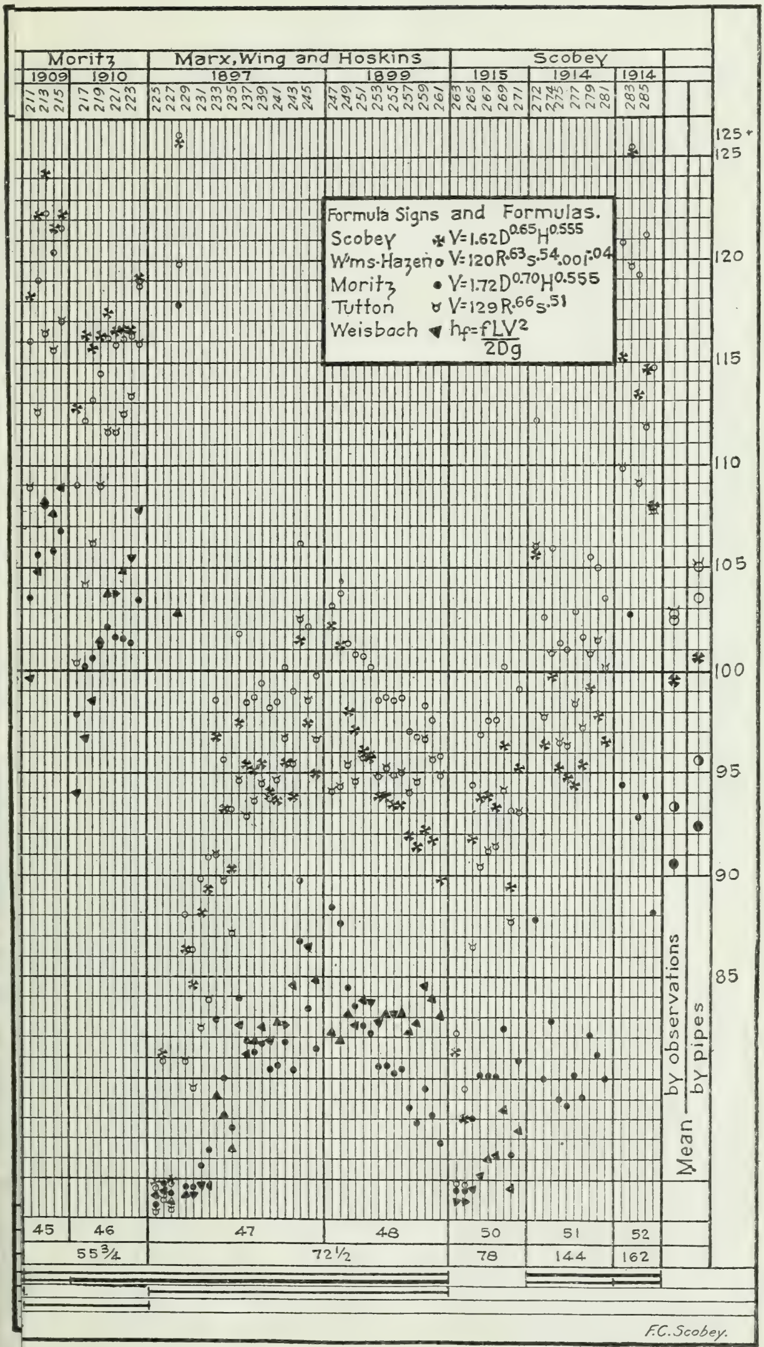
Substituting in the general formula (20, p. 49), the general equation is now evolved for wood-stave pipes, either jointed or of continuous-stave construction, based on the weighted average condition of all round stave pipe upon which accepted experiments have been made. This formula is

$$H = 7.68\, d^{-1.17}\, V^{1.8} = 0.419\, D^{-1.17}\, V^{1.8}$$

becoming

$$H = \frac{7.68\, V^{1.8}}{d^{1.17}} = \frac{0.419\, V^{1.8}}{D^{1.17}} \qquad (12)$$

which is shown, with the related formulas, on page 7.




AMS-HAZEN ($C_W=120$), MORITZ, TUTTON, AND WEISBACH FORMULAS.

68796°—25. (Face p. 54.)

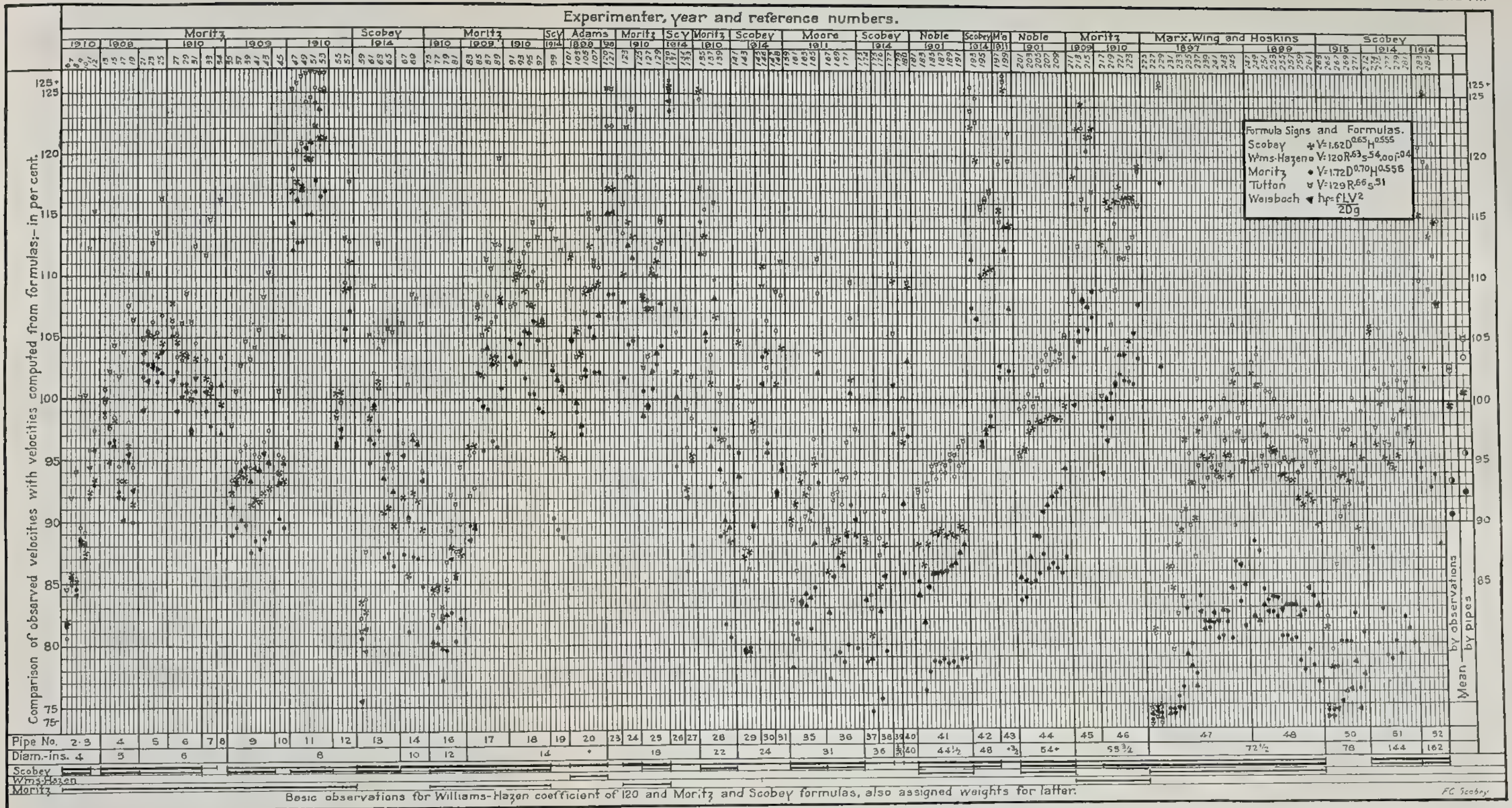



CHART SHOWING DEGREE OF CONFORMITY OF OBSERVED VELOCITIES OF WATER IN WOOD-STAVE PIPES TO CALCULATED VELOCITIES FOR GIVEN LOSS OF HEAD, BY SCOBEY, WILLIAMS-HAZEN ($C_W$=120), MORITZ, TUTTON, AND WEISBACH FORMULAS.

08796°—25. (Face p. 54.)

## COMPARISON OF THE VARIOUS FORMULAS.

The comparison of the various formulas is shown in columns 19 to 23 and 18 to 22, inclusive, Tables 2 and 3, respectively, and graphically in Plate VII, which presents the following information:

First, a comparison in per cent of observed velocities to velocities computed by the Williams-Hazen formula (with $C_w = 120$), the Moritz, Tutton, Weisbach, and the new formulas, for all accepted experiments on wood-stave pipes known to the writer where sufficient data are given.

Second, the mean of the various percentages, awarding each observation the same weight; also the mean of the various percentages, awarding the average percentage for each reach of pipe the same weight. These items correspond with the footings under columns 19 to 23, inclusive, Table 2, and columns 18 to 22, Table 3.

Third, lines underscoring the observations used in deriving their formulas by Moritz and Scobey, and the observations leading Williams and Hazen to recommend a value of 120 as the coefficient to be used in their formula in the design of wood-stave pipe. (The Weisbach formula was derived from tests on metal pipes.)

Tutton apparently assigned the same weight to each series of tests, although he had but one observation on the Moon Island Conduit (No. 49) against five for No. 1, and eight for each of the other two (Nos. 22 to 33).

For the new formula double lines are used, the upper line denoting the observations used and the weight assigned (1, 2, or 3) in determining the general equation for $m'$, and the lower line denoting the observations used and the weights assigned in determining the exponent of V. (These lines correspond to the figures in columns 15 and 14, respectively, Table 3.)

As an example of the use of this chart, take observation No. 274 (run 9 on pipe No. 51). Near the top of the plate above the figures *274* (the reference number), *Scobey* is given for the experimenter and *1914* as the year. Under 274 it will be noted (as indicated by the cross) that the observed velocity (column 8, Table 2, 6.19 feet per second), is 0.1 per cent less (column 19, Table 2) than the velocity (6.20 feet per second, column 14, Table 2), as computed by the new formula for the same sized pipe with the same loss of head. Similarly the open circle shows that it is 5.9 per cent more than the velocity (5.83 feet per second) as computed by the Williams-Hazen formula (column 20, Table 2); the black dot shows it to be 17.2 per cent less than the velocity (7.48 feet per second) computed by the Moritz formula (column 21, Table 2); the winged circle shows it to be 0.8 per cent more than the velocity (6.14 feet per second) computed by the Tutton formula (column 22, Table 2); the fact that there are no triangles (see other observations on Pl. VII) shows that listed tables of $f$ in the Weisbach formula do not extend to 144-inch pipes; hence comparison was not made with the Weisbach formula (column 23, Table 2).

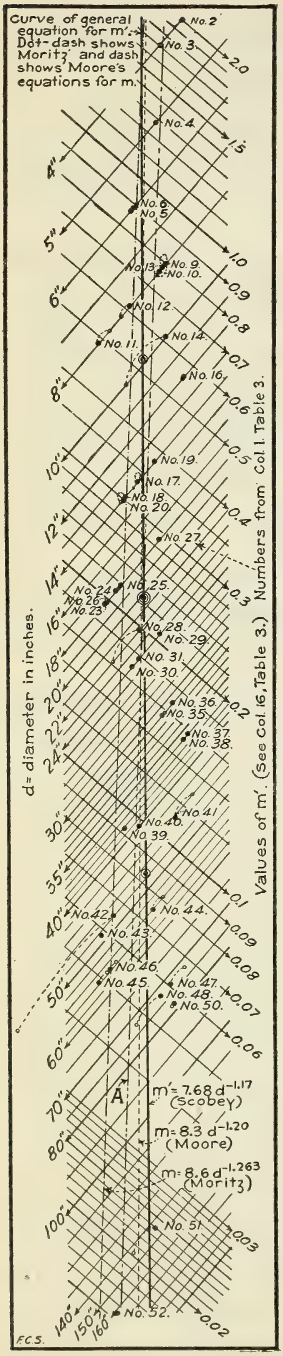



FIG. 4.—Logarithmic diagram developing curve for equation $m' = 7.68\, d^{-1.17}$. Small circles show values of m before revising to m'.

At the bottom of the chart the reason for the blank opposite "Moritz" is quite obvious, since this observation was made subsequent to his own tests. Opposite Scobey's name the heavy upper line indicates that all the observations in this series received a weight of 3 in determining the general value of the intercept equation (fig. 4). The light line under the heavy one indicates that these observations did not receive much weight in determining the general value of the exponent of V (see p. 51, and column 14 Table 3).

At the extreme right of the chart the same symbols are used to show the relative positions of the mean of all observation percentages (see foot of columns 19 to 23 inclusive, Table 2) and also the means of the average percentages by pipes (see foot of columns 18 to 22, inclusive, Table 3).

The new formulas and the Moritz formulas agree for a 4-inch pipe, diverging as the diameters increase exactly as do the curves in figure 4. Thus by the time a pipe 144 inches in diameter is reached the Moritz formula shows 20 per cent greater capacity than that shown by the new formulas while a glance at the larger sizes of pipes (Pl. VII) shows that even the new formulas give a greater carrying capacity than observations on most pipes larger than 24 inches would promise.

## KUTTER'S FORMULA AS APPLIED TO WOOD-STAVE PIPE.

In discussing the Moritz experiments with reference to the value of $n$ in Kutter's formula, Hering states[1] that he "recog-

[1] Trans. Amer. Soc. Civ. Engin., 74 (1911), p. 459.

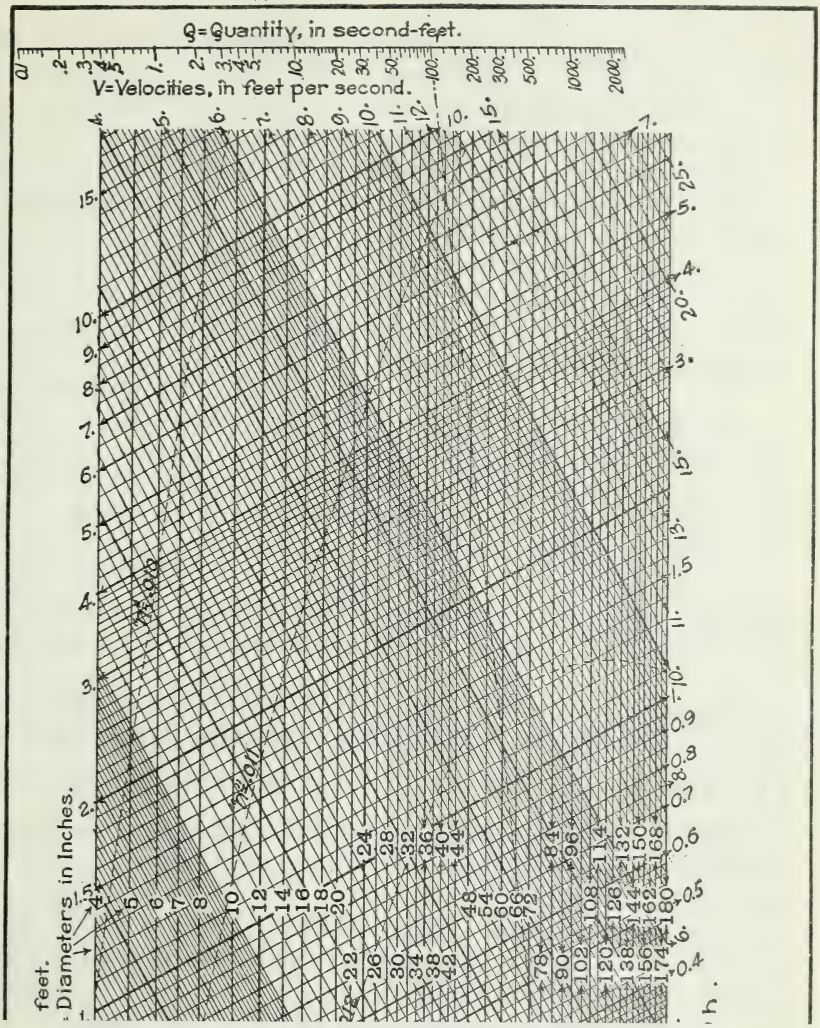
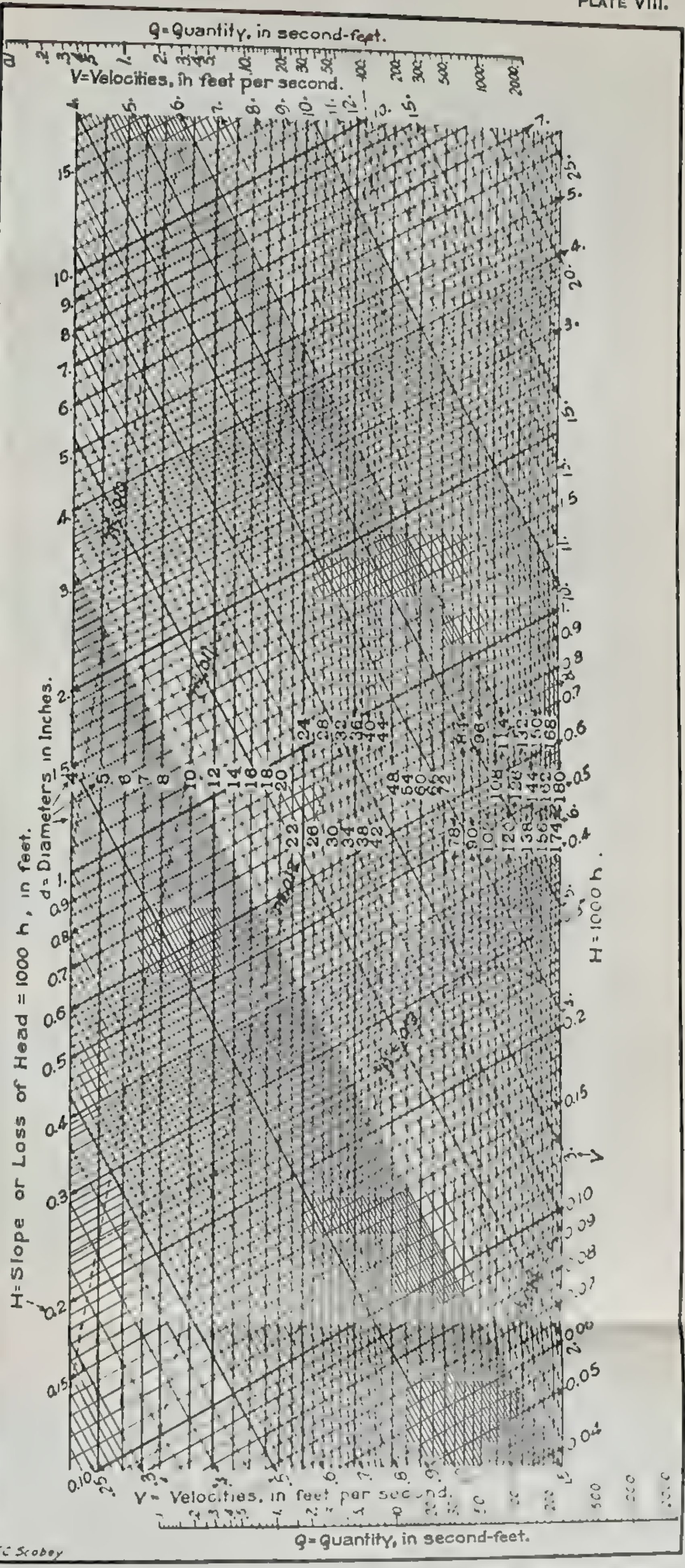

Q=Quantity, in second-feet.
V=Velocities, in feet per second.
Diameters in Inches.
feet.

PLATE VIII.




LOGARITHMIC DIAGRAM FOR FLOW OF WATER IN W[illegible]D-STAVE PIPE B[illegible] F[illegible] V=1.62D [illegible] H [illegible]. SIMULTANEOUS VALUES OF $n$ IN THE KUTTER F[illegible] ARE GIVEN FOR COMPARISON.

nized as well as did Mr. Kutter himself, almost at the outset, that $n$ was not to be considered a precise and unvarying constant, although it was more nearly so than any other constant before proposed." [1]

The fact that $n$ does vary has been understood by hydraulicians specializing in work involving the Kutter formula, but notwithstanding this the tables and charts which have been accepted as standard have assigned values of $n$ to certain degrees of roughness without reference to other conditions. The usual understanding regarding variation occurring in the value for $n$ has been that $n$ is less in large channels than in small ones, although the writer has not been able to show from a study of all available data that this variation is as great as suggested by Johnston and Goodrich[2].

In the case of wood-stave pipes an opposite effect is noted; that is, the value of $n$ becomes greater as the value of R (which is directly proportional to the diameter) becomes greater. Referring to Plate VIII it will be noted that all of the straight lines are based on the new formula (13), page 7, while the $n$ curves are determined in the following manner: To determine the curve for $n=0.012$, the intersections of the $n$ curve with the diameter curves for various pipes are found and these give the locus for all pipes and velocities with $n=0.012$.

Each intersection is found by solving formulas 5 and 13 (pp. 6 and 7) as simultaneous equations, eliminating V, substituting a known value for D (from which the known value of R is found, as $R=\frac{D}{4}$) and solving for H, which is equal to 1000s in the Kutter formula. Note that the value of $n$ increases for a given velocity as the size of pipe increases and that the value of $n$ decreases for a given size of pipe as the velocity increases. These last two statements are borne out by a glance at the general trend of column 10, Table 2. Assume that Plate VIII, which is a graph of formula 13, page 7, correctly represents the flow of water in an average wood-stave pipe. This assumption is supported by the figures at the foot of columns 19 and 18 in Tables 2 and 3 respectively. Assume also that the $n$ curves represent the simultaneous values of $n$ for any position on the graph. Then the variations in the proper value of $n$ to assume in the design of wood-stave pipe become so complicated that the Kutter formula had better be abandoned in favor of the exponential type of formula. This would leave the Kutter formula for its originally intended purpose, that of design of open channels, for which it is eminently fitted.[3]

---

[1] E. Ganguillet and W. R. Kutter, translated by Rudolph Hering and John C. Trautwine, jr. A General Formula for the Uniform Flow of Water in Rivers and other Channels, New York, 1907, 2d ed.

[2] C. T. Johnston and R. D. Goodrich. A Formula and Diagram for Determining the Velocity of Flow in Ditches and Canals. Eng. Rec., 64 (1911), No. 19, p. 542.

[3] The Flow of Water in Irrigation Channels. Fred. C. Scobey, U. S. Dept. Agr. Bul. 194, p. 60.

## EFFECT OF AGE UPON THE CARRYING CAPACITY OF WOOD-STAVE PIPE.

Some manufacturers and hydraulicians have contended that wood-stave pipe becomes smoother with length of use, and that therefore the capacity of the pipe increases with its age.

In order to study this question the writer prepared figure 5. This chart shows that, judging by available experimental data, there is no definite law between age and change in capacity, but unfortunately the results of but one test are accessible on any pipe older than 7 years. That pipe (No. 31, Ogden, Utah), although 24 years

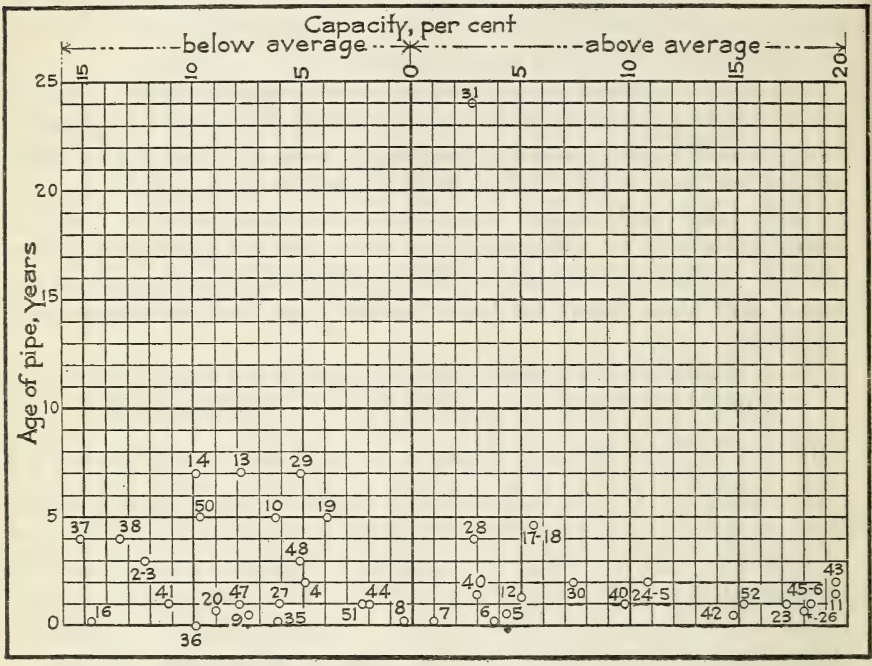



FIG. 5.—Diagram showing lack of relationship between age and carrying capacity. Numbers correspond with those in column 1, Tables 2 and 3. Ages taken from column 4, Table 3. Relative capacities taken from column 18, Table 3.

old at time of test, shows a capacity only about 3 per cent greater than the discharge computed by the new formula.

## CAPACITY OF WOOD-STAVE PIPES.

In the following pages the design of wood-stave pipes is considered with reference to carrying capacity alone. Such structural features as thickness of staves, banding, cradles, etc., do not come within the scope of this paper.

The total loss of head necessary in the conveyance of a given quantity of water will be the sum of the velocity head, $h_v$; the entry head, $h_e$; and the friction head, $h_f$, or its equivalent per unit length;

less any velocity head, $h_v'$, that may be recovered as the water approaches the pipe outlet at a velocity relatively high compared with the velocity in the open water below the outlet chamber. This total may be expressed by the formula

$$H_E = h_v + h_e + h_f - h_v' \tag{21}$$

where $H_E$ has the significance shown in figure 1 and $h_v$, $h_e$, $h_f$, and $h_v'$ have the significance defined on page 3. The influence of gentle curves was included in the data upon which the formulas were based, so that an additional loss for slight bends or curves need not be considered in the design of the usual pipe on irrigation systems. If sharp bends can not be avoided then an additional loss of head must be anticipated. The results of such tests as have been made on bends in pipes are given in standard works on hydraulics.

### VELOCITY AND ENTRY LOSSES.

In designing pipes of small diameter and great length, the losses due to velocity and entry heads, $h_v$ and $h_e$, are so small compared with the friction loss that they may be neglected. Otherwise they should be included in the allowance for total lost head.

As a rule a wood-stave pipe line begins under one of four general conditions:

1. Intake chamber located in a reservoir, where the velocity of the water is practically zero. No taper or transition section between intake and pipe.

2. Intake chamber located on an open channel where there is an appreciable velocity toward the structure but where this velocity is not available because a bend or well at the intake practically dissipates the velocity head.

3. Intake chamber followed by a transition section in which the velocity is increased over that existing in the leading channel or reservoir. The outlet end of a pipe beginning under this condition is usually provided with a similar transition section.

4. The wood pipe but a continuation of another pipe of the same size but of concrete, steel, or other material. In this case there is little or no loss due to entry or velocity, the only factor introduced being the change in friction head due to change of material.

In conditions 1 and 2 it is best to consider the water above the intake as at rest. From this state of rest velocity must be created and increased to the mean velocity, V, existing in the pipe. The head, $h_v$, necessary to create a given velocity is shown in column 2, Table 5. The entry loss will be from 0.5 $h_v$ where the pipe of standard size begins at a headwall and is without bell or taper mouth, to about 0.25 $h_v$ for a rounded intake, and 0.05 $h_v$ for a bell-mouth intake. Many of the structures built by the United States Reclamation

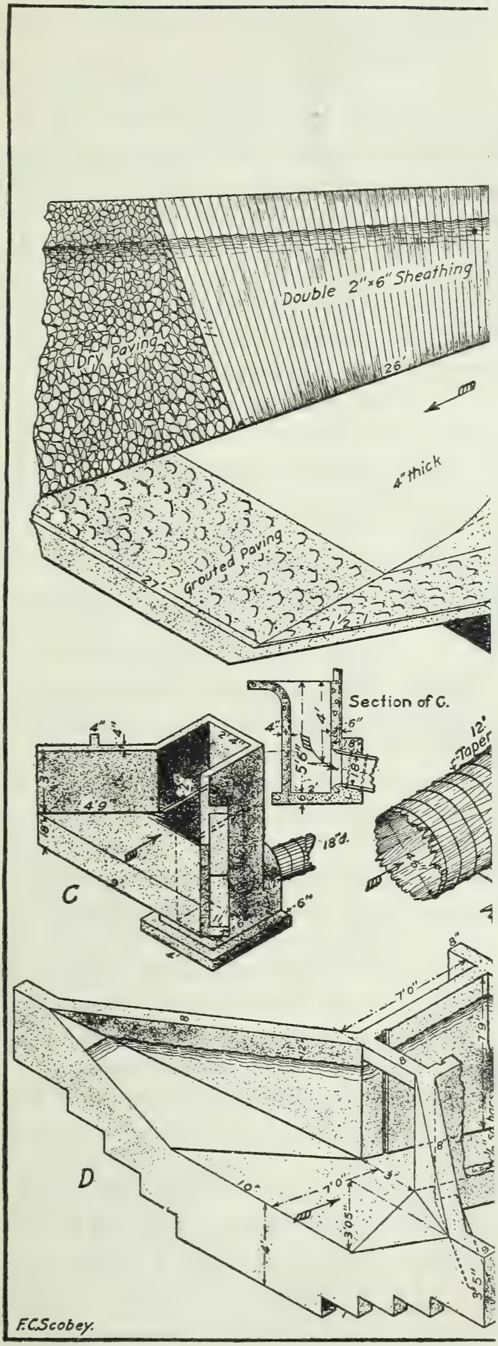
Service were designed with the entry loss taken as half the velocity head, even though there were more or less rounding and taper in the intake structures. In Table 5, column 3, is shown the amount of entry loss when taken as half the velocity head (column 2); and the sum of the entry and velocity losses is shown in column 4.

TABLE 5.—*Mean velocity in pipe, V, in feet per second; and head of elevation lost creating this velocity and overcoming entrance conditions, $h_v+h_e$, in feet.*

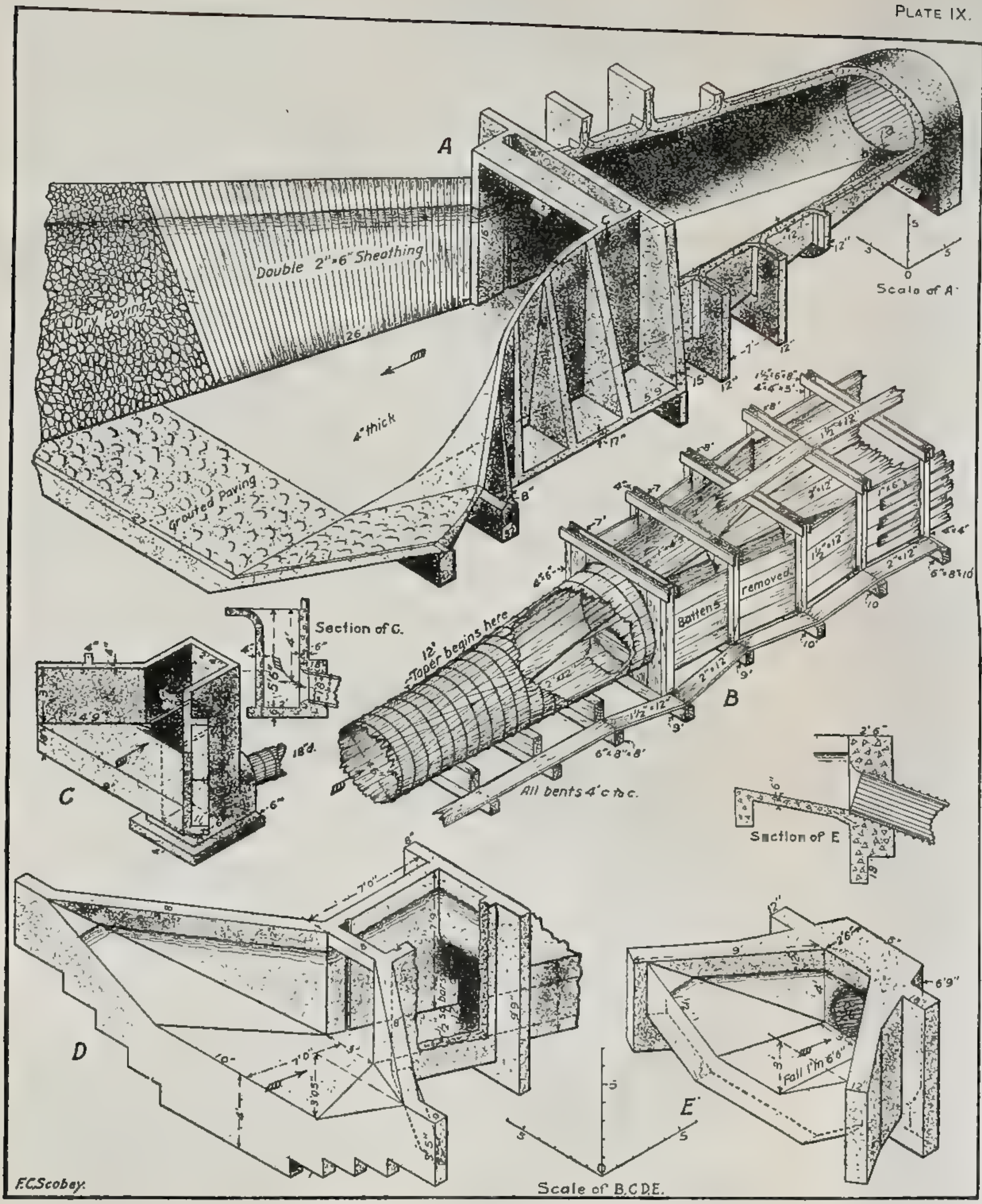
| 1<br>V | 2<br>$h_v$ | 3<br>$h_e$ | 4<br>$h_v+h_e$ | 1<br>V | 2<br>$h_v$ | 3<br>$h_e$ | 4<br>$h_v+h_e$ |
|---|---|---|---|---|---|---|---|
| *Ft. per sec.* | *Feet.* | *Feet.* | *Feet.* | *Ft. per sec.* | *Feet.* | *Feet.* | *Feet.* |
| 1.0 | 0.016 | 0.008 | 0.024 | 5.0 | 0.389 | 0.195 | 0.584 |
| .2 | .022 | .011 | .033 | .2 | .420 | .210 | .630 |
| .4 | .030 | .015 | .045 | .4 | .453 | .227 | .680 |
| .6 | .040 | .020 | .060 | .6 | .488 | .244 | .732 |
| .8 | .050 | .025 | .075 | .8 | .523 | .262 | .785 |
| 2.0 | .062 | .031 | .093 | 6.0 | .560 | .280 | .840 |
| .2 | .075 | .037 | .112 | .2 | .598 | .299 | .897 |
| .4 | .090 | .045 | .135 | .4 | .637 | .319 | .956 |
| .6 | .105 | .053 | .158 | .6 | .677 | .339 | 1.016 |
| .8 | .122 | .061 | .183 | .8 | .719 | .359 | 1.078 |
| 3.0 | .140 | .070 | .210 | 7.0 | .762 | .381 | 1.143 |
| .2 | .159 | .080 | .239 | .2 | .806 | .403 | 1.209 |
| .4 | .180 | .090 | .270 | .4 | .851 | .426 | 1.277 |
| .6 | .202 | .101 | .303 | .6 | .898 | .449 | 1.347 |
| .8 | .224 | .112 | .336 | .8 | .946 | .473 | 1.419 |
| 4.0 | .249 | .125 | .374 | 8.0 | .995 | .498 | 1.493 |
| .2 | .274 | .137 | .411 | .2 | 1.045 | .523 | 1.568 |
| .4 | .301 | .151 | .452 | .4 | 1.097 | .549 | 1.646 |
| .6 | .329 | .165 | .494 | .6 | 1.150 | .575 | 1.725 |
| .8 | .358 | .179 | .537 | .8 | 1.204 | .602 | 1.806 |

Where the usual types of inlet and outlet structures are employed, with but little construction and consequent expense incurred for conservation of entry and velocity heads it is recommended that the figures in Table 5 be used. In that case any influence on the total loss of head, derived from the rate of flow toward the intake as in condition 2, where water enters the pipe from an open channel, will introduce a small factor of safety for conservative construction. The same may be said of any slight recovered velocity head where the pipe discharges into an open channel.

In figure 1, Plate XII, probably the most common form of construction for both inlet and outlet of a wood-stave siphon is shown. In some cases taper staves are used in both inlet and outlet, so that the velocity is gradually increased in entering the pipe, thus reducing the entry loss. This construction classes the pipe under condition 3. The velocity is gradually decreased at the outlet, preserving the velocity head. The usual practice in this type of construction is to place the center of the pipe opening for the inlet chamber at or below the bottom of the leading canal. The pipe at the outlet is usually placed so that the top of the opening is slightly below the high-water line at full capacity.




SUGGESTIVE INLET AND OU




SUGGESTIVE INLET AND OUTLET STRUCTURES FOR INVERTED SIPHONS.

The type of construction with a well having a rounded intake is shown in C, Plate IX. This type is generally used where the hillside is very steep just at the pipe intake or where a drop in grade line is included in the well structure.

In D, Plate IX, is shown a type of entrance structure for both round and square pipes quite frequently used by the United States Reclamation Service where moderate velocities (5 or 6 feet per second) only are to be considered.

The west Okanogan irrigation district (Washington) uses a general type like E, Plate IX, for both inlet and outlet structures. In the inlet structure shown the concrete rounds into the pipe opening, the center of which is level with the bottom of the canal.

The forms, reinforcement, and final entrance of a large siphon in Wyoming are shown in Plate XIII.

A pipe with both inlet and outlet tapering, such as condition 3, will have the maximum efficiency as it approaches a "Venturi tube with elongated throat," as described to the writer by D. C. Henny. Such a structure would have the sides of the inlet converge at the rate of about 1 in 5, while the transition section at the outlet would diverge at the rate of about 1 in 24. On such a pipe less than 5 per cent of the velocity head will be unrecovered, charging all losses other than friction to entry head.

The transition section usually includes part of the intake or outlet structure proper and also a short length of the wood pipe. On the Arkansas Valley conduit of the Colorado Fuel & Iron Co. there are 25 siphons of wood, incased in concrete.[1] The intake ends of these siphons taper at the rate of 1 inch per foot of pipe until the diameter at the opening is 1 foot greater than that of the main pipe. The inlet to one of these siphons is shown in figure 3, Plate XII.

This argument regarding conservation of velocity head and reduction of entry head is exemplified in the recently completed designs for a large siphon carrying water at a very high velocity at the Sun River crossing on the Sun River project of the United States Reclamation Service. The outlet structure is shown as A in Plate IX.

The water section in the leading canal has an area of 928 square feet with a velocity of 1.08 feet per second. By tapering wing walls and concrete intake structure the area at the upper end of the wood-stave pipe has been reduced to 50.3 square feet (96-inch pipe) and the velocity increased to 19.9 feet per second. By this time 6.14 feet of head of elevation has been devoted to building up a high velocity. Of course it is important that as much as possible of this velocity head be recovered at the outlet end.

[1] Frictional Resistance in Artificial Waterways. V. M. Cone, R. E. Trimble, and P. S. Jones, Colorado Sta. Bul. 194 (1914).

Throughout approximately the last 100 feet of wood pipe ending at a, Plate IX, tapering staves are inserted in the pipe until an elliptical section 12 feet wide and 9 feet high is reached at a. The area has been increased so gradually up to 84.82 square feet that, it is computed, 3.99 feet of velocity head have been recovered, the velocity meanwhile being reduced to 11.8 feet per second. Between b and c the transition section changes from an elliptical to a rectangular shape 13¾ feet wide by 10.6 feet high, with an area of 153.12 square feet. In this transition section the vertical walls and flat floor and roof begin at b with zero width, increasing to full width at c, the corners being rounded out in the concrete. The velocity is further diminished to 6.54 feet per second and the computations show an additional velocity head of 1.51 feet recovered. At the upper end of the canal leading from the structure the velocity is further reduced to 2.10 feet per second by enlarging the section, the additional recovered velocity head being computed as 0.59 feet. Thus of the 6.14 feet devoted at the inlet end to increasing the velocity, the computations show the recovery of all but the 0.05 foot, which is due to the difference in velocities in the channels above and below the structure. However, even with carefully designed transition sections the computations show an aggregate of 1.80 feet devoted to "entry head" at the various changes in cross section.

The outlet structure of the Similkameen Siphon of the West Okanogan Irrigation District, Washington, is also designed with a view to conservation of velocity head. This structure (B, Pl. IX) consists of a 46-inch stave pipe tapered in a length of 12 feet to a diameter of 57.5 inches, the pipe then discharging into a wooden flume. The most noticeable feature of the structure is the use of guide wings extending into the flume. These prevent a sudden enlargement of the cross section at the end of the pipe and tend to recover the velocity head. The floor of the flume is extended into the pipe to the point where the taper section begins, thus preventing contraction and consequent loss of head due to extension of the segment of the pipe below the floor line at the bulkhead. No attempt is made to secure watertightness in these guide wings, but the water is allowed to enter between the wings and the flume proper so that no pressure may be brought against the light wings. All tightness is secured at the bulkhead and in the flume proper.

Where a change is made in the size of pipe a long taper transition section is usually installed. In the Altmar pipe (No. 51) the diameter is changed from 12 to 11 feet. This change is so gradual that it can hardly be detected by the eye. In a similar way the Mabton pressure pipe (Nos. 43, 45, and 46) is reduced from 55¾ inches to 48¾ inches. Where changes in sectional area are made in this manner probably the loss of head due to such change is negligible, the change in velocity head alone being appreciable.

Unless a tapered outlet structure is installed it will be best to consider all of the velocity head within the pipe as dissipated in impact and eddies due to the sudden enlargement of the sectional area in the outlet chamber. That is, for purposes of design recovered velocity head should not be counted upon.

During the season of 1915 the writer endeavored to secure information as to the amount of head lost between the surface of the water at the intake and a point 3 diameters down the pipe, charging such loss of head to velocity and entry losses jointly. Some of the pipes tested were of concrete and some of wood, but this difference did not alter the value of the information secured. The latter was meager, however, for the reason that designers have been ultraconservative in allowing for friction losses of head in the pipe; consequently the entrance in most cases is not submerged. The water from the canal rushes down the first reaches of pipe and in a very turbulent and air-charged condition finally fills the pipe.

Table 6 shows the results of such tests as could be made. These were incident to those made for the determination of friction losses in the pipe.

TABLE 6.—*Tests for loss of head at inlet of wood and concrete pipes.*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|
| Test. | Diameter. | Mean velocity in pipe per second. | Loss of head, intake to gauge 1. | Loss of head per foot of pipe, gauge 1–2. | Length of pipe, 3D to gauge 1. | Total loss from 3D to gauge 1. | Loss between intake and 3D. | $h_v$= velocity head for V, col. 3. | $h_e$= entry head $=\frac{1}{2} h_v$. | $h_v+h_e$. |
| | *Inches.* | *Feet.* | *Foot.* | *Foot.* | *Feet.* | *Foot.* | *Foot.* | *Foot.* | *Foot.* | *Foot.* |
| 1 | 8 | 3.51 | 0.039 | 0.0108 | 3.8 | 0.041 | −0.002 | 0.191 | 0.095 | 0.286 |
| 2 | 8 | 3.56 | .014 | .0108 | 3.8 | .041 | − .027 | .197 | .097 | .294 |
| 3 | 12 | 1.60 | .021 | .00126 | 7.0 | .009 | + .012 | .040 | .020 | .060 |
| 4 | 12 | 1.60 | .047 | .00146 | 7.0 | .010 | + .037 | .040 | .020 | .060 |
| 5 | 60 | 3.08 | .125 | .00054 | 65.0 | .035 | + .090 | .150 | .075 | .225 |
| 6 | 60 | 3.03 | .098 | .00056 | 65.0 | .036 | + .062 | .144 | .072 | .216 |
| 7 | 54 | 4.03 | .498 | .0015 | 12.8 | .019 | + .479 | .254 | .127 | .381 |
| 8 | 54 | 4.02 | .431 | .0016 | 12.8 | .021 | + .410 | .252 | .126 | .378 |

It is appreciated that this table is of but little assistance in the design of intakes, but it is offered as a start toward the collection of information on this subject. Except in the case of tests 1 and 2 the velocity of approach was indeterminate, due to changes in channel section and to eddying conditions. It will have served its purpose if it brings out the fact that close computations on entry and velocity head losses can be but approximate.

A hook gauge in a stilling box in the intake gave the water surface at that point, while the elevation of the top of the equivalent water column (see p. 22) at gauge No. 1, deducted from the elevation of the water surface at the intake, gave the loss of head between the intake and gauge No. 1. These losses are shown in column 4. Column 7 gives the friction loss between a point 3 diameters down the pipe from the intake and gauge No. 1. This column is based upon the friction loss per foot within the pipe (column 5) multiplied by the number of feet (column 6) back from gauge No. 1 to the 3-diameter point. Column 4 less column 7 gives the computed loss of head (column 8) due to velocity and entry heads combined between the intake and the 3-diameter point. Theoretically column 8 should approximate column 11, which is the sum of columns 9 and 10, but in most cases the velocity of approach was sufficient to make the entries in column 8 much smaller than those in column 11.

Referring to these two columns: Tests 1 and 2 were conducted on a concrete pipe where the water entered a 16-inch standpipe from an 8-inch pipe and left the opposite side in an 8-inch pipe. The observations show that no head was lost within the standpipe. Tests 3 and 4 were on pipes in an installation similar except that the water left the standpipe in a 12-inch pipe at right angles to an 8-inch pipe through which it entered. Tests 5 and 6 were on the pipe shown in Plate XII, figure 3. Here the velocity of approach in the canal acted directly on the intake opening, greatly reducing the loss of head. Tests 7 and 8 were on a similar pipe, but in this instance the canal turned an abrupt right angle just before entering the pipe, causing a violently turbulent condition which probably introduced a large error in the observed head at the intake.

### AIR IN PIPE.

In speaking of a pipe that did not show sufficient carrying capacity Moritz states:[1]

> Examination showed that air imprisoned in the pipe was causing the difficulty. This was overcome by inserting a ½-inch wrought-iron standpipe in the top of the pipe about 15 feet below the intake. In this way the air was, to all appearances, entirely removed, and the carrying capacity was raised to 1.54 cubic feet per second, an increase of about 60 per cent.

Pipes taking water directly from reservoirs are, of course, not subject to these troubles, the depth above the intake being, as a rule, sufficient to insure filling of the pipe with water alone.

Siphon pipes and, in even greater degree, pipe chutes are often reduced in carrying capacity by entrained air. In his investigations on wood-stave pipes the writer has observed that air troubles are minimized under the following conditions: (*a*) Low velocity in channel approaching inlet; (*b*) inlet end set well below the hydraulic gradient, as a rule with top of pipe at about same elevation as bottom of the canal above the inlet; (*c*) intake chamber designed to minimize eddies.

[1] Trans. Amer. Soc. Civ. Engin., 74 (1911), p. 435.

Moritz suggests the extensive use of air valves in some form. The best air outlet is probably a "chimney" rising above the hydraulic gradient. There should be several connections to the siphon, either normal to the pipe or, better, pointing slightly upstream. These may be independent of each other or all may connect to a common pipe extending along the top of the siphon, the upper end passing through the head wall of the intake chamber so that any water that blows out with the air will fall back into the pipe. The last connection should be at a lower elevation than the water surface in the outlet chamber so that, with a small discharge, the air entrained will be collected and passed off. As a rule low discharges entrain more air than does a full discharge, since the water rushes down the initial reaches of pipe in a turbulent condition. On the other hand, the upper air vents are necessary to care for air entrained and compressed during discharges approaching maximum capacity. These vents may be from 1 to 12 inches in diameter, depending on the size of the wood pipe, and should be so assembled that they may be taken apart, as débris collects in such vents and must be periodically removed. If excessive air troubles are present, a collecting chamber may be attached to the siphon at each vent, the air pipe being attached to the top of the chamber rather than directly to the siphon pipe.

## FRICTION LOSSES.

The loss of head necessary to overcome internal resistances within the pipe is proportional to the length of the pipe but is independent of the static pressure in the pipe. That is, the loss necessary in the conveyance of a given quantity of water through a siphon pipe will be the same whether the low point is, say, 10 feet or 150 feet, below the hydraulic grade line, the other factors remaining unchanged. The influence of temperature upon the frictional resistances was found by Saph and Schoder to be considerable in small brass pipes but has not been studied in connection with tests on large wood pipes. It is doubtful whether the influence of temperature could be differentiated from that of friction alone in tests on large pipes in commercial service.

In order to determine the size of pipe and the loss of head necessary to overcome the frictional resistances in the conveyance of a given quantity of water, two estimate diagrams and a table have been prepared. Two examples of typical pipe problems are given. In these the use of the diagrams only is explained, as the table is considered self-explanatory. The factors of safety given below should be considered in each problem, as a study of Plate VII shows that an averaging formula, accepted literally, can not assure the desired discharge for a given loss of head.

### FACTORS OF SAFETY.

A study of Plate VII shows that a general formula may be often 10 per cent, sometimes as much as 15 per cent, and in isolated cases 25 per cent, at variance with observed capacities for given losses of head. Likewise a study of the conditions holding in various pipes fails to disclose just when high or low relative carrying capacities are to be expected. However, the following factors of safety appear to be warranted:

Five per cent when only a rough approximation to the actual needs of the pipe is possible; when water enters the pipe from a settling reservoir and velocities in the pipe are so high that a clean-scoured condition will always be present inside the pipe; and also where conditions of operation are such that no penalties are attached to a slight insufficiency of carrying capacity.

Ten per cent when the above conditions for a very clean pipe are assured, but where penalties are attached to lack of capacity; or where no direct penalties are attached but silted waters and low velocities may permit deposits and growths of *Spongilla* or other vegetable life.

Fifteen per cent where rock ravelings may reduce the interior area of the pipe, or when penalties are attached and silted water or vegetable growth are likely to cause excess retardation of flow.

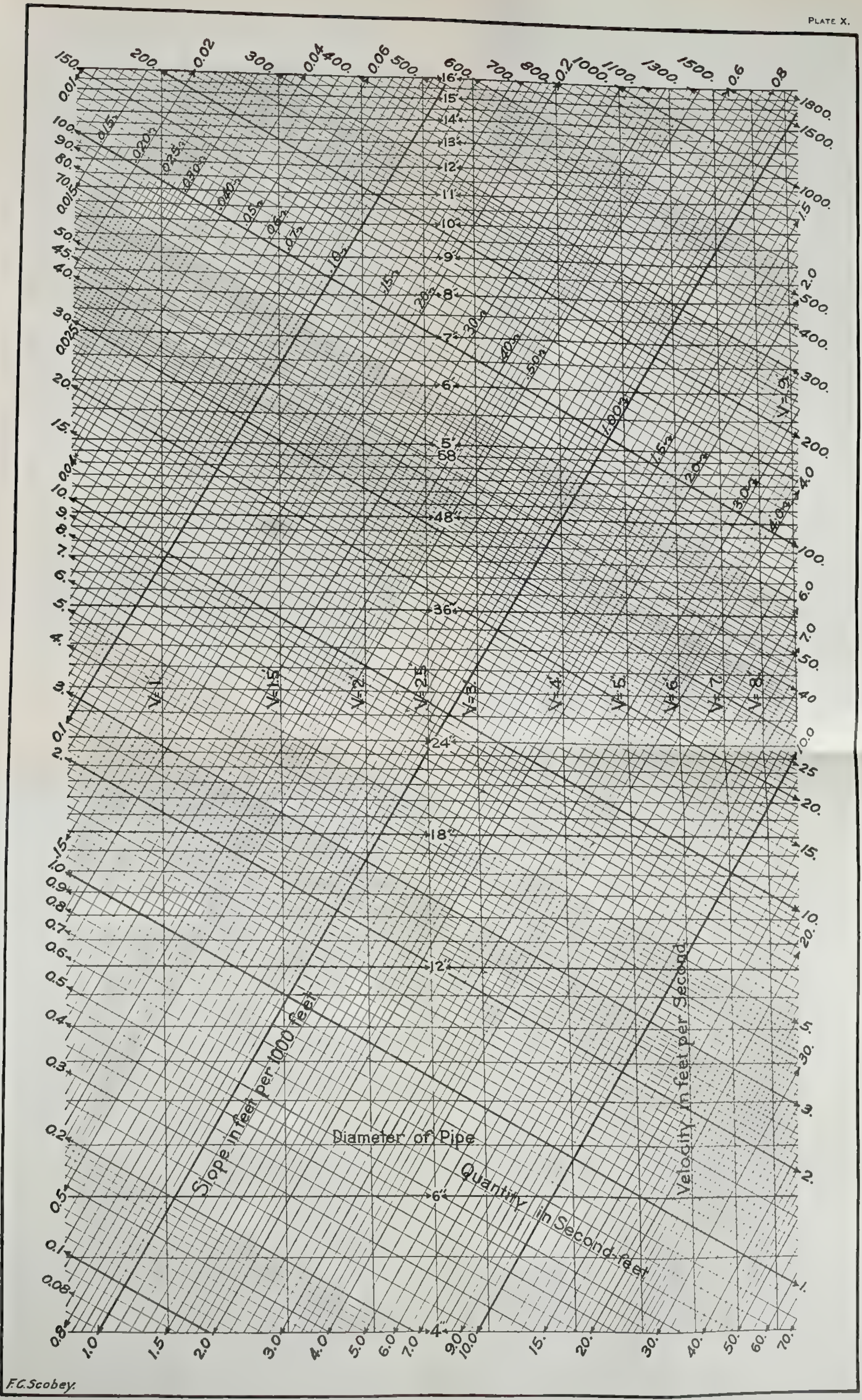
The designer may safely assume that the capacity of wood pipe will not change unless the pipe is subject to silting, ravelings, or vegetable growth. (See fig. 5, p. 58.)

### ESTIMATE DIAGRAMS AND TABLE; SOLUTIONS FOR TYPICAL PIPE PROBLEMS.

1. An inverted siphon is required to convey 60 second-feet of water a length of 2,800 feet with an allowable total loss of head of 1.8 feet. Water has settled in a reservoir before entering the canal. No direct penalty has been attached for lack of capacity. Required, diameter of the pipe.

Allowing a 5 per cent overload as a factor of safety, the rated capacity will be $60+3=63$ second-feet. Since the velocity is not known, the entry and velocity head combined can not be determined at present. For preliminary figures, 2,800 feet $=2.8\times1{,}000$ feet; therefore $\frac{1.8}{2.8}=0.642=H$. Referring to Plate X,[1] enter diagram at 63 second-feet. Intersection of $Q=63$ with $H=0.642$ is about on the diameter line for 58 inches and at a velocity point of about 3.6 feet per second. Referring to Table 5, opposite $V=3.6$ the combined

[1] Plate X was prepared by the writer from the new formula (No. 14, p. 7) in a manner similar to that first used by Schoder in Engineering Record, Sept. 3, 1904.




LOGARITHMIC DIAGRAM FOR USE IN DESIGNING WOOD-STAVE PIPE. BASED ON FORMULA: $Q=1.272D^{2.65}H^{0.555}$.

Any point on the diagram gives simultaneous values of quantity, Q; diameter of pipe, D; loss of head per 1,000 feet, H; and velocity, V. For problems involving velocities less than 0.7 foot per second or more than 9.0 feet per second, see Plate VIII.

velocity and entry head is found to be 0.303 feet. Therefore, the final figures are $\frac{1.8-0.3}{2.8}=0.536=H$.

Again, referring to Plate X, at the intersection of $Q=63$ and $H=0.536$ the diameter of the required pipe is found to be 60 inches and the peak-load velocity to be 3.3 feet per second. The difference between the preliminary figure for combined velocity and entry heads and the final figure is not sufficient to warrant more trials.

2. A power trunk line from a reservoir to a surge tank to convey a peak load of 700 second-feet is required. The length of pipe will be 11.3 miles, the total loss of head under peak load shall not exceed 20 feet, and the value of head shall be sufficient to warrant a factor of safety of 15 per cent in designing. Required for comparison, the size of pipe for both a single and a double pipe line with the same loss of head.

The length of pipe is so great that velocity and entry head may be ignored.

One hundred and fifteen per cent of $700=805$ second-feet.

Eleven and three-tenths miles $=11.3\times 5{,}280=59.664\times 1{,}000$ feet.

$$\frac{20.0}{59.7}=0.335 \text{ feet per } 1{,}000 \text{ feet}=H.$$

Enter Plate X at $Q=805$. Intersection of $Q=805$ with $H=0.335$ is at $D=14.5$ feet and at $V=5$ feet per second. Thus a single pipe line 14.5 feet in diameter will convey the peak load at a velocity of about 5 feet per second.

To study the possibilities of a double pipe line, turn to figure 6. Enter at intersection of diameter 14.5 feet and relative capacity 1. From this point the left slanting line intersects relative capacity line $\frac{1}{2}$ on diameter line 135 inches or diameter line 11.25 feet. Thus twin lines each $11\frac{1}{4}$ feet in diameter will convey the given quantity of water with the same loss of head as will a single line $14\frac{1}{2}$ feet in diameter.

Pipe problems involving velocities less than 0.7 foot per second or more than 9 feet per second may be solved by the use of Plate VIII. With a straightedge join the two discharge scales at the given discharge. All points on the straightedge will now give simultaneous values of diameter, loss of head, and velocity. For instance, the dash-dot line representing 100 second-feet intersects the 84-inch pipe line on the H-line of 0.237 foot per 1,000 feet and on the V-line of 2.58 feet per second. Thus an 84-inch pipe will convey 100 second-feet of water at a velocity of 2.58 feet per second with a loss of head of 0.237 foot per thousand feet of pipe.

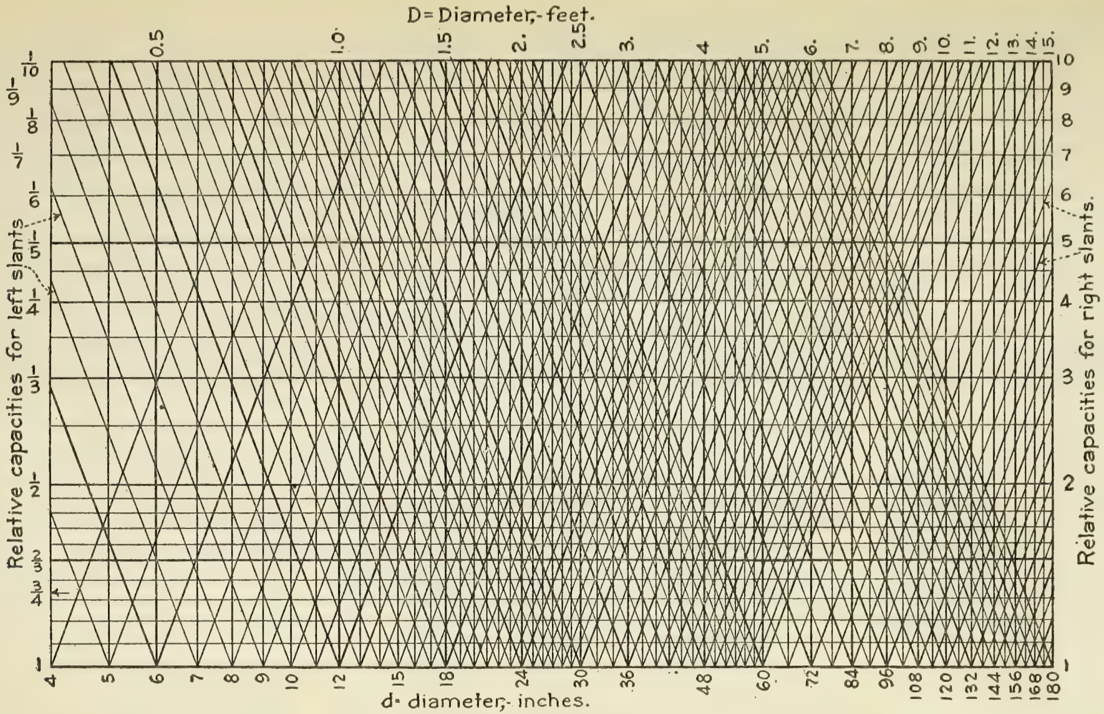



FIG. 6.—Logarithmic diagram showing relative capacities of wood-stave pipe of various diameters for any given hydraulic gradient. For instance, an 8-inch pipe will carry one-third as much as a 12-inch pipe, and an 18-inch pipe will carry three times as much as a 12-inch pipe. For the first problem, enter the diagram at the bottom on the left slanting line leading from 12 inches as a base. The intersection of this slant with the vertical line above 8 is approximately on the horizontal line representing 1/3, as shown by figures at left of diagram. Similarly for the second problem follow the right slant from 12 as a base to the intersection of this slant with the vertical line from 18. This intersection is approximately on the horizontal line representing 3 as shown by figures at right of diagram.

FIG. 1.—PIPES FROM SURGE TANK TO POWER HOUSE.
Right-hand pipe held at constant velocity. 13½-foot pipe in distance. (No. 52.)

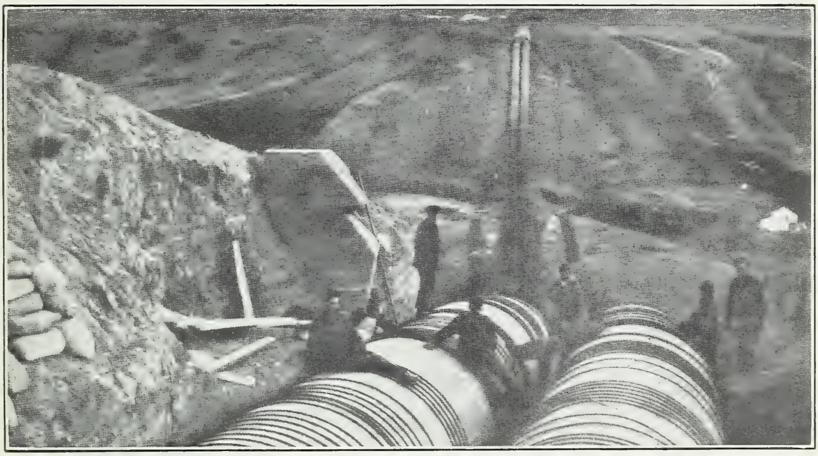


FIG. 2.—AN EXAMPLE OF TWIN LINE CONSTRUCTION.

FIG. 3.—WINTER FLOW IS RETARDED BY SLUSH ICE.
Note rings for grating removed to prevent ice accumulation.

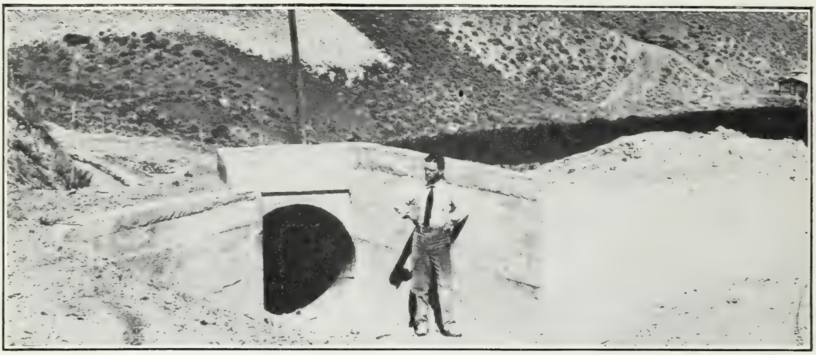


FIG. 1.—TYPICAL OUTLET STRUCTURE. WILL PARTIALLY RECOVER VELOCITY HEAD.
Pipe is one-half diameter too high for inlet structure. Too much air would enter.

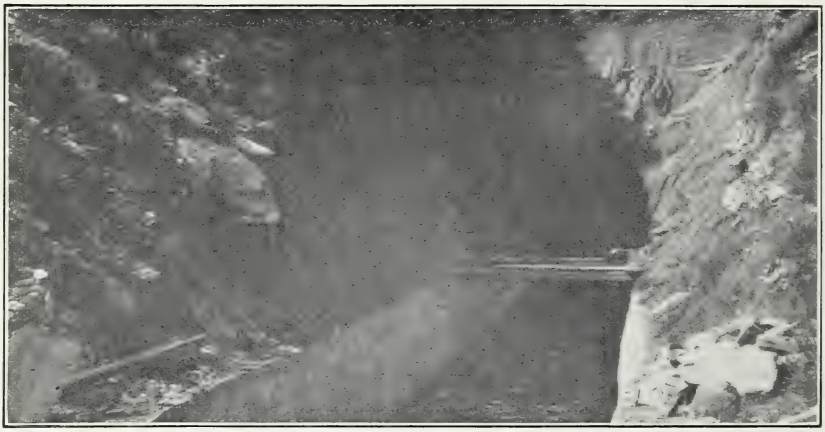


FIG. 2.—VIEW TAKEN FROM STRUCTURE IN FIGURE 3.
Hillside cut ravelings enter pipe and reduce capacity. A condition to be avoided.

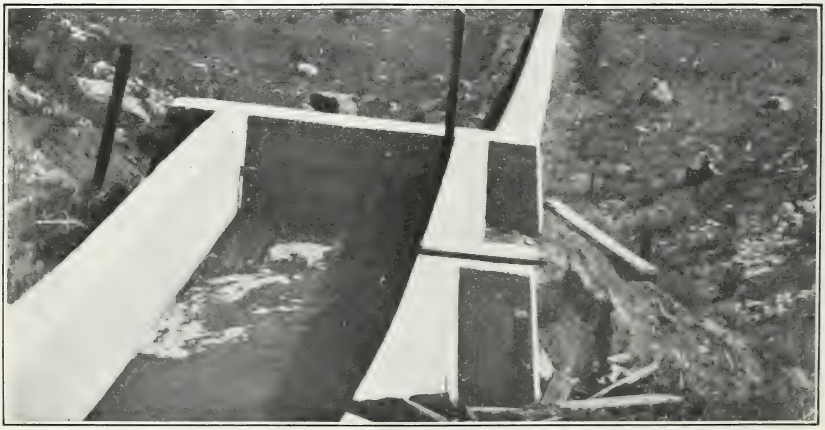


FIG. 3.—ENTRANCE WELL SUBMERGED, REDUCING AMOUNT OF AIR CARRIED INTO PIPE.

FIG. 1.—SIPHON UNDER UNION PACIFIC RAILROAD, ROCK CREEK CONSERVATION CO., WYOMING.

Form for inlet bowl to reduce entry loss. Pipe under construction in distance. See figures 2 and 3.

FIG. 2.—FORM FOR BOWL, FLOOR REINFORCEMENT, AND CAST-IRON PIPE FOR INLET SECTION FOR STRUCTURE IN FIGURES 1 AND 3.

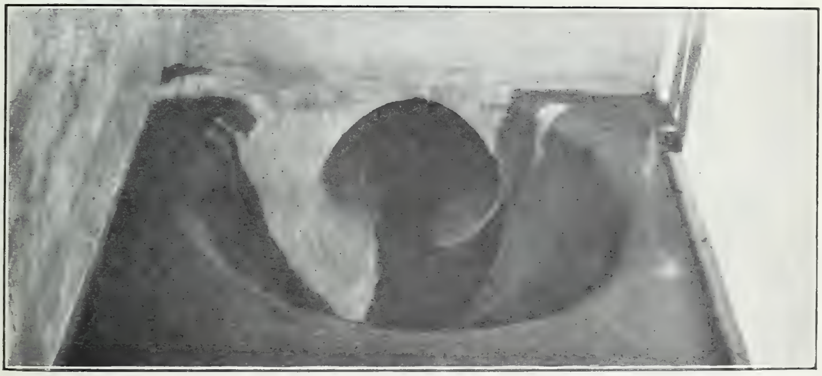


FIG. 3.—SIPHON INLET MADE FROM FORM SHOWN IN FIGURES 1 AND 2. ENTRANCE WELL SUBMERGED, PREVENTING AIR BEING CARRIED INTO PIPE.

FIG. 1.—EVEN WITH 27 CAST-IRON BENDS LIKE THIS THE ASTORIA, WASH., PIPE SHOWS A CAPACITY 17 PER CENT MORE THAN THE AVERAGE. (NO. 23.)

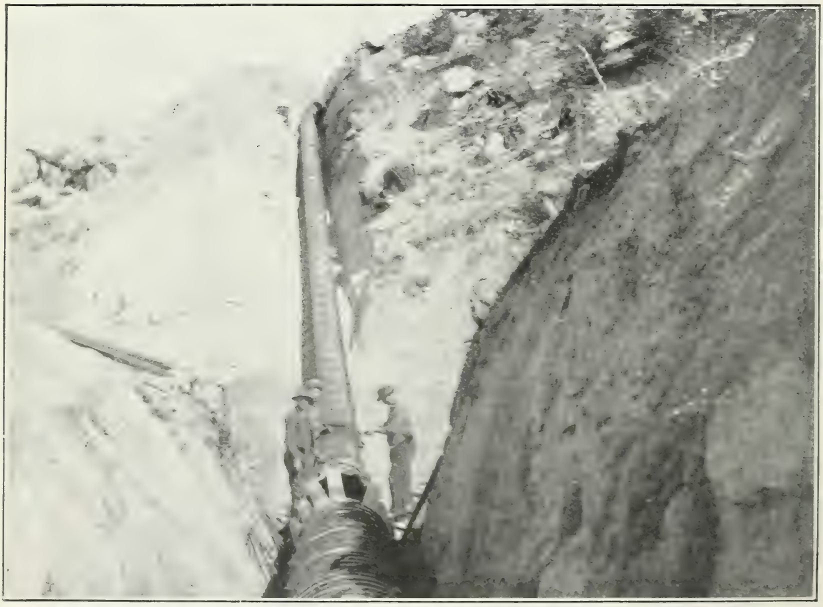


FIG. 2.—PIPE FOR BUTTE, MONT., MUNICIPAL SUPPLY. (NO. 32.) SPRINGING IN A BUCKLE JOINT.

TABLE 7.—*Velocity V in feet per second and loss of head H in feet per thousand feet of pipe, necessary to the conveyance of a given quantity of water, Q, in second-feet and in millions of U. S. gallons per day through wood-stave pipe, based on formula* $H=\frac{7.68\ V^{1.8}}{d^{1.17}}$. *For instance, 5 second-feet will be carried by a 16-inch pipe at a velocity of 3.58 feet per second with a loss of head of 2.98 per thousand feet of pipe.*

| Quantity. | Inside diameter, in inches, and corresponding area, A, in square feet. | | | | | | | | | | | | | | Quantity, millions per day. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 A=0.0218. | | 3 A=0.0491. | | 4 A=0.0873. | | 5 A=0.1364. | | 6 A=0.1963. | | 8 A=0.3491. | | 10 A=0.5454. | | |
| Q | V | H | V | H | V | H | V | H | V | H | V | H | V | H | |
| *Sec.-ft.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Gals.* |
| 0.02 | 0.92 | 2.92 | 0.41 | 0.43 | 0.23 | 0.10 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 0.0129 |
| .04 | 1.83 | 10.1 | .82 | 1.49 | .46 | .38 | 0.29 | 0.13 | ...... | ...... | ...... | ...... | ...... | ...... | .0258 |
| .06 | 2.75 | 21.2 | 1.22 | 3.04 | .69 | .77 | .44 | .27 | ...... | ...... | ...... | ...... | ...... | ...... | .0388 |
| .08 | 3.67 | 35.4 | 1.63 | 5.12 | .92 | 1.31 | .59 | .45 | ...... | ...... | ...... | ...... | ...... | ...... | .0517 |
| .10 | 4.59 | 52.9 | 2.04 | 7.67 | 1.14 | 1.94 | .73 | .66 | 0.51 | 0.28 | 0.29 | 0.07 | ...... | ...... | .0646 |
| .15 | 6.88 | 111 | 3.05 | 15.8 | 1.71 | 4.05 | 1.10 | 1.39 | .76 | .58 | .43 | .15 | 0.27 | ...... | .0969 |
| .20 | 9.17 | 185 | 4.07 | 26.6 | 2.29 | 6.77 | 1.47 | 2.33 | 1.02 | .98 | .57 | .25 | .37 | 0.09 | .129 |
| .3 | 13.8 | 385 | 6.11 | 55.2 | 3.44 | 14.0 | 2.20 | 4.82 | 1.53 | 2.02 | .86 | .51 | .55 | .18 | .194 |
| .4 | 18.3 | 649 | 8.14 | 93.7 | 4.58 | 23.4 | 2.93 | 8.10 | 2.04 | 3.40 | 1.15 | .86 | .73 | .29 | .259 |
| .5 | 22.9 | 966 | 10.2 | 140 | 5.73 | 35.1 | 3.67 | 12.1 | 2.55 | 5.10 | 1.43 | 1.28 | .92 | .45 | .323 |
| .6 | ...... | ...... | 12.2 | 192 | 6.87 | 48.7 | 4.40 | 16.8 | 3.06 | 7.05 | 1.72 | 1.79 | 1.10 | .60 | .388 |
| .7 | ...... | ...... | 14.3 | 255 | 8.02 | 64.3 | 5.13 | 22.2 | 3.57 | 9.34 | 2.01 | 2.37 | 1.28 | .81 | .452 |
| .8 | ...... | ...... | 16.3 | 325 | 9.16 | 81.7 | 5.86 | 28.2 | 4.08 | 11.8 | 2.29 | 3.00 | 1.47 | 1.02 | .517 |
| .9 | ...... | ...... | ...... | ...... | 10.3 | 102.0 | 6.60 | 34.9 | 4.59 | 14.6 | 2.58 | 3.71 | 1.65 | 1.28 | .582 |
| 1.0 | ...... | ...... | ...... | ...... | 11.4 | 121.0 | 7.33 | 42.1 | 5.10 | 17.7 | 2.87 | 4.42 | 1.83 | 1.52 | .646 |
| 1.2 | ...... | ...... | ...... | ...... | 13.7 | 169.0 | 8.80 | 58.5 | 6.11 | 24.6 | 3.44 | 6.22 | 2.20 | 2.10 | .776 |
| 1.4 | ...... | ...... | ...... | ...... | 16.0 | 224.0 | 10.3 | 77.1 | 7.13 | 22.4 | 4.01 | 8.21 | 2.57 | 2.78 | .905 |
| 1.6 | ...... | ...... | ...... | ...... | 18.3 | 285.0 | 11.7 | 98.8 | 8.15 | 41.3 | 4.58 | 10.4 | 2.93 | 3.54 | 1.034 |
| 1.8 | ...... | ...... | ...... | ...... | 20.6 | 352.0 | 13.2 | 121 | 9.17 | 51.0 | 5.16 | 12.9 | 3.30 | 4.45 | 1.163 |
| 2.0 | ...... | ...... | ...... | ...... | ...... | ...... | 14.7 | 147 | 10.2 | 61.6 | 5.72 | 15.6 | 3.67 | 5.39 | 1.293 |
| 2.5 | ...... | ...... | ...... | ...... | ...... | ...... | 18.3 | 219 | 12.7 | 92.1 | 7.16 | 23.3 | 4.58 | 8.03 | 1.616 |
| 3.0 | ...... | ...... | ...... | ...... | ...... | ...... | 22.0 | 304 | 15.3 | 128 | 8.60 | 32.4 | 5.50 | 11.0 | 1.939 |
| 4.0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 20.4 | 215 | 11.5 | 54.3 | 7.33 | 18.6 | 2.585 |
| 5.0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 14.3 | 81.2 | 9.17 | 28.0 | 3.232 |
| 6.0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 17.2 | 113 | 11.0 | 38.9 | 3.878 |

| Quantity. | 12 A=0.7854. | | 14 A=1.069. | | 16 A=1.396. | | 18 A=1.767. | | 20 A=2.182. | | 22 A=2.640. | | 24 A=3.142. | | Quantity, millions per day. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q | V | H | V | H | V | H | V | H | V | H | V | H | V | H | |
| 1.0 | 1.27 | 0.65 | 0.94 | 0.31 | 0.72 | 0.16 | 0.57 | 0.09 | ...... | ...... | ...... | ...... | ...... | ...... | 0.646 |
| 1.2 | 1.53 | .90 | 1.12 | .43 | .86 | .23 | .68 | .13 | 0.55 | 0.08 | ...... | ...... | ...... | ...... | .776 |
| 1.4 | 1.78 | 1.19 | 1.31 | .57 | 1.00 | .30 | .79 | .17 | .64 | .10 | 0.53 | 0.07 | ...... | ...... | .905 |
| 1.6 | 2.04 | 1.51 | 1.50 | .72 | 1.15 | .38 | .91 | .22 | .73 | .13 | .61 | .08 | ...... | ...... | 1.034 |
| 1.8 | 2.29 | 1.87 | 1.68 | .90 | 1.29 | .47 | 1.02 | .27 | .83 | .16 | .68 | .10 | ...... | ...... | 1.163 |
| 2.0 | 2.55 | 2.26 | 1.87 | 1.08 | 1.43 | .57 | 1.13 | .33 | .92 | .20 | .76 | .12 | 0.64 | 0.08 | 1.293 |
| 2.5 | 3.18 | 3.37 | 2.34 | 1.62 | 1.79 | .85 | 1.42 | .49 | 1.15 | .29 | .95 | .19 | .80 | .12 | 1.616 |
| 3.0 | 3.82 | 4.67 | 2.81 | 2.24 | 2.15 | 1.19 | 1.70 | .68 | 1.37 | .41 | 1.14 | .26 | .95 | .17 | 1.939 |
| 3.5 | 4.46 | 6.17 | 3.27 | 2.96 | 2.51 | 1.57 | 1.98 | .89 | 1.60 | .54 | 1.33 | .34 | 1.11 | .23 | 2.262 |
| 4.0 | 5.09 | 7.86 | 3.74 | 3.76 | 2.87 | 1.99 | 2.23 | 1.14 | 1.83 | .69 | 1.52 | .44 | 1.27 | .29 | 2.585 |
| 4.5 | 5.73 | 9.69 | 4.21 | 4.65 | 3.22 | 2.46 | 2.55 | 1.40 | 2.06 | .85 | 1.70 | .54 | 1.43 | .36 | 2.908 |
| 5.0 | 6.37 | 11.7 | 4.68 | 5.63 | 3.58 | 2.98 | 2.83 | 1.70 | 2.29 | 1.03 | 1.89 | .65 | 1.59 | .43 | 3.232 |
| 5.5 | 7.00 | 13.9 | 5.15 | 6.67 | 3.94 | 3.49 | 3.11 | 2.02 | 2.52 | 1.22 | 2.08 | .78 | 1.75 | .51 | 3.555 |
| 6.0 | 7.64 | 16.3 | 5.61 | 7.80 | 4.30 | 4.13 | 3.40 | 2.32 | 2.75 | 1.42 | 2.27 | .90 | 1.91 | .60 | 3.878 |
| 6.5 | 8.27 | 18.8 | 6.08 | 9.02 | 4.66 | 4.77 | 3.68 | 2.72 | 2.98 | 1.65 | 2.46 | 1.04 | 2.07 | .69 | 4.201 |
| 7.0 | 8.91 | 21.5 | 6.55 | 10.3 | 5.01 | 5.45 | 3.96 | 3.11 | 3.21 | 1.88 | 2.65 | 1.19 | 2.23 | .79 | 4.524 |
| 7.5 | 9.55 | 24.4 | 7.02 | 11.7 | 5.37 | 6.16 | 4.24 | 3.52 | 3.44 | 2.13 | 2.84 | 1.35 | 2.39 | .89 | 4.847 |
| 8.0 | 10.2 | 27.3 | 7.48 | 13.1 | 5.73 | 6.94 | 4.53 | 3.96 | 3.67 | 2.39 | 3.03 | 1.52 | 2.55 | 1.00 | 5.171 |
| 8.5 | 10.8 | 30.5 | 7.95 | 14.6 | 6.09 | 7.73 | 4.81 | 4.41 | 3.90 | 2.67 | 3.22 | 1.69 | 2.71 | 1.12 | 5.494 |
| 9.0 | 11.5 | 33.7 | 8.42 | 16.4 | 6.45 | 8.40 | 5.10 | 4.89 | 4.12 | 2.96 | 3.41 | 1.87 | 2.86 | 1.24 | 5.817 |
| 9.5 | 12.1 | 37.2 | 8.89 | 17.9 | 6.80 | 9.45 | 5.38 | 5.39 | 4.35 | 3.27 | 3.60 | 2.06 | 3.02 | 1.37 | 6.140 |
| 10 | 12.7 | 40.8 | 9.35 | 19.6 | 7.16 | 10.4 | 5.66 | 5.91 | 4.58 | 3.59 | 3.79 | 2.27 | 3.18 | 1.49 | 6.463 |
| 11 | 14.0 | 48.5 | 10.3 | 23.2 | 7.88 | 12.3 | 6.22 | 7.01 | 5.04 | 4.28 | 4.17 | 2.68 | 3.50 | 1.78 | 7.109 |
| 12 | 15.3 | 56.8 | 11.2 | 27.3 | 8.60 | 14.4 | 6.79 | 8.21 | 5.50 | 4.97 | 4.55 | 3.16 | 3.82 | 2.08 | 7.756 |
| 13 | 16.6 | 65.6 | 12.2 | 31.4 | 9.31 | 16.6 | 7.36 | 9.48 | 5.96 | 5.74 | 4.92 | 3.63 | 4.14 | 2.41 | 8.402 |
| 14 | 17.8 | 74.8 | 13.1 | 35.9 | 10.0 | 19.0 | 7.92 | 10.8 | 6.42 | 6.55 | 5.30 | 4.15 | 4.46 | 2.74 | 9.048 |
| 15 | 19.1 | 84.7 | 14.0 | 40.8 | 10.7 | 21.5 | 8.49 | 12.3 | 6.87 | 7.43 | 5.68 | 4.70 | 4.77 | 3.11 | 9.695 |
| 16 | 20.4 | 95.2 | 15.0 | 45.7 | 11.5 | 24.2 | 9.06 | 13.8 | 7.33 | 8.33 | 6.06 | 5.28 | 5.09 | 3.49 | 10.341 |
| 17 | ...... | ...... | 15.9 | 51.0 | 12.2 | 27.0 | 9.62 | 15.4 | 7.79 | 9.30 | 6.44 | 5.84 | 5.41 | 3.90 | 10.987 |
| 18 | ...... | ...... | 16.8 | 56.6 | 12.9 | 29.8 | 10.2 | 17.0 | 8.25 | 10.3 | 6.82 | 6.54 | 5.73 | 4.31 | 11.634 |
| 19 | ...... | ...... | 17.8 | 62.2 | 13.6 | 32.9 | 10.7 | 18.8 | 8.71 | 11.4 | 7.20 | 7.20 | 6.05 | 4.76 | 12.280 |
| 20 | ...... | ...... | 18.7 | 68.1 | 14.3 | 36.1 | 11.3 | 20.6 | 9.17 | 12.4 | 7.58 | 7.90 | 6.37 | 5.22 | 12.926 |
| 21 | ...... | ...... | 19.6 | 74.5 | 15.0 | 39.4 | 11.9 | 22.5 | 9.62 | 13.6 | 7.96 | 8.63 | 6.68 | 5.70 | 13.573 |
| 22 | ...... | ...... | 20.6 | 81.1 | 15.8 | 42.9 | 12.4 | 24.4 | 10.1 | 14.8 | 8.33 | 9.37 | 7.00 | 6.19 | 14.219 |
| 23 | ...... | ...... | ...... | ...... | 16.5 | 46.4 | 13.0 | 26.5 | 10.5 | 16.0 | 8.71 | 10.2 | 7.32 | 6.71 | 14.865 |

TABLE 7 (Continued).—*Velocity V in feet per second and loss of head H in feet per thousand feet of pipe, necessary to the conveyance of a given quantity of water, Q, in second-feet and in millions of U. S. gallons per day through wood-stave pipe. For instance, 160 second-feet will be carried by a 42-inch pipe at a velocity of 16.6 feet per second with a loss of head of 15.3 feet per thousand feet of pipe.*

| Quantity. | Inside diameter, in inches and corresponding area, A, in square feet. | | | | | | | | | | | | | | Quantity, millions per day. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 26 A=3.687. | | 28 A=4.276. | | 30 A=4.909. | | 32 A=5.585. | | 34 A=6.305. | | 36 A=7.069. | | 38 A=7.876. | | |
| Q | V | H | V | H | V | H | V | H | V | H | V | H | V | H | |
| *Sec.-ft.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet* | *Gals.* |
| 8 | 2.17 | 0.68 | 1.87 | 0.48 | 1.63 | 0.34 | 1.43 | 0.25 | 1.27 | 0.19 | 1.13 | 0.14 | 1.02 | 0.11 | 5.171 |
| 9 | 2.44 | .85 | 2.10 | .59 | 1.83 | .43 | 1.61 | .31 | 1.43 | .23 | 1.27 | .18 | 1.14 | .14 | 5.817 |
| 10 | 2.71 | 1.02 | 2.34 | .72 | 2.04 | .52 | 1.79 | .38 | 1.59 | .28 | 1.41 | .22 | 1.27 | .17 | 6.463 |
| 11 | 2.98 | 1.21 | 2.57 | .85 | 2.24 | .62 | 1.97 | .45 | 1.75 | .34 | 1.56 | .26 | 1.40 | .20 | 7.109 |
| 12 | 3.25 | 1.42 | 2.81 | 1.00 | 2.45 | .72 | 2.15 | .53 | 1.90 | .39 | 1.70 | .30 | 1.52 | .23 | 7.756 |
| 13 | 3.53 | 1.64 | 3.04 | 1.15 | 2.65 | .82 | 2.33 | .61 | 2.06 | .46 | 1.84 | .35 | 1.65 | .27 | 8.402 |
| 14 | 3.80 | 1.87 | 3.27 | 1.32 | 2.85 | .95 | 2.51 | .70 | 2.22 | .52 | 1.98 | .40 | 1.78 | .31 | 9.048 |
| 16 | 4.34 | 2.38 | 3.74 | 1.67 | 3.26 | 1.20 | 2.87 | .89 | 2.54 | .67 | 2.26 | .50 | 2.03 | .39 | 10.341 |
| 18 | 4.88 | 2.94 | 4.21 | 2.07 | 3.67 | 1.49 | 3.22 | 1.09 | 2.86 | .82 | 2.55 | .62 | 2.29 | .48 | 11.634 |
| 20 | 5.42 | 3.56 | 4.68 | 2.50 | 4.07 | 1.80 | 3.58 | 1.32 | 3.17 | .99 | 2.83 | .75 | 2.54 | .58 | 12.926 |
| 22 | 5.97 | 4.23 | 5.15 | 2.96 | 4.48 | 2.14 | 3.94 | 1.57 | 3.49 | 1.18 | 3.11 | .90 | 2.79 | .69 | 14.219 |
| 24 | 6.51 | 4.94 | 5.61 | 3.47 | 4.89 | 2.50 | 4.30 | 1.84 | 3.81 | 1.38 | 3.40 | 1.05 | 3.05 | .81 | 15.512 |
| 26 | 7.05 | 5.70 | 6.08 | 4.02 | 5.30 | 2.89 | 4.66 | 2.12 | 4.12 | 1.59 | 3.68 | 1.21 | 3.30 | .93 | 16.804 |
| 28 | 7.59 | 6.55 | 6.55 | 4.58 | 5.70 | 3.30 | 5.01 | 2.42 | 4.44 | 1.82 | 3.96 | 1.38 | 3.56 | 1.07 | 18.097 |
| 30 | 8.14 | 7.40 | 7.02 | 5.18 | 6.11 | 3.73 | 5.37 | 2.74 | 4.76 | 2.05 | 4.24 | 1.56 | 3.81 | 1.21 | 19.389 |
| 32 | 8.68 | 8.30 | 7.48 | 5.82 | 6.52 | 4.19 | 5.73 | 3.08 | 5.08 | 2.29 | 4.53 | 1.76 | 4.06 | 1.36 | 20.682 |
| 36 | 9.76 | 10.25 | 8.42 | 7.19 | 7.33 | 5.18 | 6.45 | 3.81 | 5.71 | 2.85 | 5.09 | 2.17 | 4.57 | 1.67 | 23.267 |
| 40 | 10.8 | 12.4 | 9.35 | 8.72 | 8.15 | 6.26 | 7.16 | 4.61 | 6.34 | 3.45 | 5.66 | 2.62 | 5.08 | 2.04 | 25.853 |
| 45 | 12.2 | 15.3 | 10.5 | 10.8 | 9.17 | 7.74 | 8.06 | 5.70 | 7.14 | 4.27 | 6.37 | 3.25 | 5.71 | 2.51 | 29.084 |
| 50 | 13.6 | 18.5 | 11.7 | 13.0 | 10.2 | 9.36 | 8.95 | 6.90 | 7.93 | 5.16 | 7.07 | 3.92 | 6.35 | 3.04 | 32.316 |
| 55 | 14.9 | 22.0 | 12.9 | 15.5 | 11.2 | 11.1 | 9.85 | 8.15 | 8.72 | 6.11 | 7.78 | 4.66 | 6.98 | 3.59 | 35.547 |
| 60 | 16.3 | 25.6 | 14.0 | 18.1 | 12.2 | 13.0 | 10.7 | 9.56 | 9.52 | 7.16 | 8.49 | 5.44 | 7.62 | 4.21 | 38.779 |
| 65 | 17.6 | 29.6 | 15.2 | 20.9 | 13.2 | 15.0 | 11.6 | 11.0 | 10.3 | 8.27 | 9.20 | 6.29 | 8.25 | 4.87 | 42.010 |
| 70 | 19.0 | 33.9 | 16.4 | 23.8 | 14.3 | 17.1 | 12.5 | 12.6 | 11.1 | 9.44 | 9.90 | 7.19 | 8.89 | 5.55 | 45.242 |
| 75 | 20.3 | 38.2 | 17.5 | 26.9 | 15.3 | 19.4 | 13.4 | 14.3 | 11.9 | 10.7 | 10.6 | 8.13 | 9.52 | 6.29 | 48.474 |
| 80 | ...... | ...... | 18.7 | 30.2 | 16.3 | 21.8 | 14.3 | 16.0 | 12.7 | 12.0 | 11.4 | 9.13 | 10.2 | 7.07 | 51.705 |
| 85 | ...... | ...... | 19.9 | 33.9 | 17.3 | 24.3 | 15.2 | 17.9 | 13.5 | 13.4 | 12.0 | 10.2 | 10.8 | 7.87 | 54.937 |
| 90 | ...... | ...... | 21.0 | 37.4 | 18.3 | 26.9 | 16.1 | 19.8 | 14.3 | 14.8 | 12.7 | 11.3 | 11.4 | 8.73 | 58.168 |
| 95 | ...... | ...... | ...... | ...... | 19.4 | 29.7 | 17.0 | 21.8 | 15.1 | 16.4 | 13.4 | 12.5 | 12.1 | 9.61 | 61.400 |
| 100 | ...... | ...... | ...... | ...... | 20.4 | 32.6 | 17.9 | 24.0 | 15.9 | 17.9 | 14.2 | 13.7 | 12.7 | 10.6 | 64.632 |

| Quantity. | 40 A=8.727. | | 42 A=9.621. | | 44 A=10.56. | | 46 A=11.54. | | 48 A=12.57. | | 54 A=15.90. | | 60 A=19.64. | | Quantity, millions per day. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q | V | H | V | H | V | H | V | H | V | H | V | H | V | H | |
| 30 | 3.44 | 0.95 | 3.12 | 0.75 | 2.85 | 0.60 | 2.60 | 0.49 | 2.39 | 0.40 | 1.89 | 0.23 | 1.53 | 0.14 | 19.389 |
| 35 | 4.01 | 1.26 | 3.64 | .99 | 3.31 | .79 | 3.03 | .64 | 2.78 | .52 | 2.20 | .30 | 1.78 | .18 | 22.621 |
| 40 | 4.58 | 1.59 | 4.16 | 1.26 | 3.79 | 1.00 | 3.47 | .82 | 3.18 | .67 | 2.52 | .38 | 2.04 | .23 | 25.853 |
| 45 | 5.16 | 1.97 | 4.68 | 1.56 | 4.26 | 1.25 | 3.90 | 1.01 | 3.58 | .82 | 2.83 | .47 | 2.29 | .28 | 29.084 |
| 50 | 5.73 | 2.26 | 5.20 | 1.88 | 4.74 | 1.50 | 4.33 | 1.22 | 3.98 | .99 | 3.14 | .57 | 2.55 | .34 | 32.316 |
| 55 | 6.30 | 2.82 | 5.72 | 2.24 | 5.21 | 1.79 | 4.77 | 1.45 | 4.38 | 1.18 | 3.46 | .67 | 2.80 | .41 | 35.547 |
| 60 | 6.88 | 3.29 | 6.24 | 2.62 | 5.68 | 2.09 | 5.20 | 1.69 | 4.77 | 1.38 | 3.77 | .79 | 3.06 | .48 | 38.779 |
| 65 | 7.45 | 3.80 | 6.76 | 3.01 | 6.16 | 2.42 | 5.63 | 1.95 | 5.17 | 1.59 | 4.09 | .91 | 3.31 | .55 | 42.010 |
| 70 | 8.02 | 4.36 | 7.28 | 3.44 | 6.63 | 2.76 | 6.07 | 2.23 | 5.57 | 1.82 | 4.40 | 1.04 | 3.56 | .63 | 45.242 |
| 75 | 8.59 | 4.92 | 7.80 | 3.89 | 7.10 | 3.12 | 6.50 | 2.53 | 5.97 | 2.06 | 4.72 | 1.18 | 3.82 | .73 | 48.474 |
| 80 | 9.17 | 5.53 | 8.32 | 4.37 | 7.58 | 3.51 | 6.93 | 2.84 | 6.36 | 2.31 | 5.03 | 1.32 | 4.07 | .80 | 51.705 |
| 85 | 9.74 | 6.16 | 8.84 | 4.88 | 8.05 | 3.92 | 7.37 | 3.17 | 6.76 | 2.58 | 5.35 | 1.47 | 4.33 | .89 | 54.937 |
| 90 | 10.3 | 6.84 | 9.36 | 5.41 | 8.52 | 4.34 | 7.80 | 3.53 | 7.16 | 2.87 | 5.66 | 1.63 | 4.58 | .99 | 58.168 |
| 95 | 10.9 | 7.55 | 9.87 | 5.96 | 9.00 | 4.78 | 8.23 | 3.87 | 7.56 | 3.16 | 5.98 | 1.80 | 4.84 | 1.09 | 61.400 |
| 100 | 11.5 | 8.30 | 10.4 | 6.55 | 9.47 | 5.24 | 8.67 | 4.25 | 7.96 | 3.46 | 6.29 | 1.97 | 5.09 | 1.19 | 64.631 |
| 110 | 12.6 | 9.79 | 11.4 | 7.77 | 10.4 | 6.24 | 9.53 | 5.04 | 8.75 | 4.11 | 6.92 | 2.35 | 5.60 | 1.42 | 71.095 |
| 120 | 13.8 | 11.5 | 12.5 | 9.09 | 11.4 | 7.23 | 10.4 | 5.89 | 9.55 | 4.81 | 7.55 | 2.74 | 6.11 | 1.65 | 77.558 |
| 130 | 14.9 | 13.3 | 13.5 | 10.5 | 12.3 | 8.41 | 11.3 | 6.81 | 10.34 | 5.55 | 8.18 | 3.17 | 6.62 | 1.91 | 84.021 |
| 140 | 16.0 | 15.1 | 14.6 | 12.0 | 13.3 | 9.60 | 12.1 | 7.77 | 11.1 | 6.35 | 8.81 | 3.62 | 7.13 | 2.19 | 90.484 |
| 150 | 17.2 | 17.1 | 15.6 | 13.6 | 14.2 | 10.9 | 13.0 | 8.81 | 11.9 | 7.18 | 9.43 | 4.10 | 7.64 | 2.48 | 96.947 |
| 160 | 18.3 | 19.3 | 16.6 | 15.3 | 15.2 | 12.2 | 13.9 | 9.89 | 12.7 | 8.07 | 10.1 | 4.60 | 8.15 | 2.78 | 103.41 |
| 170 | 19.5 | 21.4 | 17.7 | 17.0 | 16.1 | 13.6 | 14.7 | 11.0 | 13.5 | 8.98 | 10.7 | 5.13 | 8.66 | 3.12 | 109.87 |
| 180 | 20.6 | 23.8 | 18.7 | 18.9 | 17.0 | 15.1 | 15.6 | 12.2 | 14.3 | 9.96 | 11.3 | 5.70 | 9.17 | 3.43 | 116.34 |
| 190 | ...... | ...... | 19.8 | 20.8 | 18.0 | 16.7 | 16.5 | 13.5 | 15.1 | 11.0 | 12.0 | 6.28 | 9.67 | 3.79 | 122.80 |
| 200 | ...... | ...... | 20.8 | 22.8 | 18.9 | 18.3 | 17.3 | 14.8 | 15.9 | 12.1 | 12.6 | 6.89 | 10.2 | 4.16 | 129.26 |
| 210 | ...... | ...... | ...... | ...... | 19.8 | 20.0 | 18.2 | 16.1 | 16.7 | 13.2 | 13.2 | 7.51 | 10.7 | 4.54 | 135.73 |
| 220 | ...... | ...... | ...... | ...... | 20.8 | 21.7 | 19.1 | 17.5 | 17.5 | 14.3 | 13.8 | 8.17 | 11.2 | 4.94 | 142.19 |
| 230 | ...... | ...... | ...... | ...... | ...... | ...... | 19.9 | 19.0 | 18.3 | 15.5 | 14.5 | 8.86 | 11.7 | 5.34 | 148.65 |
| 240 | ...... | ...... | ...... | ...... | ...... | ...... | 20.8 | 20.5 | 19.1 | 16.8 | 15.1 | 9.54 | 12.2 | 5.78 | 155.12 |
| 250 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 19.9 | 18.0 | 15.7 | 10.3 | 12.7 | 6.22 | 161.58 |

TABLE 7 (Continued).—*Velocity V in feet per second and loss of head H in feet per thousand feet of pipe, necessary to the conveyance of a given quantity of water, Q, in second-feet and in millions of U. S. gallons per day through wood-stave pipe. For instance, 550 second-feet will be carried by a 120-inch pipe at a velocity of 7 feet per second with a loss of head of 0.94 foot per thousand feet of pipe.*

| Quantity. | Inside diameter, in inches and corresponding area, A, in square feet. | | | | | | | | | | | | | | Quantity, millions per day. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 66 A=23.76 | | 72 A=28.27 | | 78 A=33.18 | | 84 A=38.48 | | 90 A=44.18 | | 96 A=50.26 | | 102 A=56.74 | | |
| Q | V | H | V | H | V | H | V | H | V | H | V | H | V | H | |
| *Sec.-ft.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Gals.* |
| 60 | 2.53 | 0.30 | 2.12 | 0.20 | 1.81 | 0.14 | 1.56 | 0.10 | 1.36 | 0.07 | 1.19 | 0.05 | 1.05 | 0.04 | 38.78 |
| 70 | 2.95 | .40 | 2.48 | .26 | 2.11 | .18 | 1.82 | .13 | 1.58 | .09 | 1.39 | .07 | 1.23 | .05 | 45.24 |
| 80 | 3.37 | .51 | 2.83 | .33 | 2.41 | .23 | 2.08 | .16 | 1.81 | .12 | 1.59 | .09 | 1.41 | .06 | 51.70 |
| 90 | 3.79 | .63 | 3.18 | .41 | 2.71 | .28 | 2.34 | .20 | 2.04 | .14 | 1.79 | .11 | 1.59 | .08 | 58.17 |
| 100 | 4.21 | .76 | 3.54 | .50 | 3.01 | .34 | 2.60 | .24 | 2.26 | .17 | 1.99 | .13 | 1.76 | .09 | 64.63 |
| 110 | 4.63 | .90 | 3.89 | .59 | 3.32 | .41 | 2.86 | .28 | 2.49 | .20 | 2.19 | .15 | 1.94 | .11 | 71.09 |
| 120 | 5.05 | 1.05 | 4.25 | .69 | 3.62 | .47 | 3.12 | .33 | 2.72 | .24 | 2.39 | .18 | 2.11 | .13 | 77.56 |
| 130 | 5.47 | 1.21 | 4.60 | .80 | 3.92 | .55 | 3.38 | .38 | 2.94 | .28 | 2.59 | .20 | 2.29 | .15 | 84.02 |
| 140 | 5.89 | 1.39 | 4.95 | .91 | 4.22 | .63 | 3.64 | .44 | 3.17 | .32 | 2.79 | .23 | 2.47 | .17 | 90.48 |
| 150 | 6.31 | 1.57 | 5.31 | 1.04 | 4.52 | .71 | 3.90 | .50 | 3.39 | .36 | 2.98 | .26 | 2.64 | .20 | 96.95 |
| 160 | 6.73 | 1.77 | 5.66 | 1.17 | 4.82 | .80 | 4.16 | .56 | 3.62 | .40 | 3.18 | .30 | 2.82 | .22 | 103.41 |
| 170 | 7.16 | 1.97 | 6.01 | 1.30 | 5.12 | .89 | 4.42 | .62 | 3.85 | .45 | 3.38 | .33 | 3.00 | .25 | 109.87 |
| 180 | 7.58 | 2.18 | 6.37 | 1.44 | 5.43 | .99 | 4.68 | .69 | 4.07 | .50 | 3.58 | .37 | 3.17 | .27 | 116.34 |
| 190 | 8.00 | 2.41 | 6.72 | 1.59 | 5.73 | 1.08 | 4.94 | .76 | 4.30 | .55 | 3.78 | .40 | 3.35 | .30 | 122.80 |
| 200 | 8.42 | 2.64 | 7.08 | 1.74 | 6.03 | 1.19 | 5.20 | .84 | 4.53 | .60 | 3.98 | .44 | 3.53 | .33 | 129.26 |
| 220 | 9.26 | 3.14 | 7.78 | 2.06 | 6.63 | 1.41 | 5.72 | .99 | 4.98 | .71 | 4.38 | .53 | 3.88 | .39 | 142.19 |
| 240 | 10.1 | 3.67 | 8.49 | 2.42 | 7.23 | 1.65 | 6.24 | 1.16 | 5.43 | .83 | 4.78 | .62 | 4.23 | .46 | 155.12 |
| 260 | 10.9 | 4.23 | 9.20 | 2.79 | 7.84 | 1.91 | 6.76 | 1.34 | 5.88 | .95 | 5.17 | .71 | 4.58 | .53 | 168.04 |
| 280 | 11.8 | 4.86 | 9.90 | 3.20 | 8.44 | 2.18 | 7.28 | 1.53 | 6.34 | 1.11 | 5.57 | .81 | 4.94 | .61 | 180.97 |
| 300 | 12.6 | 5.48 | 10.6 | 3.61 | 9.04 | 2.47 | 7.80 | 1.74 | 6.79 | 1.25 | 5.96 | .92 | 5.29 | .69 | 193.89 |
| 320 | 13.5 | 6.17 | 11.3 | 4.06 | 9.64 | 2.78 | 8.32 | 1.95 | 7.24 | 1.40 | 6.37 | 1.03 | 5.64 | .77 | 206.82 |
| 340 | 14.3 | 6.86 | 12.0 | 4.53 | 10.3 | 3.09 | 8.84 | 2.17 | 7.70 | 1.56 | 6.77 | 1.15 | 5.99 | .86 | 219.75 |
| 360 | 15.2 | 7.60 | 12.7 | 5.01 | 10.9 | 3.43 | 9.36 | 2.41 | 8.15 | 1.74 | 7.16 | 1.27 | 6.35 | .95 | 232.67 |
| 380 | 16.0 | 8.39 | 13.4 | 5.53 | 11.5 | 3.78 | 9.88 | 2.66 | 8.60 | 1.91 | 7.56 | 1.40 | 6.70 | 1.05 | 245.60 |
| 400 | 16.8 | 9.19 | 14.2 | 6.05 | 12.1 | 4.14 | 10.4 | 2.91 | 9.05 | 2.10 | 7.96 | 1.54 | 7.05 | 1.15 | 258.53 |
| 450 | 18.9 | 11.4 | 15.9 | 7.52 | 13.6 | 5.12 | 11.7 | 3.60 | 10.2 | 2.59 | 8.95 | 1.91 | 7.93 | 1.42 | 290.84 |
| 500 | 21.0 | 13.7 | 17.7 | 9.06 | 15.1 | 6.20 | 13.0 | 4.35 | 11.3 | 3.13 | 9.95 | 2.32 | 8.81 | 1.72 | 323.16 |
| 550 | ...... | ...... | 19.5 | 10.8 | 16.6 | 7.37 | 14.3 | 5.17 | 12.5 | 3.71 | 10.9 | 2.74 | 9.69 | 2.04 | 355.47 |
| 600 | ...... | ...... | 21.2 | 12.6 | 18.1 | 8.59 | 15.6 | 6.03 | 13.6 | 4.33 | 11.9 | 3.20 | 10.6 | 2.39 | 387.79 |
| 650 | ...... | ...... | ...... | ...... | 19.6 | 9.90 | 16.9 | 6.98 | 14.7 | 5.02 | 12.9 | 3.76 | 11.5 | 2.76 | 420.10 |

| Quantity. | 108 A=63.62 | | 114 A=70.88 | | 120 A=78.54 | | 132 A=95.03 | | 144 A=113.1 | | 156 A=132.7 | | 168 A=153.94 | | Quantity, millions per day. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q | V | H | V | H | V | H | V | H | V | H | V | H | V | H | |
| 200 | 3.14 | 0.25 | 2.82 | 0.19 | 2.55 | 0.15 | 2.10 | 0.10 | 1.77 | 0.06 | 1.51 | 0.04 | 1.30 | 0.03 | 129.26 |
| 250 | 3.93 | .38 | 3.53 | .24 | 3.18 | .23 | 2.63 | .14 | 2.21 | .10 | 1.88 | .07 | 1.62 | .05 | 161.58 |
| 300 | 4.72 | .52 | 4.23 | .40 | 3.82 | .32 | 3.16 | .20 | 2.65 | .13 | 2.26 | .09 | 1.95 | .06 | 193.89 |
| 350 | 5.50 | .68 | 4.94 | .53 | 4.46 | .42 | 3.68 | .26 | 3.09 | .17 | 2.64 | .12 | 2.27 | .08 | 226.21 |
| 400 | 6.29 | .88 | 5.64 | .67 | 5.09 | .53 | 4.21 | .34 | 3.54 | .22 | 3.01 | .15 | 2.60 | .11 | 258.53 |
| 450 | 7.07 | 1.09 | 6.35 | .83 | 5.73 | .66 | 4.74 | .42 | 3.98 | .27 | 3.39 | .19 | 2.92 | .13 | 290.84 |
| 500 | 7.86 | 1.31 | 7.05 | 1.01 | 6.37 | .79 | 5.26 | .50 | 4.42 | .33 | 3.77 | .23 | 3.25 | .16 | 323.16 |
| 550 | 8.65 | 1.56 | 7.76 | 1.21 | 7.00 | .94 | 5.79 | .60 | 4.86 | .39 | 4.15 | .27 | 3.57 | .19 | 355.47 |
| 600 | 9.43 | 1.82 | 8.46 | 1.42 | 7.64 | 1.10 | 6.31 | .70 | 5.31 | .46 | 4.52 | .31 | 3.90 | .22 | 387.79 |
| 650 | 10.2 | 2.11 | 9.17 | 1.63 | 8.28 | 1.27 | 6.84 | .81 | 5.75 | .53 | 4.90 | .36 | 4.22 | .26 | 420.10 |
| 700 | 11.0 | 2.40 | 9.88 | 1.86 | 8.91 | 1.45 | 7.37 | .92 | 6.19 | .61 | 5.28 | .42 | 4.55 | .29 | 452.42 |
| 750 | 11.8 | 2.72 | 10.6 | 2.11 | 9.55 | 1.65 | 7.89 | 1.04 | 6.63 | .69 | 5.65 | .47 | 4.87 | .33 | 484.74 |
| 800 | 12.6 | 3.04 | 11.3 | 2.37 | 10.2 | 1.85 | 8.42 | 1.17 | 7.07 | .77 | 6.03 | .53 | 5.20 | .37 | 517.05 |
| 850 | 13.4 | 3.41 | 12.0 | 2.65 | 10.8 | 2.06 | 8.94 | 1.31 | 7.52 | .86 | 6.41 | .59 | 5.52 | .41 | 549.37 |
| 900 | 14.2 | 3.79 | 12.7 | 2.94 | 11.5 | 2.29 | 9.47 | 1.45 | 7.96 | .96 | 6.78 | .65 | 5.85 | .45 | 581.68 |
| 950 | 14.9 | 4.17 | 13.4 | 3.23 | 12.1 | 2.52 | 10.0 | 1.60 | 8.40 | 1.06 | 7.16 | .73 | 6.17 | .51 | 614.00 |
| 1,000 | 15.7 | 4.57 | 14.1 | 3.54 | 12.7 | 2.76 | 10.5 | 1.75 | 8.84 | 1.15 | 7.54 | .79 | 6.50 | .56 | 646.31 |
| 1,050 | 16.5 | 5.00 | 14.8 | 3.86 | 13.4 | 3.02 | 11.1 | 1.91 | 9.28 | 1.26 | 7.91 | .86 | 6.82 | .61 | 678.63 |
| 1,100 | 17.3 | 5.42 | 15.5 | 4.20 | 14.0 | 3.28 | 11.6 | 2.08 | 9.73 | 1.37 | 8.29 | .94 | 7.15 | .66 | 710.95 |
| 1,150 | 18.1 | 5.88 | 16.2 | 4.55 | 14.6 | 3.55 | 12.1 | 2.25 | 10.2 | 1.49 | 8.67 | 1.00 | 7.47 | .71 | 743.26 |
| 1,200 | 18.9 | 6.34 | 16.9 | 4.90 | 15.4 | 3.84 | 12.6 | 2.43 | 10.6 | 1.61 | 9.04 | 1.10 | 7.80 | .77 | 775.58 |
| 1,250 | 19.7 | 6.83 | 17.6 | 5.30 | 15.9 | 4.13 | 13.1 | 2.62 | 11.1 | 1.73 | 9.42 | 1.18 | 8.12 | .83 | 807.90 |
| 1,300 | 20.4 | 7.32 | 18.3 | 5.70 | 16.6 | 4.43 | 13.7 | 2.81 | 11.5 | 1.86 | 9.80 | 1.27 | 8.45 | .89 | 840.21 |
| 1,400 | ...... | ...... | 19.8 | 6.50 | 17.8 | 5.06 | 14.7 | 3.21 | 12.4 | 2.12 | 10.6 | 1.45 | 9.09 | 1.02 | 904.84 |
| 1,500 | ...... | ...... | 21.2 | 7.34 | 19.1 | 5.73 | 15.8 | 3.66 | 13.3 | 2.41 | 11.3 | 1.64 | 9.74 | 1.15 | 969.47 |
| 1,600 | ...... | ...... | ...... | ...... | 20.4 | 6.44 | 16.8 | 4.09 | 14.2 | 2.70 | 12.1 | 1.84 | 10.4 | 1.29 | 1,034.1 |
| 1,700 | ...... | ...... | ...... | ...... | ...... | ...... | 17.9 | 4.56 | 15.0 | 3.01 | 12.8 | 2.05 | 11.0 | 1.44 | 1,098.7 |
| 1,800 | ...... | ...... | ...... | ...... | ...... | ...... | 18.9 | 5.05 | 15.9 | 3.34 | 13.6 | 2.28 | 11.7 | 1.58 | 1,163.4 |
| 1,900 | ...... | ...... | ...... | ...... | ...... | ...... | 20.0 | 5.57 | 16.8 | 3.68 | 14.3 | 2.51 | 12.3 | 1.76 | 1,228.0 |
| 2,000 | ...... | ...... | ...... | ...... | ...... | ...... | 21.1 | 6.11 | 17.7 | 4.02 | 15.1 | 2.75 | 13.0 | 1.93 | 1,292.6 |

## CAPACITY OF WOOD-STAVE PIPE COMPARED WITH THAT OF CAST-IRON AND RIVETED STEEL.

Table 8 gives the relative carrying capacities of wood, steel, and cast-iron pipes. The table is based on velocities of about 1, 3, and 7 feet per second in the steel and cast-iron pipes of diameters ranging from 4 to 144 inches. For a given velocity the loss of head for new cast-iron, new riveted steel, 10-year-old cast-iron, 20-year-old cast-iron, and 10-year-old-riveted steel is based on values of $C_w$ in the Williams-Hazen formula (No. 8, p. 6) of 130, 110, 110, 100 and 100, respectively, these conservative values being recommended by Williams and Hazen.

TABLE 8.—*Relative capacity, in per cent, of wood-stave pipe, compared with new cast iron, new riveted, 10-year-old cast iron, 20-year-old cast iron, and 10-year-old riveted steel or iron pipe; based on Williams and Hazen recommendation for values of C, in their formula, of 130 for new cast iron, 110 for new riveted and 10-year-old cast iron, and 100 for 20-year-old cast iron and 10-year-old riveted steel or iron pipe.*

| Diameter. | Cast-iron and riveted pipes. | | | | Wood-stave pipes. | | | Per cent of velocity in wood pipe over that in metal pipe (column 2), corresponding to columns 6, 7, 8, respectively. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Velocity per second. | Loss of head for velocity. (H) | | | Velocities corresponding to losses in columns 3, 4, 5, respectively. | | | | | |
| | | $C_w$=130. | $C_w$=110. | $C_w$=100. | | | | | | |
| *Inches.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | | | |
| 4 | 1.02 | 1.380 | .......... | 2.230 | 0.94 | ........ | 1.24 | −7.8 | ........ | +22 |
| 4 | 3.06 | 10.500 | .......... | 17.100 | 2.90 | ........ | 3.90 | −5.2 | ........ | +26 |
| 4 | 6.64 | 44.000 | .......... | 72.000 | 6.50 | ........ | 8.51 | −2.1 | ........ | +28 |
| 12 | .99 | .360 | 0.480 | .580 | .92 | 1.08 | 1.20 | −7.1 | + 9 | +20 |
| 12 | 2.96 | 2.730 | 3.710 | 4.430 | 2.83 | 3.33 | 3.70 | −4.4 | +12 | +25 |
| 12 | 6.89 | 13.200 | 17.900 | 21.300 | 6.80 | 8.00 | 8.80 | −1.3 | +16 | +28 |
| 36 | 1.09 | .121 | .164 | .196 | 1.02 | 1.25 | 1.34 | −6.4 | +15 | +23 |
| 36 | 3.06 | .810 | 1.110 | 1.320 | 2.90 | 3.50 | 3.80 | −5.2 | +14 | +24 |
| 36 | 7.00 | 3.740 | 5.100 | 6.100 | 6.90 | 8.10 | 9.00 | −1.4 | +16 | +29 |
| 72 | .98 | .044 | .060 | .072 | .92 | 1.10 | 1.20 | −6.1 | +12 | +22 |
| 72 | 3.01 | .349 | .476 | .570 | 2.90 | 3.50 | 3.80 | −3.6 | +16 | +24 |
| 72 | 7.11 | 1.720 | 2.340 | 2.790 | 7.00 | 8.30 | 9.10 | −1.5 | +17 | +28 |
| 108 | 1.10 | .034 | .046 | .055 | 1.00 | 1.20 | 1.35 | −9.1 | +11 | +23 |
| 108 | 3.14 | .237 | .321 | .382 | 3.00 | 3.60 | 4.00 | −4.4 | +15 | +27 |
| 108 | 6.92 | 1.020 | 1.380 | 1.650 | 6.90 | 8.00 | 9.00 | − .3 | +16 | +30 |
| 144 | 1.06 | .023 | .031 | .037 | 1.00 | 1.20 | 1.35 | −5.7 | +13 | +21 |
| 144 | 3.01 | .156 | .211 | .252 | 2.90 | 3.40 | 3.80 | −3.7 | +13 | +26 |
| 144 | 7.07 | .760 | 1.030 | 1.230 | 7.00 | 8.30 | 9.10 | −1.0 | +17 | +29 |

For the same sized pipe and the various losses of head the corresponding velocities in wood-stave pipe (as shown by the new formula) are compared with the velocities in the metal pipes. This comparison is on a percentage basis, with the velocity of the metal pipe as the base. As an example: The loss of head in a new cast-iron pipe ($C_W = 130$), 12 inches in diameter, for a velocity of 2.96 feet per second, is 2.73 feet per 1,000 feet of pipe. For the same velocity in new riveted steel or 10-year-old cast iron ($C_W = 110$) the loss of head in a 12-inch pipe is 3.71 feet. For the same velocity in 10-year-old riveted steel or 20-year-old cast iron ($C_W = 100$) the loss of head is 4.43 feet.

The velocity in a 12-inch wood-stave pipe for a loss of head of 2.73 feet per 1,000 feet of pipe is 2.83 feet per second or 4.4 per cent less than that in a new cast-iron pipe for the same loss of head.

The velocity in a 12-inch wood-stave pipe for a loss of head of 3.71 feet per 1,000 feet is 3.33 feet per second or 12.5 per cent more than that in a new riveted steel or 10-year-old cast-iron pipe for the same loss of head.

The velocity in a 12-inch wood-stave pipe for a loss of head of 4.43 feet per 1,000 feet is 3.7 feet per second, or 25 per cent more than that in a 10-year-old riveted steel or 20-year-old cast-iron pipe, for the same loss of head.

As shown by the table, the relative capacities change for various sizes of pipe and various velocities, but, speaking broadly, it is also shown that the capacity of wood-stave pipe is about 5 per cent less than that of new cast iron, 15 per cent more than that of new riveted steel or 10-year-old cast iron, and 25 per cent more than that of 10-year-old riveted steel or 20-year-old cast-iron pipe.

## CONCLUSIONS.

A study of the previous pages appears to warrant the following general conclusions concerning the capacity of wood-stave pipes:

1. That the new formula herein offered is the best now available for use in the design of wood-stave pipes, as its application meets (within 1 per cent) the mean of all observations and the mean capacity of all wood pipes upon which experiments have been made.

2. That a very conservative factor of safety should be used where a guaranteed capacity is to be attained.

3. That the Kutter modification of the Chezy formula is not well adapted to the design of wood-stave pipes.

4. That the data now existing do not show that the capacity of wood-stave pipe either increases or decreases with age. This statement, of course, does not consider sedimentation, a purely mechanical process.

5. That if silted waters are to be conveyed the pipe should be designed for a working velocity of from 5 to 10 feet per second.

6. That if sand is present in the water, the design should be for a velocity of about 5 feet per second, which will be high enough to carry out a large part of the sand and at the same time not so high as to seriously erode the pipe. The better method, of course, is to remove the sand by sumps or other means.

7. That air should be removed from the intake end of every pipe line, especially when the capacity load is approached.

8. That wood pipe will convey about 15 per cent more water than a 10-year-old cast-iron pipe or a new riveted pipe, and about 25 per cent more than a cast-iron pipe 20 years old or a riveted pipe 10 years old.

## ACKNOWLEDGMENTS.

The writer desires to acknowledge indebtedness to the various engineers and managers of irrigation, municipal, and power systems who permitted and aided in tests upon the pipes in their charge. Acknowledgment is also made to the engineers of the United States Reclamation Service for suggestions and drawings. Where data have been secured from other sources footnotes give the necessary references.

## APPENDIX.

The following pages are devoted to abstracts of descriptions of experiments made by agencies other than the Division of Agricultural Engineering, Bureau of Public Roads. The number before each description refers to the corresponding numbers in columns 1, Tables 2 and 3.

**No. 1. Expt. HS–X, 1¼-inch Jointed (Bored) Redwood Pipe,[1] New Almaden, Cal.**—In 1877 Hamilton Smith, jr., made tests for loss of head in a straight pipe of eight joints, made of heart redwood, bored by a pipe auger. The pipes were new and uncoated. Connections were made by driving one joint into another, an outer iron band preventing splitting during this process. The area of the pipe was determined by weighing the water contained in each joint. The total loss of head was determined from the difference in elevation of the water surface over the inlet and at the mid-point of outlet (discharge being into open air). To ascertain friction head the velocity and entry heads were deducted from the effective head. The discharge was measured accurately in a rectangular wooden tank having a total capacity of 15.2 cubic feet. In this series of tests the pipe and water discharges were so small that laboratory accuracy was practicable. This series was used by Tutton but not by Williams-Hazen, Moritz, nor the writer in derivation of formulas. The line is not a stave pipe.

**Nos. 2–3. 4-inch Jointed (Machine-Banded) Wood-Stave Pipe, Sunnyside Project, U. S. Reclamation Service, Washington.**[2]—This pipe had been used for three years for irrigation purposes when tested by Moritz. It is straight in horizontal alignment, on a continuous down grade. Discharge was measured over a 12-inch Cipolletti weir. A fungous growth was noted at the inlet, being from one-eighth to three-sixteenths inch thick. The condition of the interior of the pipe was not known. The short reach (No. 2) was included in the longer reach (No. 3). The capacity of this pipe is 12 per cent less than the discharge computed by the new formula, probably due to the fungous growth. This conclusion is reached by taking the mean of observations on reaches 2 and 3 together.

**No. 4. 5-inch Jointed (Machine-Banded) Wood-Stave Pipe, Sunnyside Project, U. S. Reclamation Service, Washington.**—This line had been used for about two years at the time of the tests, for conveying irrigation water across a wide, shallow depression. Horizontal alignment was straight. Discharge was measured over an 8-inch sharp-crested Cipolletti weir. Water columns were used for gauge No. 1 for all runs except 3 and 4, and for gauge No. 2. For runs 3 and 4 a mercury manometer was used at gauge No. 1. Some trouble with air in the pipe was experienced in these tests. The capacity of the pipe was about 5 per cent less than the discharge computed by the new formula.

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[1] Hydraulics. Hamilton Smith, jr., John Wiley & Sons, N. Y. (1886), p. 297.

[2] All tests made on the Sunnyside project were by E. A. Moritz and associates. Trans. Amer. Soc. Civ. Engin., 74 (1911), p. 411.

**No. 5. 6-inch Jointed (Machine-Banded) Wood-Stave Pipe, Sunnyside Project, U. S. Reclamation Service, Washington.**—This pipe was built for irrigation purposes about five months before the tests. It is practically straight in both horizontal and vertical planes. Water columns were used for both gauges. Discharge was measured over a 12-inch Cipolletti weir. The capacity of this pipe was about 4½ per cent greater than the discharge computed by the new formula.

**Nos. 6, 7, 8. 6-inch Jointed (Machine-Banded) Wood-Stave Pipe, Sunnyside Project, U. S. Reclamation Service, Washington.**—This new pipe had been used for irrigation purposes about four months at the time of tests. Alignment and profile were as described for the 8-inch pipe in abstracts for Nos. 9, 10, 11, and 12. Water columns were used at both gauges. Discharge was measured over a 12-inch Cipolletti weir. Usual velocity was about 3 feet per second. Three reaches on the one pipe were tested. The capacity appeared to be about that computed by the new formula.

**Nos. 9, 10, 11, 12. 8-inch Jointed (Machine-Banded) Wood-Stave Siphon Pipe, Sunnyside Project, U. S. Reclamation Service, Washington.**—This pipe, built for irrigation purposes, had been in use about five months at the time of tests in 1909. Approximately the same reaches were again tested in 1910. Nos. 9 and 11 consist of two tangents intersecting at an angle of 16° 40′ made by a gentle bend with short lengths of pipe. They include the dip in the profile, No. 11 is 120 feet longer than No. 9. Reach No. 12 includes No. 11 with an additional 540 feet of straight pipe on the upstream end. Reach No. 10 is the final 2,002 feet of Nos. 9, 11, and 12, is straight in horizontal alignment, but includes the dip. A remarkable contrast appears in these tests. In 1909 the capacity was about 7 per cent less than that computed by the new formula. In 1910 the tests on the same pipe indicated an apparent increase in capacity to about 20 per cent more than the discharge computed by the new formula, when reach 11 was considered; but reach 12 (which includes No. 11 and is but 15 per cent longer) showed the capacity to have increased to but 5 per cent more than the average. It should be noted that velocities in No. 11 were far greater than those in No. 12. A study of figure 5 fails to show a general tendency toward increase in capacity with age of pipe. The tests on reach No. 11 plot (see Pl. VI) in the zone normally occupied by those on a 10-inch pipe.

**No. 15. 10.12-inch Jointed (Machine-Banded) White Pine Pipe,[1] Bonito Pipe Line, El Paso & Southwestern Railway, New Mexico.**—This pipe line, part of which is 10-inch and part 16-inch, is more than 100 miles in length and is used in connection with a railway water-supply project. In 1908, 1909, and 1911, J. L. Campbell made tests on both sections. The larger pipe joins the lower end of the smaller pipe at an open standpipe. In measuring velocities the experimenter used bran and colors, accepting the first appearance of the bran or color in computing the period elapsed between the time of their injection and their later appearance. The fact is well known that the velocities near the center of the pipe are higher than those near the perimeter, and thus higher than the mean velocity. Hence if the first appearance of the color is accepted then a velocity in excess of the mean is indicated. In the opinion of the writer this fact accounts for the low friction factor found, and for this reason he did not use these tests in the derivation of the new formula. For additional discussion of these tests see page 11. Had the elapsed time been considered as from the moment of color injection to the mean of its first and last appearance at the outlet, a highly satisfactory series of tests would have resulted. Mr. Campbell later supplied the necessary data and these tests are included in data on page 81.

**No. 16. 12-inch Jointed (Machine-Banded) Wood-Stave Pipe, Sunnyside Project, U. S. Reclamation Service, Washington.**—This pipe was built for

[1] Engin. News, 60 (1908), p. 225; Trans. Amer. Soc. Civ. Engin., 70 (1910), p. 178; 74 (1911), p. 455.

irrigation purposes in 1910 and had been in use but three months at the time of tests. The line supplements and parallels the pipe described as No. 28. However, the vertical curve at the low point is not so sharp as in the 22-inch pipe. A water column was used for gauge No. 1 and a mercury manometer for gauge No. 2. The diameter was measured at the intake and found to average 12 inches. Discharge was taken over a Cipolletti weir at the intake. The loss of head was abnormally great, capacity being about 15 per cent below the discharge computed by the new formula. Moritz suggests the possible presence of silt in the lower portions of the pipe, as the normal velocity is but 0.8 foot per second and the water is silt-laden.

**Nos. 17, 18. 14-inch Jointed (Machine-Banded) Wood-Stave Pipe, Sunnyside Project, U. S. Reclamation Service, Washington.**—This pipe for carrying irrigation water had been in use five consecutive seasons when tested in 1909. The reach included in the tests consists of two tangents intersecting at an angle of 32° 12′, where a gentle bend of short lengths of pipe is made. The same reach was tested in both 1909 and 1910. Loss of head appeared less in 1910 than in 1909. This may have been partially due to less friction in the pipe at the later date and partially to mere difference in experimental results. Mercury manometers were used for both gauges. At a place where a stave blew out opportunity was afforded for an examination of the interior of the pipe and for measurement for area in addition to inlet and outlet. At this hole the softer portions of the fir wood had worn away, leaving longitudinal ridges of harder wood. The frictional influence of this condition was problematical. Discharge measurements in 1909 were made over a round-crested weir; those in 1910 were made over sharp-crested weir. In general the 1910 tests should be given more weight than those of 1909. The profile of the line is wavy but without pronounced vertical curve or bends. Three summits are indicated by a ground line profile, but their actual existence in the pipe is questionable. The capacity of the pipe in 1909 was about 9 per cent greater than the discharge computed by the new formula, while in 1910 it was less than 3 per cent greater than that discharge.

**No. 20. 14-inch Redwood Stave Pipe, West Los Angeles Water Co., California.**[1]—Arthur L. Adams conducted a series of seven tests upon reaches of various lengths of a 14-inch redwood pipe supplying the Pacific Branch of National Soldiers' Home, in California. Throughout the length of the pipe line vertical curves were quite numerous, but all were made without the use of "specials" and with radii of not less than approximately 40 feet. Horizontal curves were few, and 286 feet was the minimum radius. The size of the pipe was determined by numerous measurements of external circumference, the thickness of the staves being known to be constant. The discharge was measured with a 4-foot weir whose coefficient was determined by a volumetric measurement. The head on the weir was read on a hook gauge. The loss of head was observed in open standpipes and other designated structures. Points of observation were connected by wye levels. Taking the mean of all the observations on this pipe, the capacity is shown to be about 9 per cent less than as computed by the new formula. This series was used by Williams and Hazen in determining their suggested coefficient of 120. It was also used by the writer in deriving his formulas but was rejected by Moritz.

**No. 21. Bonito Pipe Line, New Mexico.**—This series is discussed under No. 15 on page 75.

**No. 22. Rectangular Unplaned Poplar Pipe.**—Tests on an experimental pipe 1.574 feet wide and 0.984 foot deep were made in France in 1859 by Darcy and Bazin.[2] The discharge was determined by weir measurement and the loss of head by piezometers. This series was used by Tutton in deriving his formula, but was rejected by Moritz and the writer, both of whom considered only round-stave pipes in deriving their formulas.

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[1] Trans. Amer. Soc. Civ. Engin., 40 (1898), p. 542.

[2] Recherches Hydrauliques, Henry Darcy and H. Bazin, Paris, 1865.

**No. 23. 18-inch Yellow Fir Continuous-Stave Pipe, Astoria Waterworks, Oregon.**[1]—A. L. Adams made two tests on long reaches of new yellow (Douglas) fir continuous-stave pipe. The gravity line supplying Astoria consists of $7\frac{1}{2}$ miles of 18-inch wood-stave, 3 miles of 16-inch and 1 mile of 14-inch steel pipe. The maximum head on the stave pipe is 172 feet. The pipe is buried from 4 to 22 feet deep. Loss of head was observed at standpipes, when the pipe line was carrying maximum capacity. Discharge was measured by the rise of water in a concrete reservoir. Leakage was tested and found to be negligible. The low friction factor found in this test is the more remarkable in view of the fact that there are "in addition to a succession of sweeping horizontal and vertical curves, 27 cast-iron bends, with a radius of curvature of 5 feet, and with an average central angle of about 31°." (Pl. XIV, fig. 1.) If but two tests at the same velocity are to be accepted as a criterion for the capacity, then the pipe will carry about 17 per cent more than as computed by the new formula. According to Henny this pipe was replaced with redwood in 1911. It had lasted 16 years.

**Nos. 24–25. 18-inch Jointed (Machine-Banded) Wood-Stave Pipe, Sunnyside Project, U. S. Reclamation Service, Washington.**—This pipe was built in 1908 for conveyance of irrigation water. The reach tested is straight except for one gentle curve through an angle of about 18°. In profile the pipe dips between gauges 1 and 2 about 20 feet in the reach 2,803 feet long. There are three minor summits in the reach. Water columns were used at both gauges. Air pulsations made tests difficult and but one measurement for internal area was possible, this being at the outlet where a distortion of about one-half inch was noted. Discharge was measured over a 6-foot Cipolletti weir and was corrected for leakage through another gate in the outlet structure. The two reaches cover approximately the same stretch of pipe. The capacity of the pipe was about 11 per cent greater than the discharge computed by the new formula.

**No. 28. 22-inch Jointed (Machine-Banded) Wood-Stave Pipe, Sunnyside Project, U. S. Reclamation Service, Washington.**—This pipe, built in 1906 to convey water for irrigation, had been used four seasons of seven months each at the time of tests. The horizontal alignment consists of two tangents intersecting at an angle of about 5°. The low point of the pipe is about 75 feet below the hydraulic gradient. There are probably no summits. The circumference of the pipe appears to be distorted about 1 inch. Water columns were used for both gauges. Measurements of diameter made at inlet and outlet gave a mean of 22 inches. Discharge was measured for runs 1 and 2 over an 8-foot round-crested weir. The discharge for remaining runs was taken over a 4-foot sharp-crested weir. Seven small leaks were measured volumetrically. Four irrigation hydrants are attached to this pipe. Referring to Plate VI it is seen that some unusual condition must be present in this pipe. Although the mean of all the observations indicates that the capacity is 3 per cent greater than that computed by the new formula, the individual observations indicate that the lowest velocity is 25 per cent greater than the discharge computed by formula, while the highest velocity is 12 per cent less than that discharge, for their respective losses of head. The intermediate velocities show the same trend through the above range. This series was rejected by Moritz, because of the unusual exponent of V. As no really definite reason was given for the rejection, and since other series of various experimenters show nearly as great peculiarities, the writer has retained the series.

**No. 32. Experiment H, 24-inch Continuous-Stave Redwood Pipe, Butte City, Mont.**—Water for the city of Butte, Mont., is conveyed from a reservoir about 9 miles distant in a redwood pipe laid in 1892 (Pl. XIV, fig. 2), which was designed as a low-pressure line following just under the hydraulic grade line as nearly as topography would permit. However, in some places a head of 200 feet is developed and a great deal of curvature, both horizontal and vertical, occurs throughout the length of

[1] Trans. Amer. Soc. Civ. Engin., 36 (1896), p. 26.

the line. Henny states [1] that too much reliance should not be placed on this test as "the only method at hand to determine the flow was from frequent determination of velocity by means of vertical floats in a semicircular flume at the upper end of the pipe." This test was not used by Williams-Hazen, Moritz, or the writer in the derivation of their formulas. The friction factor found indicates a capacity greater than the average. According to Henny's report in the Reclamation Record for August, 1915, this pipe is still sound "except some deterioration where covered with loose rock only."

**No. 33. Rectangular Unplaned Poplar Pipe.**—Tests on an experimental pipe 2.624 feet wide and 1.64 feet deep were made in France by Darcy and Bazin. As the pipe is similar to that described as No. 22 the same discussion applies to both. (See page 76.)

**No. 35. 31-inch Continuous-Stave Douglas Fir Siphon Pipe, Prosser Pipe Line, Sunnyside Project, U. S. Reclamation Service, Washington.**—In the discussion of the Moritz tests J. S. Moore gives the details of experiments conducted by him on the Prosser pressure pipe. Irrigation water is conveyed across the Yakima Valley over the Yakima River in a pressure pipe of combination type. A concrete pipe 30½ inches in diameter is used until the head reaches about 45 feet, at which point the line is changed to a 31-inch stave pipe. The reach tested has but one 5-degree curve, for about 19 degrees of central angle, located near the outlet end. At the river the maximum head is about 105 feet. The tests were conducted in August and October of the first irrigation season after the pipe was finished, the highest velocity being obtained only in August. Before backfilling, but following recinching of bands, external diameters were measured every 50 feet. The discharge was obtained from the rating curve of a 6-foot Cipolletti weir, the curve having been obtained by calibrating the weir against current-meter measurements from a meter station near the weir. The capacity of this pipe was about 6 per cent less than the discharge computed by the new formula. From the fact that the feed canal is down a very steep grade in a natural channel for part of the distance it appears to the writer that the pipe might very easily contain sufficient débris to account for any deficiency in capacity.

**No. 36.**—This is another reach of the same pipe as that last described. These tests covered a shorter piece, included in the long reach tested as No. 35. The two runs made at the highest velocity, in August, showed the same loss of head per unit of length in both reaches of pipe, but the other runs, made in October, gave divergent results, as shown on Plate VI. Mr. Moore states that he is not prepared to explain this divergence. This series of tests indicate that the capacity is 10 per cent less than the discharge computed by the new formula. (See discussion of No. 35.)

**No. 41. 44½-inch Continuous-Stave Douglas Fir Pipe, Municipal Water Supply, Seattle, Wash.**[2]—T. A. Noble conducted a series of tests on a 44-inch pipe at the time the tests on the 54-inch pipe (discussed as No. 44, p. 79) were carried on. With the exceptions noted below the same general methods were used on both pipes. The horizontal curves in the 44-inch pipe were so flat that for all practical purposes the pipe may be considered straight. For about one half the total reach the pipe follows an even gradient. For the other half it crosses a depression about 10 feet in maximum depth in a distance of about 2,000 feet. Thus, practically, the pipe is without curvature in either plane. After passing through the reach of 54-inch pipe discussed as No. 44 the water enters a settling basin. From this basin it is conveyed in the 44-inch pipe now under discussion. Water columns were used for both gauges. Gauge No. 1 was located 150.6 feet downstream from the inside wall of the basin. Gauge No. 2 was located 4,041 feet farther down the pipe line. No growth appeared within the 44-inch pipe; according to Noble the higher velocities in the 44-inch pipe

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[1] Journal Assoc. Engin. Socs., 21 (1898), p. 250.

[2] Trans. Amer. Soc. Civ. Engin., 49 (1902), p. 113.

prevent the attachment of growths. The capacity of this pipe was about 11 per cent less than the discharge computed by the new formula.

**No. 43. $48\frac{3}{4}$-inch Continuous-Stave Douglas Fir Siphon Pipe, Mabton Pressure Pipe, Sunnyside Project, U. S. Reclamation Service, Washington.**—Under and adjacent to the Yakima River the Mabton pressure pipe is reduced in size from the $55\frac{3}{4}$-inch pipe tested by Moritz and described as Nos. 45 and 46, page 79, to a $48\frac{3}{4}$-inch pipe of similar construction. At the time of the test the pipe had been in operation two and one-half irrigation seasons. During this time the mean velocity had been about 5.4 feet per second. The discharge was measured during the tests in the same way as that used for Nos. 45 and 46. Several diameters were measured at the time similar measurements were made on the $55\frac{3}{4}$-inch pipe. Mercury manometers were used for both gauges. The mean of these three observations indicates that the capacity of this pipe was about 20 per cent greater than the discharge computed by the new formula. This same excess of capacity is shown in the other portions of this siphon, discussed as Nos. 45 and 46. Subsequent to the tests described by Moritz, J. S. Moore experimented upon the portion of the Mabton pressure pipe below the point where the reduction from $55\frac{3}{4}$ inches to $48\frac{3}{4}$ inches in diameter was made. These tests are all described in the same publication. (See footnote under Nos. 2–3.)

**No. 44. $54\frac{3}{16}$-inch Continuous-Stave Douglas Fir Pipe, Municipal Water Supply, Seattle, Wash.**[1]—T. A. Noble conducted a series of tests for loss of head by friction in the reach of 54-inch pipe between the intake at the dam and the settling basin. As the line follows the sinuosities of Cedar River, it consists of gentle curves joined by short tangents. The minimum radius of curvature is 289 feet. From the appearance of the profile the pipe is laid on an even gradient, with the exception of one slight depression, where a blow-off is located. As a summit is reached after this depression, a 3-inch standpipe is carried above the hydraulic gradient. Holes for the attachment of the piezometers were made by boring with an ordinary wood bit until the tip of the bit pierced the inside of the pipe, making a hole about three-sixteenths inch in diameter. This method was afterwards adopted by Moritz for his experiments. The pipe had been in use about 10 months at the time of test. Gauge No. 1, a water column, was located 232 feet from the intake, while gauge No. 2 was a hook gauge in a well at the outlet of the pipe near the settling basin, 2,446.7 feet below gauge No. 1. The zero points of the various gauges were connected by lines of levels run by three different observers, the mean of the two nearest together being accepted as correct. Noble states that the probable error does not exceed 0.007 foot. The discharge was very carefully measured by an elaborate series of current-meter tests. For this purpose the area of the pipe was divided into four concentric zones, and each zone was covered with a sufficient number of meter readings to develop fully the mean velocity within that zone. In all, the meter was held at 50 points. The interior size of the pipe was carefully measured some two months after the tests. Vertical and horizontal diameters were taken every 100 feet. The resulting figures indicate that the pipe was badly distorted in several places. Growths of *Spongilla* in scattered bunches, each about one-fourth square inch in area and projecting about three-sixteenths inch, were distributed over the inside of the pipe, except along the bottom. The capacity of this pipe was about 2 per cent less than average, probably accounted for by the growth within the pipe; but the 44-inch pipe downstream from this one lacked an average capacity by 11 per cent, with no growth inside.

**Nos. 45 and 46. $55\frac{3}{4}$-inch Continuous-Stave Douglas Fir Siphon Pipe, Mabton Pressure Pipe, Sunnyside Project, U. S. Reclamation Service, Washington.**—Irrigation water is conveyed across the valley of the Yakima River by a siphon pipe carried under the river. At the intake end water in an open channel passes over an 18-foot rectangular weir into a 54-inch reinforced-concrete pipe. At

[1] Trans. Amer. Soc. Civ. Engin., 49 (1902), p. 112.

the end of about 3,000 feet a head of nearly 60 feet is attained and the pipe changed to a 55¾-inch continuous-stave pipe of Douglas fir. A reach of this pipe 2,848.2 feet long was tested in 1909 and again in 1910. At the time of the first series of tests the pipe had been in operation about five months. It was new, well rounded, and contained but minor distortions. There was no deposit or growth inside. Cross-sectional areas of pipe interior were determined by taking four diameters every 200 feet throughout the reach tested. Velocity in the pipe was determined by dividing the discharge, as found by the 18-foot weir, by the mean inside cross-sectional area of the pipe. Mercury manometers were used at both ends of the reach. A comparison of the capacities of this pipe and nearly all other large pipes shows that this siphon is remarkably smooth. This fact is also borne out by the tests on the 48¾-inch pipe discussed as No. 43, which is part of this same siphon. This fact is also clearly shown by the relative positions of the points for this pipe in Plate VI. The two series of tests on this pipe were the only ones on any pipe of greater diameter than 18 inches not rejected by Moritz in deriving his formula. This accounts for the difference between the Moritz formula and those of Williams-Hazen, Tutton, and the writer. Giving all weight for large pipes to these two series develops a formula indicating a far greater capacity for large wood-stave pipes than a study of all available tests on such pipes will warrant. If the new formula represents the flow in an average pipe, shown in Tables 2 and 3 to be true, then this pipe will carry more than 18 per cent more water than the average pipe. While conducting tests for the Department of Agriculture the writer visited this pipe after a lapse of four years with a view to securing additional information, but the pipe leaked so badly that tests were not feasible. The pipe was rebuilt in the winter of 1914–15.

**No. 49. Moon Island Conduit, Boston, Mass.**[1]—In October, 1884, E. C. Clarke made one test on a rectangular conduit, flowing full; that is, as a pipe. This conduit is a tight wooden flume 6 by 6 feet, made of planed plank, laid lengthwise. The experimental section was straight, 2,486.5 feet in length. During this test the flow consisted of about one-fourth sewage and about three-fourths salt water. The sides of the conduit were covered with from one-eighth to one-fourth inch of slime below the ordinary flow line. Above this line, on the sides and top, there was some slime but not so much as below the line. Discharge was measured with approximate accuracy by the strokes of the pump pistons. This test was used by Tutton in deriving his formula but rejected by other authorities as the conditions did not parallel those for which the usual pipe is designed.

**Nos. 47–48. 72½-inch Continuous-Stave Douglas Fir Power Trunk Line, Pioneer Electric Power Co., Ogden, Utah.**[2]—Soon after the construction of the Ogden Canyon pipe line supplying the Pioneer Electric Power Co. plant, near Ogden, Utah, tests were made by Profs. Marx, Wing, and Hoskins, of Leland Stanford Junior University. These tests covered loss of head in the 6-foot wood-stave pipe and the riveted-steel pipe leading from the stave pipe to the power house. Experiments were first made in 1897 [3] but were supplemented by a second series of tests in 1899.[4] In both series the discharge was measured through the Venturi meter installed at the plant. The loss of head was measured by the mercury manometers afterwards used by Moritz in the Sunnyside experiments. The relative elevations of the gauges were determined by the static head in the piezometers with the valves closed so that there was no velocity in the pipe. A constant reduction factor was used in converting the mercury column to the equivalent water column. These experiments have been criticized for this reason, but the writer is of the opinion that no error of moment was thus introduced since, in the tests conducted by him, hydrometer readings were taken

[1] E. C. Clarke. Main Drainage Works of the City of Boston, Mass., 2d ed., 1886.

[2] Trans. Amer. Soc. Civ. Engin., 38 (1897), p. 246.

[3] Id., 40 (1898), p. 471.

[4] Id., 44 (1900), p. 34.

in all the waters tested, and the variation in specific gravity from that of distilled water was found to be very slight. As it was not practicable to make an examination of the interior of this pipe the nominal size was accepted as correct. It conveys water for several miles down the very rugged canyon spoken of in the discussion of pipe No. 31. Both vertical and horizontal curves are numerous but not excessively sharp. These tests excited much comment at the time for the reason that they were the first to show that a value of about 0.010 for n in the Kutter formula would not apply to all sizes of pipe under all velocities. When compared with all other tests on large pipe, with the exception of Nos. 45 and 46, the capacity of this pipe is shown to be about equal to the discharge computed by formula. Compared to the new formula the capacity is from 5 to 8 per cent less than average. For further discussion of results on this pipe see page 9.

## ADDITIONAL DATA.[1]

The following experiments have been made on wood-stave pipes since the original publication of this bulletin, in 1916, or, if made previous to that date, have more recently been called to the attention of the writer. The Campbell tests (Nos. 15 and 21), rejected in the original publication, have been made acceptable and are now given full weight. The essential data are given in Table 9 on page 86.

**No. 53. 4-inch Inserted Joint Fir Pipe.[2] Ranch of H. R. Wells, Yakima, Wash.**—In 1908 T. A. Noble and C. W. Harris made a series of tests on a pumping line near Yakima, Wash. Of these tests they finally offered the results of two runs, one on a low-level reach of 717.7 feet and one on a high-level reach of 1,321.1 feet. The discharge was measured over a thin-lipped weir without end contractions, quantity being calculated by the Bazin formula, and afterwards checked by volumetric measurements. Mercury manometers of the pot-and-column type were used at the high-pressure ends of the reaches and water columns at the low-pressure ends. The age of this pipe and the method of making piezometer connections were not given. In this paper Mr. Noble senses our present understanding that the Kutter formula should not be used in determining the capacity of stave pipes. He writes: "There are sufficient (tests) to thoroughly demonstrate that the old method of calculating the flow by Kutter's formula is intrinsically wrong."

**No. 54. 8-inch Machine-Banded Untreated Douglas Fir Pipe. Water Supply for Marysville, Wash.[3]**—Soon after the completion of the Marysville line in the fall of 1921, R. E. Koon measured the discharge and found 0.80 second-foot of water. As the total length of the line is 46,000 feet from springs through a settling basin to an elevated tank, and the total head consumed in friction loss is 137 feet, there are sufficient data for an acceptable test. The great length of the line removes the necessity for simultaneous readings of gauges attached to piezometer connections. The line may be considered as practically straight, as there are only two right-angled bends near the point where the water is discharged into an elevated tower and two similar bends about midway of the line. This observation checks our formula within less than 1 per cent.

[1] In the first edition of this bulletin, published in 1916, there appeared an extended discussion by several engineers. This discussion pertained, for the most part, to the formula then offered for the first time. This formula has been very generally adopted by both manufacturers and engineers so that further defense does not appear necessary, and the discussion is omitted in order to make room for additional data. The reader who wishes to read the discussion is referred to the edition of 1916 which is on file in most public libraries.

[2] Wood Pipe, by Theron A. Noble, Pro. Pac. Northwest Soc. of Engrs., Vol. IX, No. 1 (1910), Seattle, Wash., p. 7.

[3] Notes for this test submitted in correspondence by R. E. Koon, consulting engineer, Portland, Oreg.

**No. 15 and No. 21. 10.12-inch and 16.12-inch Jointed Pipe, Bonito Pipe Line.**—The tests on this line were mentioned in the original publication of this bulletin (see pp. 11 and 75). Since then Mr. Campbell has supplied the data for computing the mean velocities as from time of injection of color or bran to the mean between first and last appearances. The results are given in Table 9. Like nearly all of the data on pipe capacities, there is a lack of consistency in the results. The tests were made with two years' interval between the first set and the second set and a similar interval between the second and third sets. If the tests are indicative of true conditions, then the capacity of both pipes increased during the first two years and then decreased again. At their face value the capacity of the 10-inch line appears near 5 per cent in excess of our formula capacity and the 16-inch line above 15 per cent.

**No. 55. 30-inch Continuous-Stave Redwood Pipe. Norfolk, Va., Supply Main.**[1]—In 1922 the city of Norfolk finished a new supply main some 98,000 feet long. This main employs three kinds of pipe—concrete, cast-iron, and redwood staves. Five sections, comprising 73,750 feet in aggregate length, were tested for friction losses. Two of these sections, composed of the redwood staves, offer additional data for this bulletin. (See No. 56 below.)

The reach of 30-inch pipe, tested when 2 years old under the direction of W. H. Taylor and N. Z. Ball, was 4,706 feet in length, relatively straight in both horizontal and vertical alignment. The discharge was determined by a Venturi meter which was checked before and after each test. The pressures at the ends of the reach were determined by mercury manometers, read simultaneously. These manometers were of the pot-and-column type, the column consisting of a rubber tube terminating in a gauge glass. The gauge readings, taken at five-minute intervals, were based on accurate levels over the pipe line.

This single observation on a relatively new line indicates a capacity some 12 per cent in excess of our formula. It will be interesting to watch the performance of this pipe line, as it is contemplated that these tests be repeated each year. Redwood has a very smooth surface when first milled, as these tests indicate.

**No. 56. 36-inch Continuous-Stave Redwood Pipe. Norfolk, Va., Supply Main.**—At the time of the test described under No. 55 above a similar test was made of a reach of 36-inch pipe of identical construction, but carrying a larger quantity of water. This reach, being 39,580 feet long, should yield the more reliable results as its great length causes such a gross loss of head as to completely overshadow experimental errors. The loss of head in this section indicates a capacity 12 per cent above our formula, which is reasonable for a new redwood pipe.

**No. 42. Expt. S–9 Continued. (See No. 42, p. 44.)**—After a period of nine years the writer again visited the Cowiche siphon and set up gauges on exactly the same reach of pipe as before. The only difference of conditions was that the pipe was now 9.5 years old instead of 6 months. The velocity of 5.1 feet per second exceeded the highest velocity in 1914 of 4.84 feet per second and the gauge difference indicated a deterioration in capacity of 5.4 per cent, if the loss of the two velocities nearest alike are compared. This might easily be accounted for by any slight accumulation of rock ravelings as the flume leading to the siphon undoubtedly does catch some débris, being covered in the worst places but open in others such as a rock tunnel.

**No. 57. 67¾-inch Continuous-Stave Douglas Fir Power Penstock. Municipal Light and Power Plant, Seattle, Wash.**—In 1912 J. D. Ross offered the results of a series of tests on the penstocks made in connection with general tests of plant efficiency.[2] The loss of head was computed from the record of

[1] Tests of Leakage, Friction, and Discharge in Norfolk Supply Main, by W. H. Taylor and Norman Z. Ball. Engin. News, Mar. 12, 1925, p. 446.

[2] Plant Efficiency, by J. D. Ross. Pro. Am. Inst. Elec. Engineers, May, 1912, p. 467, Abstracted in Western Engineering, November, 1912.

recording gauges, which were frequently calibrated. While such records are not sufficiently accurate for the measurement of loss in short reaches of pipe, yet they are passably acceptable when the great length, 15,865 feet, is considered, especially for the higher velocities; at 10 feet per second the gross loss was 61.9 feet from which was deducted 2.9 feet for entry and elbow losses.

The plant was put in commission in November, 1908, and the tests made in 1911. The pipe contains five steel elbows each of 15-foot radius where the curvature exceeds 20°. The total angle in these elbows is 317°. The loss at each elbow was measured by differential gauge and the total of such losses deducted from the gross loss before computing the net loss of head in the pipe proper. The original article does not state the method of measuring the quantity of water.

**No. 58. 90-inch Antelope Creek Siphon, Eastern Irrigation Block, Canadian Pacific Railway, Alberta, Canada. Continuous Stave Creosoted Douglas Fir Pipe.**[1]—In 1921 G. F. P. Boese and C. M. O'Neil made a test of the losses through a new stave siphon 1,698 feet long that replaced three barrels of a five-barreled monolithic concrete siphon. The new pipe, of pressure-creosoted fir staves, was designed by our formula, extended beyond any experimental velocities. For a required capacity of 700 second-feet the velocity in a 90-inch pipe would be 15.84 feet per second. At the time of test the flow in the canal was 639 second-feet, so a very satisfactory high-velocity test resulted. The mean velocity of 14.48 feet per second was determined by traversing the pipe across horizontal and vertical radii with a pitometer. The instrument was held at definite points that determined the velocities at definite ring areas. Unfortunately the pipe diameter was so large that the pitometer rods could not reach to the center of the line by 18½ inches in the vertical and 20¼ inches in the horizontal. Thus it was necessary to project the velocity curve to the center. This is in a measure verified by the pipe coefficient found; that is, the mean velocity divided by the center velocity was found to be 0.875, which agrees fairly well with accepted coefficients for pitometer work.

The high velocity, 14.48 feet per second, makes this experiment of particular value as indicating that our formula may be extended beyond the range of the base data. The tables in this bulletin were computed for such high velocities, but at this time it was appreciated that the base data were being extended beyond experience.

The results of this test agree with our formula within about 4 per cent.

**No. 60. 96-inch Continuous-Stave Douglas Fir Penstock. Searsburg Pipe Line, New England Co. Power System, Vermont.**[2]—In 1923 the engineering force of the Power Construction Co., under the direction of A. C. Eaton, made a series of tests on plant efficiency under the supervision of C. M. Allen, of Worcester Polytechnic Institute. These tests comprised a series of experiments on an 8-foot stave pipe line laid in 1921. The line consists of 18,406 feet of stave pipe plus seven scattered sections of steel special bends, aggregating 138 feet; also one concrete section 98 inches in diameter, 126 feet long, with additional concrete transition sections totaling 22 feet in length. The general alignment is quite sinuous. The velocity in the pipe was determined by the salt velocity method, which is used in much the same way as color except that the first and last arrival of the salt injection is determined by the deflection of an ammeter rather than by visibility. This method was used by Mr. Yarnell of the United States Bureau of Public Roads at Arlington, Va., in 1916 and was made public by Professor Allen in 1922. The loss of head was determined from readings of a staff gauge in

[1] The results of this test were submitted in correspondence to the writer by A. S. Dawson, chief engineer, Irrigation Block, Canadian Pacific Ry., Calgary, Alberta.

[2] The results of this extended series of tests were submitted in correspondence to the writer by A. C. Eaton, hydraulic engineer, New England Power Construction Co., Worcester, Mass.

the pond above the intake and readings on a mercury U-tube manometer attached to the pipe about 6 feet above the surge tank. From the gross loss must be deducted the local loss through the racks at the intake and the velocity head. The rack losses were computed by comparison with some measured losses in a similar rack at another plant. In any event the incidental losses were very small compared with total loss in a 3½-mile line. Gauge elevations were checked by readings with the turbine gates closed so that practically a static condition resulted.

The loss of head for the higher velocities agrees very closely with our formula loss, but as lower velocities are considered the observed losses of head are less than the formula calls for.

**No. 59. Expt. S–18. 96-inch Continuous-Stave Creosoted Douglas Fir Penstock. Wise Power Plant, Pacific Gas & Electric Co., near Auburn, Calif.**—The Wise power plant is served with water from a forebay at the lower end of an open canal, by means of a stave line for the first one-fourth mile, thence through a Venturi meter, and the balance of the distance of 1½ miles through a steel pipe of tapering diameters.

In 1919 the writer, while making a series of tests on the friction losses in the steel penstock, set up mercury gauges near the ends of the stave line between the forebay and the Venturi meter, giving a reach of pipe 1,238.9 feet long.

The quantity of water was determined by readings of the Venturi meter corrected for leakage losses in the stave line. These losses were concentrated and measured over triangular notch weirs. They constituted only two-tenths of 1 per cent of the total flow, so might have been neglected without materially altering the results. This pipe is slightly sinuous in both vertical and horizontal planes. The internal diameter was determined by measuring the outside circumference at four points and deducting the known thickness of the staves. The line was 2 years old at the time of test. While the reach was short, compared with the diameter of the pipe, still the velocity was so high that experimental errors were minimized. The velocity found was some 6 per cent less than that called for by our formula for the same loss of head.

**No. 61. Expt. S–19. 120-inch Untreated Fir-Stave Penstock. Montana Power Co., near Ennis, Mont.**—The power plant on the Madison River, below Ennis, Mont., offered an exceptional opportunity for tests. Between the reservoir and the surge tank were parallel lines of stave pipe, one 10 feet and the other 12 feet in diameter. These lines were nearly 7,000 feet long and were 17 years old at time of test. The combination of large sizes, reasonably long reach of pipe, relatively great age, and low pressure heads was quite unusual. Informal cooperation of the Montana Power Co. enabled the writer to make a series of tests on these two lines in 1923.

Piezometers leading to water columns in graduated gauge glasses determined the loss of head. At each end of the reach 6,698 feet long two piezometers, each containing four holes one-sixteenth inch in diameter, neutral to the current, were introduced through holes drilled in the staves at about 10 and 2 o'clock (regarding the section of the pipe as a clock dial). This gave the average pressure from eight holes. The piezometer tubes at the two ends of the reach were under the same dynamic condition. The velocities within the pipes were determined by timing the passage of fluorescein from a point near gauge 1 to its appearance in the surge tank a short distance below gauge 2. At the surge tank the stave-pipe outlets were submerged only from about 3 to 10 feet. Sunlight was admitted to the tank by the removal of boards from the roof. The first appearance of color was detected without difficulty, but in order to determine the last sight of color it was necessary to watch the "boil" from the pipe carrying color to see when the clear water cut through the green pool then resulting. Having two large pipes to manipulate, it was easy to alter the flow in either one so that three observations at widely separated velocities were possible on each pipe. During any one observation the load on the power plant was held constant, variations in load being cared for by other plants.

The observations on the 10-foot pipe indicate the capacity after 17 years' service was but 6 per cent less than that called for by our formula. As this is well within the range of difference between actual performance and formula for many of the relatively new pipes which formed the basis for the formula then, it would still appear that there is little or no depreciation in the capacity of stave pipes with the lapse of time. This statement, of course, excludes depreciation due to mud and gravel deposits. (See No. 62 below.)

**No. 62. Expt. S–20. 144-inch Untreated Fir Stave Penstock, Montana Power Co., near Ennis, Mont.**—This pipe adjoins pipe No. 61 above, and the description of tests is found above. The capacity of this pipe was something less than 10 per cent below that called for by our formula. The three observations, at velocities ranging from about 3.5 feet per second to 7.3 feet per second, did not yield results as consistent as did those on the 10-foot pipe.

## ADDITIONAL CONCLUSIONS.

Following nine years' experience in the use of the Scobey formula for capacity offered in this bulletin, the writer feels that there is no occasion to change any of the factors in it. A great many pipes of all sizes and with a wide range of velocities have been constructed under the guidance here offered and no adverse criticism whatever has resulted. A study of Table 9, column 19, shows that the data indicate a pipe capacity slightly above the quantities as computed by this formula. However, there are enough observations that show the opposite trend to prevent a change in the formula.

The writer wishes to acknowledge indebtedness to the various organizations that have sent results of tests from time to time. He will appreciate future cooperation along this line and will welcome any information that will perfect our knowledge of the actual field capacities of wood-stave pipes.

TABLE 9.—*Elements of additional experiments for the determination of friction losses in wood-stave pipes, with percentage comparison of observed velocities to formula velocities.*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Coefficients of retardation. | | | | Comparison, by various formulas, of observed to calculated velocities. | | | | | | | | | |
| | | | | | | | | | | | | | Velocities, by formulas, for given H, per second. | | | | | Column 8 compared to columns 14–18, inclusive. | | | | |
| Pipe No. | Reference No. | Experimenter and year. | Observation. | d Diameter. | Name and description of pipe. | Q Discharge, per second. | V Mean velocity, per second. | H Loss of head, per 1,000 feet. | n Kutter, by observation. | n Kutter, normal. | C Chezy. | $C_w$ Williams-Hazen. | Scobey. | Williams-Hazen ($C_w$=120). | Moritz. | Tutton. | Weisbach. | Scobey. | Williams-Hazen ($C_w$=120). | Moritz. | Tutton. | Weisbach. |
| | | | | *Inches.* | | *Cu. ft.* | *Feet.* | *Feet.* | | | | | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* |
| 53 | 287 | NH-1908 | A | 4 | H. R. Wells pumping line, Yakima, Wash. | 0.135 | 1.545 | 2.769 | 0.0092 | 0.0098 | 101.7 | 134.9 | 1.39 | 1.37 | 1.40 | 1.24 | 1.38 | +10.8 | +11.1 | +10.8 | +24.5 | +12.3 |
| | 288 | | F | | | .187 | 2.144 | 6.721 | .0100 | .0097 | 90.6 | 116.0 | 2.28 | 2.22 | 2.30 | 1.95 | 2.27 | − 5.9 | − 3.4 | − 6.6 | + 9.9 | − 5.5 |
| 54 | 289 | 1921 | .... | 8 | Marysville, Wash. .......... | .80 | 2.29 | 2.98 | .0105 | .0104 | 102.7 | 124.2 | 2.28 | 2.22 | 2.38 | 2.04 | 2.25 | + 0.4 | + 3.6 | − 3.4 | +12.3 | − 1.8 |
| 15 | 290 | C-1909 | .... | 10.12 | Bonita pipe line, N. Mex. See p. 30. | 5.73 | 10.35 | 33.38 | .0096 | .0098 | 123.6 | 131.6 | 10.14 | 9.44 | 10.67 | 8.13 | 9.37 | + 2.1 | + 9.6 | − 3.0 | +27.3 | +10.4 |
| | 291 | C-1911 | | | | 6.04 | 10.90 | 33.38 | .0092 | .0098 | 130.2 | 138.6 | 10.14 | 9.44 | 10.67 | 8.13 | 9.37 | + 7.6 | +15.4 | + 2.2 | +34.1 | +16.3 |
| | 292 | C-1913 | | | | 5.89 | 10.63 | 33.38 | .0094 | .0098 | 127.0 | 135.2 | 10.14 | 9.44 | 10.67 | 8.13 | 9.37 | + 4.8 | +12.6 | − 0.4 | +30.7 | +13.4 |
| 21 | 293 | C-1909 | .... | 16.12 | Bonita pipe line, N. Mex. See p. 30. | 5.70 | 4.08 | 3.062 | .0103 | .0108 | 127.4 | 140.4 | 3.65 | 3.49 | 3.93 | 3.27 | 3.59 | +11.9 | +17.0 | + 3.8 | +24.7 | +13.6 |
| | 294 | C-1911 | | | | 6.00 | 4.30 | 3.062 | .0097 | .0108 | 134.1 | 148.0 | 3.65 | 3.49 | 3.93 | 3.27 | 3.59 | +17.9 | +23.5 | + 9.5 | +31.4 | +19.8 |
| | 295 | C-1913 | | | | 5.85 | 4.19 | 3.062 | .0100 | .0108 | 130.8 | 144.2 | 3.65 | 3.49 | 3.93 | 3.27 | 3.59 | +14.9 | +20.3 | + 6.7 | +28.0 | +16.7 |
| 55 | 296 | 1925 | .... | 30 | Norfolk, Va., supply line.... | 15.78 | 3.22 | .956 | .0108 | .0117 | 131.7 | 140.3 | 2.87 | 2.75 | 3.19 | 2.73 | 2.95 | +12.3 | +16.9 | + 0.9 | +18.0 | + 9.2 |
| 56 | 297 | 1925 | .... | 36 | Norfolk, Va., supply line.... | 20.42 | 2.89 | .644 | .0111 | .0121 | 131.5 | 138.9 | 2.59 | 2.50 | 2.91 | 2.52 | 2.76 | +11.5 | +15.8 | − 0.7 | +14.8 | + 4.9 |
| 42 | 298 | S-1923 | .... | 48 | Cowiche siphon. See p. 34.. | 64.11 | 5.10 | 1.43 | .0114 | .0118 | 134.9 | 132.9 | 4.86 | 4.60 | 5.54 | 4.57 | 5.06 | + 4.8 | +10.8 | − 7.8 | +11.6 | + 0.8 |
| 57 | 299 | 1911 | .... | 67.75 | Seattle, Wash., municipal light and power plant. Continuous-stave fir pipe 3 years old. | 62.6 | 2.50 | .246 | .0119 | .0131 | 134.1 | 135.7 | 2.29 | 2.21 | 2.65 | 2.34 | 2.71 | + 9.1 | +13.1 | − 5.7 | + 7.0 | − 7.7 |
| | 300 | | | | | 125.2 | 5.00 | .931 | .0118 | .0122 | 138.0 | 132.3 | 4.80 | 4.54 | 5.55 | 4.61 | 5.33 | + 4.2 | +10.2 | − 9.8 | + 8.5 | − 6.3 |
| | 301 | | | | | 187.8 | 7.50 | 2.042 | .0117 | .0117 | 139.7 | 131.7 | 7.42 | 6.93 | 8.58 | 6.87 | 7.89 | + 1.1 | + 8.3 | −12.6 | + 9.1 | − 5.0 |
| | 302 | | | | | 250.4 | 10.00 | 3.775 | .0119 | .0114 | 137.0 | 124.2 | 10.43 | 9.66 | 12.08 | 9.41 | 10.83 | − 4.1 | + 3.5 | −17.2 | + 6.3 | − 7.7 |
| 58 | 303 | 1921 | .... | 90 | Antelope siphon, Alberta, Canada, C. P. Ry. system. | 639.0 | 14.48 | 5.30 | .0117 | .0113 | 145.3 | 125.2 | 15.15 | 13.87 | 17.78 | 13.50 | 15.54 | − 4.4 | + 7.3 | −18.5 | + 7.3 | − 6.8 |

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 59 | 305 | S-1919 | .... | 96 | Wise penstock, Pacific Gas & Electric Co., Calif. | 310.6 | 6.18 | 1.094 | .0129 | .0122 | 132.1 | 120.3 | 6.58 | 6.16 | 7.75 | 6.30 | 7.33 | − 6.1 | + 0.2 | −20.5 | − 1.9 | −15.7 |
| 60 | 306 | 1923 | .... | 96 | Searsburg, Vt., penstock, New England Co. Power system. Continuous-stave fir pipe. Inside slightly slimed. Alignment sinuous. Contains 7 steel bends with central angles from 40 to 90 degrees. Pipe 2 years old. | 90.1 | 1.79 | .080 | .0117 | .0137 | 141.5 | 143.1 | 1.55 | 1.50 | 1.82 | 1.66 | 1.97 | +15.5 | +19.1 | − 1.7 | + 7.9 | − 9.1 |
| | 307 | | | | | 114.2 | 2.27 | .122 | .0115 | .0136 | 145.3 | 144.4 | 1.95 | 1.89 | 2.29 | 2.06 | 2.44 | +16.6 | +20.3 | − 1.0 | +10.3 | − 6.8 |
| | 308 | | | | | 156.4 | 3.11 | .221 | .0114 | .0130 | 147.9 | 143.6 | 2.71 | 2.60 | 3.19 | 2.79 | 3.28 | +14.8 | +19.7 | − 2.5 | +11.6 | − 5.1 |
| | 309 | | | | | 183.9 | 3.66 | .330 | .0119 | .0128 | 142.5 | 136.1 | 3.38 | 3.22 | 3.98 | 3.42 | 4.02 | + 8.2 | +13.4 | − 8.1 | + 7.1 | − 9.0 |
| | 310 | | | | | 222.0 | 4.42 | .483 | .0119 | .0126 | 142.1 | 133.8 | 4.17 | 3.96 | 4.92 | 4.15 | 4.87 | + 6.0 | +11.5 | −10.2 | + 6.5 | − 9.2 |
| | 311 | | | | | 245.0 | 4.88 | .593 | .0120 | .0124 | 141.7 | 132.2 | 4.68 | 4.43 | 5.52 | 4.61 | 5.39 | + 4.2 | +10.2 | −11.5 | + 5.9 | − 9.5 |
| | 312 | | | | | 257.2 | 5.12 | .645 | .0119 | .0124 | 142.6 | 132.6 | 4.91 | 4.63 | 5.78 | 4.81 | 5.63 | + 4.3 | +10.5 | −11.4 | + 6.5 | − 9.0 |
| | 313 | | | | | 275.8 | 5.49 | .761 | .0121 | .0123 | 140.7 | 130.0 | 5.38 | 5.07 | 6.34 | 5.23 | 6.11 | + 2.1 | + 8.3 | −13.4 | + 4.9 | −10.1 |
| | 314 | | | | | 292.2 | 5.81 | .860 | .0121 | .0123 | 140.1 | 128.8 | 5.76 | 5.41 | 6.78 | 5.57 | 6.50 | + 0.9 | + 7.3 | −14.3 | + 4.3 | −10.6 |
| | 315 | | | | | 309.5 | 6.16 | .966 | .0122 | .0122 | 140.1 | 128.2 | 6.14 | 5.76 | 7.23 | 5.91 | 6.88 | + 0.3 | + 6.9 | −14.8 | + 4.2 | −10.5 |
| | 316 | | | | | 321.0 | 6.39 | 1.033 | .0121 | .0121 | 140.6 | 128.3 | 6.37 | 5.98 | 7.51 | 6.12 | 7.12 | + 0.3 | + 6.9 | −14.9 | + 4.5 | −10.3 |
| 61 | 317 | S-1923 | .... | 120 | Madison River penstock, Montana Power Co. Untreated stave pipe, 17 years old. | 247 | 3.15 | .254 | .0139 | .0133 | 125.0 | 117.2 | 3.38 | 3.22 | 4.03 | 3.46 | ..... | − 6.9 | − 2.3 | −21.8 | − 9.1 | ......... |
| | 318 | | | | | 417 | 5.31 | .627 | .0131 | .0125 | 134.1 | 121.3 | 5.59 | 5.25 | 6.65 | 5.49 | ..... | − 4.9 | + 1.1 | −20.4 | − 3.3 | ......... |
| | 319 | | | | | 615 | 7.83 | 1.282 | .0127 | .0120 | 138.3 | 121.6 | 8.31 | 7.73 | 9.90 | 7.91 | ..... | − 5.7 | + 1.3 | −20.9 | − 1.0 | ......... |
| 62 | 320 | S-1923 | .... | 144 | Montana Power Co. This penstock paralleled No. 61 above. | 394 | 3.48 | .210 | .0129 | .0132 | 138.6 | 127.9 | 3.43 | 3.26 | 4.12 | 3.55 | ..... | + 1.6 | + 6.6 | −15.5 | − 1.9 | ......... |
| | 321 | | | | | 584 | 5.16 | .483 | .0132 | .0127 | 135.6 | 121.0 | 5.44 | 5.12 | 6.54 | 5.42 | ..... | − 5.1 | + 0.8 | −21.1 | − 4.9 | ......... |
| | 322 | | | | | 827 | 7.30 | .994 | .0134 | .0124 | 133.7 | 115.9 | 8.12 | 7.56 | 9.76 | 7.84 | ..... | −10.0 | − 3.4 | −25.5 | − 6.8 | ......... |
| | | | | | Total plus | | | | | | | | | | | | | 188.2 | 343.1 | 23.1 | 344.8 | 117.4 |
| | | | | | Total minus | | | | | | | | | | | | | 53.0 | 9.1 | 328.6 | 28.9 | 155.7 |
| | | | | | Difference, plus | | | | | | | | | | | | | 135.2 | 334.0 | ......... | 315.9 | ......... |
| | | | | | Difference, minus | | | | | | | | | | | | | ......... | ......... | 305.5 | ......... | 38.3 |
| | | | | | Difference, plus—forward from Table 2 | | | | | | | | | | | | | ......... | 692.5 | ......... | 760.9 | ......... |
| | | | | | Difference, minus—forward from Table 2 | | | | | | | | | | | | | 80.3 | ......... | 2,401.1 | ......... | 1,616.6 |
| | | | | | Grand net difference | | | | | | | | | | | | | +54.9 | +1,026.5 | −2,706.6 | +1,076.8 | −1,654.9 |
| | | | | | Number of item | | | | | | | | | | | | | 287 | 287 | 287 | 303 | 266 |
| | | | | | Grand average per cent | | | | | | | | | | | | | +0.19 | +3.6 | −9.4 | +3.6 | −6.2 |

## ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE.

**January 9, 1926.**

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