FLOW OF WATER

IN

OPEN CHANNELS

PIPES, SEWERS, CONDUITS, &c.,

WITH TABLES,

BASED ON THE

FORMULÆ OF D'ARCY, KUTTER AND BAZIN.

BY

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PREFACE.

The formulæ of D'Arcy, Kutter and Bazin are gradually, but surely, being adopted instead of the old formulæ of D'Aubisson, De Prony, Downing, &c.

The former formulæ, however, though admitted to be more accurate, are also, as a rule, more complicated in form, and more troublesome and tedious in their application, than most of the old formulæ in use. In these days, when numerous works on Sewerage, Water Supply, Irrigation, &c., are being constructed in this country, and in fact all over the civilized world, hydraulic formulæ are, perhaps, in more general use by Engineers than at any former time, and therefore, any ready method which combines rapidity with accuracy in the application of the new formulæ will, very likely, tend to their more general use than at present.

It is believed that this combination of rapidity with accuracy can be gained by the proper use of the tables in this book; and Hydraulic Engineers, who make it a practice to use the formulæ of D'Arcy, Kutter and Bazin, and to whom a saving of time and tedious computation is an object, will find the tables of material help in the solution of problems relating to the flow of water in open and closed channels.

CONTENTS.

FLOW OF WATER IN OPEN CHANNELS,

PIPES, SEWERS, CONDUITS, &c.

In the following formulæ let—

V = velocity in feet per second.

Q = discharge in cubic feet per second.

C = coefficient of mean velocity.

S = fall of water surface (h), in any distance (l), divided by that distance $= \frac{h}{l} =$ sine of slope.

$a =$ area of cross-section of pipe, conduit or open channel in square feet.

$p =$ wetted perimeter of pipe, conduit or open channel in lineal feet.

$r =$ hydraulic mean depth in feet = area of cross-section of pipe, conduit or open channel in square feet (a) divided by its wetted perimeter in lineal ft. $r = \frac{a}{p}$

d = diameter of pipe or conduit.

n = the natural coefficient, the value of which depends on the nature and condition of the bed of the channel through which the water flows, or in other words, its degree of roughness.

The plan on which the tables are constructed will be briefly stated here and their use will be more fully explained further on.

Chezy's general form of formula for velocity is—

$$V = c\sqrt{rs} = c\sqrt{r} \times \sqrt{s}$$

therefore

$$Q = ac\sqrt{rs} = ac\sqrt{r} \times \sqrt{s}$$

The factors on the right hand side of the equations are tabulated, $c\sqrt{r}$ and $ac\sqrt{r}$ for diameters usually adopted in practice, and $\sqrt{s}$ for 986 slopes.

Now to find the velocity, the diameter and slope being given. Look out and note down the number representing $c\sqrt{r}$ in its column and opposite the given diameter; also look out and note down the number representing $\sqrt{s}$ opposite the given slope. The product of these two numbers will give the required velocity. Again, given the slope and velocity in feet per second to find the diameter. From the equation

$$V = c\sqrt{r} \times \sqrt{s}$$

we have

$$c\sqrt{r} = \frac{V}{\sqrt{s}}$$

Look out the value of $\sqrt{s}$ corresponding to the given slope and divide the velocity by it. The quotient will be the value of $c\sqrt{r}$. In the column of $c\sqrt{r}$ look out the nearest number to the value of $c\sqrt{r}$ so found, and opposite to it in the same line will be the diameter required. At the same time the area and hydraulic mean depth can be found on the same line and the discharge can be found by looking out the value of $ac\sqrt{r}$ and dividing it by $\sqrt{s}$. In fact by inspection of the tables and the multiplication or division of two numbers, problems can be rapidly and accurately solved, which, by the use of any one of the formulæ, would be a tedious and troublesome operation. When the value of $c\sqrt{r}$ or $ac\sqrt{r}$ is found, the diameter can at once be found by inspection on the same line.

When the slope and velocity are given and the diameter is required it is not found directly. The value of $c\sqrt{r}$ is first computed by formula (9) and in the same line with this value in the tables will be found the required diameter. In a similar way the slope and discharge being given and the diameter required. The value of $ac\sqrt{r}$ is first computed by formula (14) and in the same line with this value in the tables will be found the required diameter.

The columns of $c\sqrt{r}$ and $ac\sqrt{r}$ can be used to compare velocities and discharges of pipes with equal slopes, and this can be done even when the channels have different degrees of roughness and different diameters.

For instance, a pipe say of 3 feet diameter has a discharge of 20 cubic feet per second by D'Arcy's formula, and it is required to find the diameter of a pipe of similar material which shall discharge 30 cubic feet per second, that is an increase of 50 per cent., the slope being the same in both pipes. Find in Table 1 the value of $ac\sqrt{r}$ opposite 3 feet diameter and it is $= 686.76$, and this increased by 50 per cent. $= 1030.14 =$ the value of $ac\sqrt{r}$ corresponding to the required diameter. By inspection of Table 1 the nearest value of $ac\sqrt{r}$ greater than this is found to be 1072.6 opposite a diameter of 3 feet 7 inches, which is the required diameter. In a similar manner velocities can be compared by the use of the column giving the values of $c\sqrt{r}$.

For feet measures D'Arcy's formula is

$$V = \left\{ \frac{rs}{.00007726 + \frac{.00000162}{r}} \right\}^{\frac{1}{2}} \qquad (1)$$

and from this we have

$$S = \left(.00007726 + \frac{.00000162}{r} \right) \frac{V^2}{r} \qquad (2)$$

In order to simplify, *substitute for r in feet the diameter d in inches*, and we have

$$S = \left(.00007726 + \frac{.00000162 \times 48}{d}\right)\frac{48\ V^2}{d}$$

$$\therefore S = \left(.00370848\, d + .00373248\right)\frac{V^2}{d^2}$$

As the change will not materially affect the result, Mr. J. B. Francis, C. E., simplifies this into the form

$$S = .00371\left(d+1\right)\frac{V^2}{d^2} \qquad (3)$$

$$\therefore V = \left\{\frac{S\, d^2}{.00371(d+1)}\right\}^{\frac{1}{2}} \qquad (4)$$

In order, however, to further simplify the equation into the Chezy form of formula, which is the form required for the preparation and use of the tables adopted by the writer and given in this book, let equation (3) be transformed into one with the *diameter d in feet* and it becomes

$$S = .00371\left(12\, d + 1\right)\frac{V^2}{144\, d^2}$$

$$\therefore V = \left\{\frac{144\, d^2\, S}{.00371\ (12\, d+1)}\right\}^{\frac{1}{2}}$$

but $d^2 = 16\ r^2 = 16 r \times r = 4\ d \times r$ substitute this value for d^2 in the last equation, and

$$V = \left\{ \frac{144 \times 4\ d \times r \times S}{.00371\ (12\ d+1)} \right\}^{\frac{1}{2}}$$

therefore, *for feet measures* D'Arcy's formula for velocity is simplified into

$$V = \left(\frac{155256\ d}{12\ d+1} \right)^{\frac{1}{2}} \times \sqrt{rs} \qquad (5)$$

and putting the first factor on the right-hand side of the equation $= c$, we have

$$V = c\sqrt{rs} = c\sqrt{r} \times \sqrt{s}$$

Kutter's formula for feet measure is

$$V = \left[\frac{41.6 + \frac{1.811}{n} + \frac{.00281}{s}}{1 + \left(41.6 + \frac{.00281}{S}\right) \frac{n}{\sqrt{r}}} \right] \times \sqrt{rs} \quad (6)$$

and putting the first factor on the right-hand side of the equation $= c$ we have

$$V = c\sqrt{r} \times \sqrt{s}$$

Bazin's formula for *open channels* of the *second category* and applicable to channels with an even lining of cut stone, brickwork, or materials with surfaces of equal roughness, exposed to the flow of water, is:

$$V=\sqrt{1\div.0000133\left(4.354+\frac{1}{r}\right)}\times\sqrt{rs} \quad (7)$$

and putting the first factor under the radical sign, in the right hand side of the equation $= c$ we have:

$$V=c\sqrt{r}\times\sqrt{s} \quad (8)$$

$$\therefore\ c\sqrt{r}=\frac{V}{\sqrt{s}} \quad (9)$$

$$\sqrt{s}=\frac{V}{c\sqrt{r}} \quad (10)$$

$$S=\left(\frac{V}{c\sqrt{r}}\right)^2 \quad (11)$$

Now

$$Q=a\,V=ac\sqrt{r}\times\sqrt{s} \quad (12)$$

$$\therefore\ a=\frac{Q}{v} \quad (13)$$

$$ac\sqrt{r}=\frac{Q}{\sqrt{s}} \quad (14)$$

$$\sqrt{s}=\frac{Q}{ac\sqrt{r}} \quad (15)$$

$$s=\left(\frac{Q}{ac\sqrt{r}}\right)^2 \quad (16)$$

By the use of the tables of factors as applied to the solution of these formulæ all the information relative to pipes, such as velocity, slope, diameter, etc., can be obtained.

In that admirable and useful work, "Molesworth's Pocket Book of Engineering Formulæ," a modified form of Kutter's formula for pipe discharge is given in which the value of

$$C = \frac{181 + \frac{.00281}{s}}{1 + .026\left(41.6 + \frac{.00281}{s}\right)} \qquad \textbf{(17)}$$

For facility of reference I will call this formula Molesworth's Kutter (17).

No mention is made by Molesworth of the value of n, that is as to whether the formula is intended to apply to pipes having a *rough* or a *smooth* inner surface. An investigation will, however, show that his formula is accurately applicable to *only one diameter*, that is, to a diameter of one foot and with the value of $n = .013$.

The value of the term $\frac{n}{\sqrt{r}}$ in formula

(6) is given by Molesworth in formula (17) as a *constant* quantity, and $=.026$, whereas, in fact, it is a variable quantity, its value—with the same value of n—changing with every change in the hydraulic mean radius or diameter of pipe.

Now, assuming the value of n taken by Molesworth to be $=.013$ and substituting this value for n in Kutter's formula (6) we have

$$C=\frac{41.6+\frac{1.811}{.013}+\frac{.00281}{s}}{1+\left(41.6+\frac{.00281}{s}\right)\frac{.013}{\sqrt{r}}}$$

$$\therefore c=\frac{181+\frac{.00281}{s}}{1+\left(41.6+\frac{.00281}{s}\right)\frac{.013}{\sqrt{r}}} \quad (18)$$

but by Molesworth's Kutter (17)

$$\frac{013}{\sqrt{r}}=.026$$

$$\therefore \sqrt{r}=.5$$

$$r=.25$$

and $$d=1$$

If we substitute in formula (18) for $\sqrt{r}$ its value 0.5, we have:

$$c=\frac{181+\frac{.00281}{s}}{1+.026\left(41.6+\frac{.00281}{s}\right)}$$

which is Molesworth's Kutter (17).

It is therefore apparent that, no matter what the value of n may be, Molesworth's Kutter (17) does not give the same results as Kutter's formula (6), as it gives a constant coefficient of velocity c for all diameters having the same slope and the same value of n.

Kutter's formula (6) has certain peculiarities which are wanting in Molesworth's Kutter, and an investigation will show that Molesworth's differs materially from Kutter's formula (6), and that its application, except to one diameter, is sure to lead to serious error. I will briefly explain:

1. By Kutter's formula (6) the value of c, or the velocity, changes with every change in the value of r, s, or n, and

with the *same slope* and the same value of n, the value of c increases with the increase of r, that is with the increase in diameter. It is on this variability of its coefficient to suit the different changes of slope, diameter and lining of channel that the accuracy of Kutter's formula depends. By Molesworth's Kutter a change in the diameter, other things remaining the same, does not affect the value of c. With the same slope the value of c is constant for all diameters.

As an instance with a slope of 1 in 1,000:

	6 inches diameter. $c =$	20 feet diameter. $c =$
By Kutter's formula (6).	69.5	146.0
"Molesworth's Kutter (17)	85.3	85 3

It will thus be seen that the value of c by Kutter's formula (6), when $s=.001$, has a large range, from 69.5 to 146.0, showing an increase of 111 per cent. from a diameter of 6 inches to a diameter of 20 feet.

It will be further found that Molesworth's formula gives the value of *c*, and therefore the value of the velocity and discharge, too high for diameters less than one foot, and too low for diameters above one foot, and the more the diameter differs from one foot the greater is the error. In these respects it follows the errors of the old formulæ.

2. According to Kutter's formula (6) the value of *c* increases with the increase of slope for all diameters whose hydraulic mean depth is less than 3.281 feet—one metre—and with a hydraulic mean depth greater than 3.281 feet, an increase of slope gives a diminution in the value of *c*.

The small table, herewith given, shows this:

	12 feet diameter.	
	1 in 1,000.	1 in 40.
Molesworth's Kutter c =...	85.3	86.9
Kutter's formula c =.........	137.7	137.9

	20 feet diameter.	
	1 in 1,000.	1 in 40.
Molesworth's Kutter c =...	85.3	86.9
Kutter's formula c =.........	146.0	145.7

It will thus be seen that by Kutter's formula (6), when $r = 3$ feet, that is, less than 3.281 feet, an increase in the slope from 1 in 1,000 to 1 in 40, causes a slight increase in the coefficient, but when r is 5 feet, that is more than 3.281 feet, the same increase in the slope causes a slight diminution in the value of c.

By Molesworth's Kutter (17), when $r=3$

feet, an increase in the slope from 1 in 1,000 to 1 in 40 causes a greater proportional increase in the coefficient than Kutter gives, and when $r=5$ feet the value of the coefficient does not diminish with the increase of slope, but on the contrary, it increases with the increase in slope, and its value is the same as when $r=3$ feet.

3. By Kutter's formula (6), when the hydraulic mean depth is equal to 3.281 feet, one metre, the value of c is *constant* for all slopes, and is $=\frac{1.811}{n}$, which in this case $=\frac{1.811}{.013}=139.31$.

Let $r=3.281$ feet, and therefore, $\sqrt{r}=\sqrt{3.281}=1.811$, substitute this value in Kutter's formula (6), and we have

$$c=\frac{41.6+\frac{1.811.}{n}+\frac{00.281}{s}}{1+\left(41.6+\frac{.00281}{s}\right)\frac{n}{1.811}}$$

and $\therefore c=\frac{1.811}{n}$ and when $n=.013$

$c=139.31.$

This is the only instance, I believe, where Kutter's formula (6) gives a constant coefficient with a change of slope. By Molesworth's Kutter (17), on the contrary, the value of c changes with every change of slope when $r=3.281$.

It is evident that Molesworth's Kutter was adopted in order to simplify the application of Kutter's formula (6), but its simplification is of no practical use as it gives very inaccurate results.

As shown above, with the exception of its application to one diameter, the formula is not Kutter's, although in appearance bearing a resemblance to it.

However, a modification of Kutter's formula can be made, simpler in form than even Molesworth's Kutter (17), and giving results near enough for all practical purposes to those obtained by the use of the more complicated Kutter formula (6).

The value of c in Kutter's formula (6), with a slope of 1 in 1,000, and $n=.013$, is thus expressed,

$$c=\frac{41.6+\frac{1.811}{.013}+\frac{.00281}{.001}}{1+\left(41.6+\frac{.00281}{.001}\right)\frac{.013}{\sqrt{r}}}$$

$$\therefore c=\frac{183.72}{1+44.41\times\frac{.013}{\sqrt{r}}} \qquad (19)$$

The following table will show the value of the coefficient c for several slopes and diameters, according to formulæ (17), (6), and (19):

	Molesworth Kutter (17) $c=$	Kutter's formula (6) $c=$	Formula (19) $c=$
6 inch diameter, slope 1 in 40	86.9	71.5	69.5
6 inch diameter, slope 1 in 1,000	85.3	69.5	69.5
4 feet diameter, slope 1 in 400	87.2	117.0	116.5
4 feet diameter, slope 1 in 1.000	85.3	116.5	116.5
8 feet diameter, slope 1 in 700	85.8	130.5	130.5
8 feet diameter, slope 1 in 2,600	82.9	129.8	130.5

This table shows the close agreement of formula (19) with Kutter's formula (6), and it also shows the inaccurate results obtained by the use of Molesworth's Kutter.

The first column of this table shows that a formula with a *constant* value of $c=85$, that is:

$$V = 85\sqrt{rs}$$

will give results differing in an extreme case only 2½ per cent. from Molesworth's Kutter, and in the greater number of cases differing only about one per cent.

The second column of the table shows the wide range of the coefficient c by Kutter's formula (6) from 69.5 to 130.5 to suit the different changes in the hydraulic mean depth and slope.

The objection to the old formulæ was that they gave velocities too high for small pipes and channels, and too low for large pipes and channels. The following table will show that the same inaccurate results are obtained by the use of Molesworth's Kutter (17):

	Velocity in feet per second by		
	Molesworth (17).	Kutter (6).	Formula 19).
6 inch diameter, slope 1 in 40	4.86	4.00	3.89
6 inches diameter, slope 1 in 1,000	0.95	0.78	0.78
4 feet diameter, slope 1 in 400	4.36	5.85	5.83
4 feet diameter, slope 1 in 1,000	2.70	3.68	3.68
8 feet diameter, slope 1 in 700	4.59	6.97	6.97
8 feet diameter, slope 1 in 2,600	2.30	3.60	3.62

This table shows that there is a wide difference between the velocities obtained by Molesworth's Kutter (17) and Kutter's formula (6), and it further shows that for the slopes usually adopted in practice for pipes, sewers, conduits, etc., that is for slopes not flatter than 2 feet per mile, or 1 in 2640, formula (19) will give velocities that for all practical purposes may be considered as almost identical with the velocities obtained by Kutter's formula (6).

The tables of factors $c\sqrt{r}$ and $ac\sqrt{r}$ of Kutter in this work are computed by formulæ (19) and the table just given, and also the tables (10) and (11) show how small is the difference in velocity found by the tables of factors and by formula (6). The difference is generally less than one per cent., and it seldom reaches 3 per cent. Further illustrations of the close agreement of these two formulæ will be found further on.

Mr. L. D'A. Jackson, C. E., in his "Hydraulic Manual," and Mr. R. Hering, C.E., in a paper read before the Am. Soc. C. E., in 1878, extend the range of materials to which the different values of n adopted by Kutter apply.

A table of the value of n for different materials compiled from Kutter, Jackson and Hering, is herewith given, and this value of n, applies also, in each instance, to the surfaces of other material equally rough.

n=.009 well planed timber, in perfect order and alignment; otherwise perhaps .010 would be suitable.

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

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

n=.012 unplaned timber when perfectly continuous on the inside. Flumes.

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

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

$n = .017$ brickwork, ashlar, and stoneware in an inferior condition; tuberculated iron pipes; rubble in cement or plaster in good order; fine gravel, well rammed, ⅓ to ⅔ inches diameter; and generally the materials mentioned with $n = .013$ when in bad order and condition.

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

$n = .0225$ coarse dry set rubble in bad condition.

$n = .025$ suitable to rivers and canals with earthen beds in perfect order and regimen, and perfectly free from stones and weeds.

$n = .030$ suitable to rivers and canals with earthen beds in moderately good order and regimen, having stones and weeds occasionally.

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

The tables in this book are computed:

1*st*. By D'Arcy's formula (5) for clean pipes flowing under full pressure.

2*d*. By Kutter's formula (19) for pipes, sewers, conduits, etc., flowing full and also for open channels with:

$n = .011$

$n = .012$

$n = .013$ and

3*d*. By the *second type* of Bazin's formula (7) for open channels, applicable to channels with an even lining of cut stone, brickwork, and other materials with surfaces of equal roughness.

The accuracy of the results by Kutter's formula depends on the proper selection of the value of n for the surface of the material over which the water flows.

With reference to the fixing of values of n to some materials Mr. Jackson, in his "Hydraulic Manual," remarks:

"A coefficient of roughness $n = .010$ has been assumed as applicable to glazed or enameled pipes, and one of .013 for ordinary metal or earthenware or stoneware pipes under ordinary conditions, but not new; and there is every reason to believe that these assumptions are generally correct; if we compare the smoothness of surface of a glazed pipe with that of very smooth plaster in cement, and that of an ordinary pipe, in average condition, with that of ashlar or good brickwork; in addition to this, such few partial and limited experimental data as are available, support the assumption."

Again referring to the simplified form of Kutter's formula (19), if we call the numerator on the right hand side of the equation K, for any value of n, we have:

$$c = \frac{K}{1 + 44.41 + \frac{n}{\sqrt{r}}}$$

$$\text{and } V = \left\{ \frac{K}{1 + \left(44.41 \times \frac{n}{\sqrt{r}}\right)} \right\} \sqrt{rs} \qquad (20)$$

In the following table the value of K is given for the several values of n already referred to, except those for earthen channels.

$n=$	K=	$n=$	K=
.009	245.63	.015	165.14
.010	225.51	.017	150.94
.011	209.05	.020	134.96
.012	195.33	.0225	124.90
.013	183.72		

If, therefore, in the application of formula (20), within the limits of n, as given in the table, we substitute for n its value, and also the equivalent value of k, we have a simplified form of Kutter's formula (6).

For instance, when $n=.011$,

$$V=\left\{\frac{209.05}{1=\left(44.41\times\frac{.011}{\sqrt{r}}\right)}\right\}\times\sqrt{rs}$$

To further simplify formula (20) the value of $\sqrt{r}$ for a large range of diameters will be found in Table 6.

In Table 8 the coefficients of D'Arcy, and Kutter with $n = .011$ for smooth pipes, are placed in parallel columns for the purpose of comparison. It will be seen that beginning with the small pipes D'Arcy's coefficients have, for the same diameter, a greater value than Kutter's, but that as the diameters increase, the value of the coefficients approach nearer to each other, until at 14 inches diameter they are equal. From this point as the diameters increase, Kutter's coefficients are the greater, the difference increasing with the increased diameter of pipes. For diameters greater than 10 feet D'Arcy's coefficient is almost constant. It increases very little more than 113.5 even for a diameter of 16 feet or more, but Kutter's coefficient continues to increase until such a diameter is reached as is never likely to be required in practice.

Now, the experiments on which D'Arcy's formula is based were made on clean pipes, of the diameters usually adopted in practice, flowing under pressure and under conditions somewhat similar to pipes in actual use, and therefore, as the experiments were conducted with great accuracy, the results are entitled to the confidence of engineers. D'Arcy's experiments did not, however, include pipes of a very large hydraulic mean radius. In one respect he differs from most of the modern authorities, inasmuch as the slope has no effect on the value of the coefficient of his formula.

Mr. J. W. Adams, C. E., in *Engineering News* of March 10th, 1883, writes:

"When the Loch Katrine Water Works for Glasgow were being extended some years since, a portion of the distance was carried over low grounds by a cast-iron trough 6½ feet deep, and 8 feet in width, supported on masonry piers, and giving good opportunity to determine the daily flow. By this and other means, it was found that the cast-iron pipes, 4 feet in diameter, which with a fall of 1 in 1056 on the rest of the line, had been computed to carry 21,000,000 gallons, were really discharging daily 23,430,000 gallons. The engineer, Mr. Gale, brought the matter to Professor Rankine's attention; who, in a paper and subsequent discussion before the Institution of Engineers of Scotland, March 17th, 1869, uses this language: 'It might be interesting to the Institution to know that there was a formula which agreed exactly with the results of Mr. Gale's experiments. Suppose that before these four-feet pipes were laid, the probable discharge had been calculated by D'Arcy's formula, the result would have differed *by one part in a thousand*, from the actual discharge, which was 23,430,000 gallons daily. This went to show that they now possessed a general formula for the flow of water in pipes, and the resistance to that flow which applied to large as well as to small pipes, it applied to pipes of an inch in diameter, and from Mr. Gale's experiments they would see that it also applied to pipes four *feet* in diameter.' The Glasgow pipes had been coated with Dr. Smith's process, and were treated as clean pipes and calculated by the formula (for clean pipes). I think that D'Arcy's experiments, conducted as they were under circumstances which contributed in every way to inspire confidence. Mr. Francis' labors in presenting this formula to us in an English dress, with the prestige growing out of his well-known capacity for careful investigation and computation, and Professor Rankine's indorsement of its applicability to all conditions of pipe discharge up to four feet diameter, must be considered as establishing the practical value of *this* special formula for the flow through *iron pipes*."

Further on it will be shown, when explaining the use of the tables, that the velocity in the Loch Katrine pipes, found readily by the use of the tables, agrees exactly with the actual velocity, and also with the velocity by D'Arcy's formula.

M. W. Humber, C. E., in his work on "Water Supply," states:

"That which is known as D'Arcy's formula, in pipes of large diameter appears to approach in its results nearer to the actual discharge than any other, and it was the opinion of Professor Rankine, that the resistance decreases to a greater extent in pipes of larger diameter than has been previously supposed. The experiments were made with, and the formula of D'Arcy deduced from, pipes which had been long in use without offering any impediments from incrustation."

Kutter's formula is derived not only from experiments made on channels with small hydraulic radius, but also on channels with large hydraulic radius, and his coefficients for very large pipes are therefore more likely to agree with the actual discharge than D'Arcy's constant coefficient of 113.5 for very large pipes. But, again, Kutter's formula is open to the objection that it is based on experiments made on open channels. I may here remark, although it is only remotely connected with pipe discharge, that Major Allan Cunningham states, as the result of his extensive experiments for four years on the Ganges Canal, that Kutter's formula alone, of all those tried by him, was found generally applicable to all conditions of discharge, and that it gave nearer results to the actual velocity than any of the other formulæ tried by him. It gave results with a difference from the actual velocity seldom exceeding 7½ per cent., and usually much less than that. When we contrast the wide divergence of the old formulæ under varying flow from the actual velocity, with the results obtained by Kutter's formula, it will be seen that the latter is the most accurate formula for channels with large hydraulic mean radius.

In Tables 2, 3, and 4, the values of the factors of Kutter's formula are not given for diameters less than 5 inches. Mr. L. D'A. Jackson, C. E., in his *Hydraulic Manual*, states:

"For the present, and until further experiments have thrown more light on the subject, it may be assumed that the coefficient of discharge for all full cylindrical pipes, having a diameter less than 0.4 feet, will be the same as those of that diameter."

Although Mr. Jackson's opinion is entitled to great weight, still the facts all tend to prove that the coefficients of diameters below 5 inches should diminish with the diminution of diameter. The smaller the diameter the more effect will the roughness of the surface have in diminishing the discharge. Table 9 shows that Kutter's coefficient for 5 inches diameter with $n = .011$ is 82.9, and therefore, according to Mr. Jackson, all the diameters from 5 inches to $\frac{3}{8}$ inch should have a coefficient of 82.9. This is contrary to the principle of Kutter's formula, the accuracy of which is due to the fact that, other things being equal, its coefficients vary with the diameter. The following proofs are given in support of the opinion that coefficients of diameters below 5 inches should diminish according to the diminution of diameter.

1. In Table 9 the coefficients of D'Arcy's formula are seen to diminish with the diminution of diameter. At 5 inches diameter the coefficient is 103.8, and at $\frac{3}{8}$ inch diameter 59.4.

2. In Table 9 the coefficients of Fanning's formula diminish from 4 inches diameter with a coefficient of 103.4 to

one inch diameter with a coefficient of 80.4.

These coefficients are derived from the mean velocities in clean pipes with a slope of 1 in 125 given in Fanning's tables.

3. In Table 9 the coefficients, as found by Kutter's formula with a slope of 1 in 1,000, and $n=.011$, are for 5 inches diameter, 82.9, and for ⅜ inch diameter, 32.0.

The facts, therefore, show that the coefficients diminish from a diameter of 5 inches to smaller diameters, and it is a safer plan to adopt coefficients varying with the diameter than a constant coefficient. No opinion is advanced as to what coefficients should be used with Kutter's formula for small diameters. The facts are simply stated, giving the results of well-known authors.

As the coefficients of D'Arcy's formula vary only with the diameter, the values of the factors $c\sqrt{r}$ and $ac\sqrt{r}$, given in Table 1 for D'Arcy's formula are practically the exact values for all diameters and slopes given, and the results found by the use of the tables will be the same as the results found by using the formula.

In Tables 2, 3, and 4, the values of $c\sqrt{r}$ and $ac\sqrt{r}$ for Kutter's formula sometimes differ by a small quantity from the actual values as found by the use of formula (6). These values by Kutter's formula depend not only on r, but also on n and s, so that a change in any of these three quantities causes a change in the values of $c\sqrt{r}$ and $ac\sqrt{r}$. It is found, however, that the slope of 1 in 1,000 will give coefficients which practically differ very little from the coefficients derived from the slopes usually given to lines of pipe.

The values of the coefficients from Kutter's formula given in the tables have been computed for a slope of 1 in 1,000, and they give values of $c\sqrt{r}$ and $ac\sqrt{r}$ near enough for practical work.

I will here give another instance of the correctness of the tables. In a late report on the Sewerage of Washington, D. C., by Captain F. V. Greene, U. S. Engineers, a table is given of the discharge of several egg-shaped and also two circular sewers of brickwork computed by Kutter's formula (6) with n=.013.

The small table, now given, shows the discharge of the circular sewers as taken from Captain Greene's report, and also the discharge as computed by the tables in this work.

	Discharge in cubic feet per second.	
	By Capt. Greene's Report.	By the Tables in this Work.
10 feet diameter, slope 1 in 100	1673.66	1670.90
10 feet diameter, slope 1 in 200	1183.28	1181.49
10 feet diameter, slope 1 in 300	965.70	964.69
20 feet diameter, slope 1 in 100	10240.64	10255.90
20 feet diameter, slope 1 in 200	7240.13	7251.95
20 feet diameter, slope 1 in 300	5908.85	5921.24

The difference in discharge is so very small that the results as given by the rapid method of the tables may, for all practical purposes, be taken as identical to those given by the use of the troublesome and tedious formula (6).

Should the engineer, however, prefer to use formula (6), even then the tables will give a ready means of checking the computations.

EXPLANATION AND USE OF THE TABLES.

The velocity mentioned below means velocity in feet per second. The discharge mentioned below means the discharge in cubic feet per second.

Example 1. What is the velocity and discharge by Kutter's formula of an iron pipe of 2 feet diameter, and with a fall of 9 feet per mile, the value of n being assumed equal to .013.

By formula (8) $V=c\sqrt{r}\times\sqrt{s}$

and by formula (12) $Q=ac\sqrt{r}\times\sqrt{s}$

In Table 7 look out the value of $\sqrt{s}$ corresponding to a fall of 9 feet per mile, and it is found $=.041286$. Look out also in Table 4 the value of $c\sqrt{r}$ and $ac\sqrt{r}$ opposite a diameter of 2 feet, and they will be found to be respectively equal to 71.49 and 224.63—substituting the values so found in equations (8) and (12), and we have

$V = 71.49 \times .041286 = 2.95$ feet per second velocity.

$Q = 224.63 \times .041286 = 9.27$ c. feet per second discharge.

If the velocity and discharge are found by Kutter's formula (6) it will be seen that a very great saving of work is effected by the use of the tables.

Example 2. An open channel constructed of brick masonry, rectangular in cross section, four feet wide on bottom and with vertical sides, carries two feet in depth of water and has a slope of 1 in 160. What is its velocity and discharge by Bazin's formula for open channels? As the channel is of brickwork it comes under the head of the second type of Bazin's formula for open channels by which Table 5 is constructed. The hydraulic mean depth $r = \frac{\text{area}}{\text{wetted perimeter}} = {}^8/_8 = 1$. In Table 5 we find that when $r = 1$ the value of $c\sqrt{r} = 118.5$. We also find in Table 7 that the $\sqrt{s}$ corresponding to a slope of 1 in $160 = .079057$, substitute these values in formula (8) and $V=118.5\times.079057=9.37$ feet per second and $Q=aV=8\times9.37=74.96$ cubic feet per second.

Example 3. An iron pipe one foot six inches in diameter, whose natural coefficient of roughness is assumed =.011, is to have a velocity not to exceed 3 feet per second. What should its slope be by the use of Kutter's formula?

By formula (10)

$$\sqrt{s}=\frac{V}{c\sqrt{r}}$$

Find by inspection in Table 2 the value of $c\sqrt{r}$ opposite 1 foot 6 inches. It is equal to 7.108. Substitute this value and also the given velocity in equation (11) and we have

$$\sqrt{s}=\frac{3}{71.08}=.042206$$

Look out the nearest value of $\sqrt{s}$ to this in Table 7, and it will be found to be .043519 opposite a slope of 10 feet per mile, which is the slope required.

Example 4. A 3 feet 6 inch old iron pipe whose natural coefficient is assumed

=.013 is to be replaced by a new pipe capable of discharging double that of the old pipe, the slope remaining unchanged. What is the diameter by Kutter's formula of the new pipe, its natural coefficient being assumed = .011.

Find by inspection in Table 4 the value of $ac\sqrt{r}$ opposite 3 feet 6 inches diameter. It is found equal to 1021.1. Then 1021.1 $\times 2 = 2042.2$. As the value of n for the new pipe = .011, look out in Table 2 the value of $ac\sqrt{r}$ nearest to 2042.2, and it is found to be 2072.7 opposite a diameter of 4 feet 3 inches, which is the diameter required.

Look up the values of $c\sqrt{r}$ for each pipe, and it will be seen that the velocity in the new pipe is to that in the old as 146:106.

Example. 5. Find by Kutter's formula the slope of a flume, constructed of unplaned planks, 5 feet wide on bottom and with vertical sides 2½ feet high, in order that it may discharge 102 cubic feet per second.

Table 3 with $n = .012$ is applicable to this channel.

$$r = \frac{\text{area}}{\text{wetted perimeter}} = \frac{12.5}{10} = 1.25$$

In Table 3 when $r = 1.25$, the corresponding value of $c\sqrt{r} = 147.9$

$$V = \frac{Q}{a} = \frac{102}{12.5} = 8.16 \text{ feet per second.}$$

substitute these values of $c\sqrt{r}$ and V in formula (10), and we have:

$$\sqrt{s} = \frac{8.16}{147.9} = .055172.$$

Now look out in Table 7 the nearest value of $\sqrt{s}$ to this, and we find it to be opposite a slope of 1 in 330, which is the slope required.

Example 6. This example is taken from Weisbach's *Mechanics of Engineering.*

A system of pipes consisting of one main and two branches is required to discharge by one branch 15, and by another 24 cubic feet of water per minute. The levels show the main pipe to have a fall of 4 feet in 1,000, the first branch 3 feet in 600, and the other branch 1 foot in 200. What diameter should the pipes have?

For the solution of this example table 1, derived from D'Arcy's formula, will be used.

The main is to discharge 39 cubic feet per minute, equal to 0.65 cubic feet per second with a slope of 1 in 250. One branch 15 cubic feet per minute, equal to 0.25 cubic feet per second, with a fall of 1 in 200, and the other branch, 24 cubic feet per minute $=$ 0.4 cubic feet per second, with a fall of 1 in 200.

By inspection find in Table 7 the value of $\sqrt{s}$ nearest to 1 in 250 (21 feet per mile) and it is found to be $=.063066$, and also find the value of $\sqrt{s}$ nearest to 1 in 200 (26 feet per mile). It is found $=.070173$. By formula (14).

$$ac\sqrt{r} = \frac{Q}{\sqrt{s}}$$

$$\therefore \text{ for main pipe } ac\sqrt{r} = \frac{0.65}{.063066} = 10.307$$

the nearest value of $ac\sqrt{r}$ to this in Table

1 is 10.852, opposite which is the diameter, 7 inches.

In the same manner for the first branch,

$$ac\sqrt{r} = \frac{0.25}{.070173} = 3.562$$

and the nearest value of $ac\sqrt{r}$ to this, in Table 1, is 4.561, corresponding to a diameter of 5 inches.

For the second branch,

$$ac\sqrt{r} = \frac{0.4}{.070173} = 5.7$$

and the nearest value of $ac\sqrt{r}$ to this, in Table 1, is 7.3 opposite a diameter of 6 inches. The required diameters are therefore: for the main pipe 7 inches, for the first branch 5 inches, and for the second branch 6 inches.

Although the explanation of this example, in the use of the tables may appear somewhat long, still the actual work can be done very rapidly and with little trouble. If a comparison is made of the work required for the solution of this example, as given above by the tables, with the work required for its solution by the method of approximation as given in Weisbach's *Mechanics of Engineering*, from which the example is extracted, it will be seen that there is a great saving of labor effected by the use of the tables.

Example 7. Humber, in his work on *Water Supply*, states:

"With a 48-inch cast-iron pipe in the Loch Katrine Water Works, having an inclination of 1 in 1056, or 5 feet per mile, the actual velocity was found to be 3.46 feet per second, and D'Arcy's formula gives practically the same results."

Let us now find the velocity in this pipe by the tables. A 48-inch pipe has a hydraulic mean depth r of one foot.

In Table 1, computed from D'Arcy's formula for clean pipes, we find the value of $r = 1$, and in the same line we find the value of $c\sqrt{r} = 112.6$.

We also find in Table 7 that $\sqrt{s}$ for a slope of 1 in 1056 = .030773. Subtsitute these values in the formula (8).

$V = c\sqrt{r} \times \sqrt{s}$, and we have
$V = 112.6 \times 030773 = 3.46$ feet per second, being exactly the same as the actual velocity, and also the same as the velocity found by the use of D'Arcy's formula.

Example 8. Near the head of a small irrigation canal the supply of water is carried in a rock cutting 10 feet wide at bottom; 12 feet wide at surface of water; 5 feet in depth and having a slope of 1 in 880.

The water supply carried in this cutting being insufficient it is determined to increase the supply, without, however, increasing t..e cross-sectional area of channel or its slope. The bottom and sides of the rock cutting are very rough, and in order to give them a smoother surface and increase the discharge, it is determined to fill up all the hollows in them with masonry, and after this to lay on carefully a coat of cement plaster with one-third sand, and to make the surfaces in contact with the water smooth and even.

After the plastering is finished the dimensions of the channel will be: width at bottom 9.8 feet: width at water surface 11.8 feet: depth of water 4.9 feet and the slope as before, 1 in 880.

It is assumed that a near approximation to the value of n for the rock cutting $=.0225$ and for the plastered channel $n=.011$.

Find the increase in discharge in the plastered channel over that in the original channel.

In the original channel

$$r=\frac{\text{area}}{\text{wetted perimeter}}=\frac{55}{20.2}=2.7228$$

For a slope of 1 in 880, Table 7 gives S=.001136 N=.0225.

Substitute these values of r, s and n in formula (6) and we have:

$$V=\frac{41.6+\frac{1.811}{.0225}+\frac{.00281}{.001136}}{1+\left(41.6\frac{.00281}{.001136}\right)\frac{.0225}{\sqrt{2.7228}}}\times\sqrt{2.7228\times.001136}$$

$\therefore$ V=4.327 feet per second.

Now $Q=Va=4.327\times55=238$ cubic feet per second.

In the *plastered channel:*

$$r = \frac{\text{area}}{\text{wetted perimeter}} = \frac{52.92}{19.8} = 2.673.$$

In Table 2 with $n = .011$ there is no value of r equal to 2.673, but the value of r immediately more than it, 2.687 has a value of $c\sqrt{r} = 264.0$, and the value of r less than it, 2.625 has $c\sqrt{r} = 260.2$. From these when $r = 2.673$ the value of $c\sqrt{r} = 263.15$.

In Table 7 for a slope of 1 in 880 the value of $\sqrt{s} = .03371$.

Substitute these values of r and s in formula (8), and

$$V = c\sqrt{r} \times \sqrt{s}, \text{ and}$$

$V = 263.15 \times .03371 = 8.87$ feet per second, and

$Q = Va = 8.87 \times 52.92 = 469.4$ cubic feet per second.

We here see the effect of a smooth surface in increasing the velocity and discharge of a channel. Although the cross-sectional area has been *diminished,* still the effect of giving a smooth surface to the channel has been to *more than* *double its velocity* and to *almost double the discharge.* The old formula would give almost the same velocity and discharge to the two channels, as these formulæ do not take the surfaces exposed to the flow of water into account.

Example 9. A canal with an earthen bed in moderately good order is to have a bottom width of 52 feet; depth of water 6 feet; side slopes $1\frac{1}{2}$ to 1, and a slope of one foot per mile. What is its velocity and discharge by Kutter's formula?

The value of n for this channel may be assumed as equal to 0.3 The value of s for a fall of one foot per mile will be found in Table 7 =.00018939.

$$r=\frac{\text{area}}{\text{wetted perimeter}}=\frac{366}{73.64}=4.97$$

Substitute the above values of n, r and s in formula (6) and

$$V=\frac{41.6+\frac{1.811}{.03}+\frac{.00281}{.00018939}}{1+\left(41.6+\frac{.00281}{.00018939}\right)\frac{.03}{\sqrt{4.97}}}\times\sqrt{\times 4.97_{.000318939}}$$

∴ V=2.037 feet per second, and

$Q = Va = 2.037 \times 366 = 745$ cubic feet per second.

Therefore the velocity=2 feet per second and the discharge 745 cubic feet per second.

No. 67 of "Van Nostrand's Science Series," by the author, and entitled, "Hydraulic Tables, based on Kutter's formula," contains an extensive table of slopes and $\sqrt{s}$ from 1 in 4 to 1 in 1,000, and also tables of factors for circular and egg-shaped brick sewers with $n = .015$.

TABLE 1.—Circular Pipes, Sewers, Conduits, etc., flowing under pressure.

D'Arcy's formula for clean pipes.

Table giving the values of a and r, and also the values of the factors $c\sqrt{r}$ and $ac\sqrt{r}$ for use in the formulæ.

$V=c\sqrt{r} \times \sqrt{s}$ $Q=ac\sqrt{r} \times \sqrt{s}$

These factors are to be used only for clean pipes under pressure.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
0	⅜	.00077	.0078	5.251	.00403
0	½	.00136	.0104	6.702	.00914
0	¾	.00307	.0156	9.309	.02855
0	1	.00545	.0208	11.61	.06334
0	1¼	.00852	.0260	13.68	.11659
0	1½	.01227	.0312	15.58	.19115
0	1¾	.01670	.0364	17.32	.28936
0	2	.02182	.0417	18.96	.41357
0	2½	0.0341	0.052	21.94	.74786
0	3	0.0491	0.063	24.63	1.2089
0	4	0.0873	0.084	29.37	2.5630
0	5	0.136	0.104	33.54	4.5610
0	6	0.196	0.125	37.28	7.3068

TABLE 1.—D'Arcy's formula for clean pipes.

d=diameter in f.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
0	7	0.267	0.146	40.65	10.852
0	8	0.349	0.167	43.75	15.270
0	9	0.442	0.187	46.73	20.652
0	10	0.545	0.208	49.45	26.952
0	11	0.660	0.229	52.16	34.428
1	0	0.785	0.250	54.65	42.918
1	1	0.922	0.271	57.00	52.551
1	2	1.069	0.292	59.34	63.435
1	3	1.227	0.313	61.56	75.537
1	4	1.396	0.333	63.67	88.886
1	5	1.576	0.354	65.77	103.66
1	6	1.767	0.375	67.75	119.72
1	7	1.969	0.396	69.74	137.31
1	8	2.182	0.417	71.71	156.46
1	9	2.405	0.437	73.46	176.66
1	10	2.640	0.458	75.32	198.83
1	11	2.885	0.479	77.05	222.30
2	0	3.142	0.500	78.80	247.57
2	1	3.409	0.521	80.53	274.53
2	2	3.687	0.542	82.15	302.90
2	3	3.976	0.562	83.77	333.07
2	4	4.276	0.583	85.39	365.14
2	5	4.587	0.604	86.89	398.57
2	6	4.909	0.625	88.39	433.92
2	7	5.241	0.646	90.01	471.73
2	8	5.585	0.667	91.51	511.10
2	9	5.939	0.687	92.90	551.72

TABLE 1.—D'Arcy's formula for clean pipes.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
2	10	6.305	0.708	94.40	595.17
2	11	6.681	0.729	95.78	639.88
3	0	7.068	0.750	97.17	686.76
3	1	7.466	0.771	98.55	735.75
3	2	7.875	0.792	99.93	786.94
3	3	8.295	0.812	101.2	839.38
3	4	8.726	0.833	102.6	895.07
3	5	9.169	0.854	103.8	952.10
3	6	9.621	0.875	105.1	1011.2
3	7	10.084	0.896	106.4	1072.6
3	8	10.559	0.917	107.6	1136.5
3	9	11.044	0.937	108.9	1202.7
3	10	11.541	0.958	110.2	1271.4
3	11	12.048	0.979	111.4	1342.4
4	0	12.566	1.000	112.6	1414.7
4	1	13.096	1.021	113.7	1489.4
4	2	13.635	1.042	115.0	1567.8
4	3	14.186	1.062	116.1	1647.6
4	4	14.748	1.083	117.3	1729.8
4	5	15.321	1.104	118.4	1814.6
4	6	15.904	1.125	119.6	1901.9
4	7	16.499	1.146	120.6	1990.1
4	8	17.104	1.167	121.8	2082.6
4	9	17.721	1.187	122.8	2176.1
4	10	18.348	1.208	124.0	2274.1
4	11	18.986	1.229	125.1	2374.8
5	0	19.635	1.250	126.1	2476.4

TABLE 1.—D'Arcy's formula for clean pipes.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
5	1	20.295	1.271	127.2	2580.5
5	2	20.966	1.292	128.3	2689.9
5	3	21.648	1.312	129.3	2799.7
5	4	22.340	1.333	130.4	2912.4
5	5	23.044	1.354	131.4	3027.8
5	6	23.758	1.375	132.4	3146.3
5	7	24.484	1.396	133.4	3264.9
5	8	25.220	1.417	134.4	3388.9
5	9	25 967	1.437	135.4	3516.0
5	10	26.725	1.558	136.4	3646.1
5	11	27.494	1.479	137.4	3776.2
6	0	28.274	1.500	138.4	3912.8
6	3	30.680	1.562	141.3	4333.6
6	6	33.183	1.625	144.1	4782.1
6	9	35.785	1.687	146.9	5255.1
7	0	38.485	1.750	149.6	5757.5
7	3	41.283	1.812	152.2	6284.6
7	6	44.179	1.879	154.9	6841.6
7	9	47.173	1.937	157.5	7429.3
8	0	50.266	2.000	160.0	8043.0
8	3	53.456	2.062	162.5	8688.0
8	6	56.745	2.125	165.0	9364.7
8	9	60.132	2.187	167.4	10068.
9	0	63.617	2.250	169.8	10804.
9	3	67.201	2.312	172.2	11575.
9	6	70.882	2.375	174.5	12370.
9	9	74.662	2.437	176.8	13200.

TABLE 1.—D'Arcy's formula for clean pipes.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
10	0	78.540	2.500	179.1	14066.
10	3	82.516	2.562	181.4	14967.
10	6	86.590	2.625	183.6	15893.
10	9	90.763	2.687	185.7	16856.
11	0	95.033	2.750	187.9	17855.
11	3	99.402	2.812	190.1	18892.
11	6	103.869	2.875	192.2	19966.
11	9	108.434	2.937	194.3	21065.
12	0	113.098	3.000	196.3	22204.
12	3	117.859	3.062	198.4	23379.
12	6	122.719	3.125	200.4	24598.
12	9	127.677	3.187	202.4	25840.
13	0	132.733	3.250	204.4	27134.
13	3	137.887	3.312	206.4	28456.
13	6	143.139	3.375	208.3	29818.
13	9	148.490	3.437	210.2	31219.
14	0	153.938	3.500	212.2	32664.
14	6	165.130	3.625	216.0	35660.
15	0	176.715	3.750	219.6	38807.
15	6	188.692	3.875	223.3	42125.
16	0	201.062	4.000	226.9	45621.
16	6	213.825	4.125	230.4	49273.
17	0	226.981	4.250	233.9	53082.
17	6	240.529	4.375	237.3	57074
18	0	254.470	4.500	240.7	61249.
19	0	283.529	4.750	247.4	70154.
20	0	314.159	5.000	253.8	79736.

TABLE 2.—Circular Pipes, Sewers, Conduits, etc., flowing full. Kutter's formula with $n=.011$.

Table giving the values of a and r and also the values of the factors $c\sqrt{r}$ and $ac\sqrt{r}$ for use in the formulæ,

$$V=c\sqrt{r} \times \sqrt{s} \qquad Q=ac\sqrt{r}\times \sqrt{s}$$

These factors are to be used only where the value of n, that is the coefficient of roughness of lining of channel, $=.011$, as for surfaces carefully plastered with cement with one-third sand in good condition, also for iron, cement and terra-cotta pipes, well jointed and in best order, and also surfaces of other material equally rough.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
0	5	0.136	0.104	26.76	3.6398
0	6	0.196	0.125	30.93	6.0627
0	7	0.267	0.146	34.94	9.3294
0	8	0.349	0.167	38.77	13.531
0	9	0.442	0.187	42.40	18.742

TABLE 2.—Kutter's formula with $n=.011$.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
0	10	0.545	0.208	45.83	24.976
0	11	0.660	0.229	49.46	32.644
1	0	0.785	0.250	52 85	41.487
1	1	0.922	0.271	55.95	51.588
1	2	1.069	0.292	59.13	63.210
1	3	1.227	0.312	62.22	76.347
1	4	1.396	0.333	65.21	91.037
1	5	1.576	0.354	68.26	107.58
1	6	1.767	0.375	71.08	125.60
1	7	1.969	0.396	73.90	145.51
1	8	2.182	0.417	76.73	167.50
1	9	2.405	0.437	79.33	190.79
1	10	2.640	0.458	82.11	216.76
1	11	2.885	0.479	84.75	244.50
2	0	3.142	0.500	87.36	274.50
2	1	3.409	0.521	89.94	306.60
2	2	3.687	0.542	92.38	340.59
2	3	3.976	0.562	94.84	377.07
2	4	4.276	0.583	97.33	416.16
2	5	4.587	0.604	99.66	457.13
2	6	4.909	0.625	102.0	500.78
2	7	5.241	0.646	104.5	547.92
2	8	5.585	0.667	106.8	596.70
2	9	5.939	0.687	109.0	647.18
2	10	6.305	0 708	111.3	701.77
2	11	6.681	0.729	113.5	758.16
3	0	7.068	0.750	115.7	817.50

TABLE 2.—Kutter's formula with n=.011.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
3	1	7.466	0.771	117.9	880.03
3	2	7.875	0.792	120.1	945.69
3	3	8.295	0.812	122.1	1013.1
3	4	8.723	0.833	124.3	1084.6
3	5	9.169	0.854	126.3	1158.0
3	6	9.621	0.875	128.3	1234.4
3	7	10.084	0.896	130.3	1314.1
3	8	10.559	0.917	132.3	1397.4
3	9	11.044	0.937	134.4	1484.2
3	10	11.541	0.958	136.4	1574.7
3	11	12.048	0.979	138.3	1666.5
4	0	12.566	1.000	140.4	1764.3
4	1	13.096	1.021	142.2	1862.7
4	2	13.635	1.042	144.3	1967.1
4	3	14.186	1.062	146.1	2072.7
4	4	14.748	1.083	148.0	2182.5
4	5	15.321	1.104	149.9	2296.0
4	6	15.904	1.125	151.7	2413.3
4	7	16.499	1.146	153.4	2531.7
4	8	17.104	1.167	155.3	2657.1
4	9	17.721	1.187	157.1	2783.4
4	10	18.348	1.208	159.0	2917.0
4	11	18.986	1.229	160.9	3054.1
5	0	19.635	1.250	162.6	3191.8
5	1	20.295	1.271	164.5	3337.5
5	2	20.966	1.292	166.0	3480.8
5	3	21.648	1.312	167.9	3634.2

TABLE 2.—Kutter's formula with n=.011.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
5	4	22.340	1.333	169.6	3789.0
5	5	23.044	1.354	171.3	3944.4
5	6	23.758	1.375	173.1	4111.9
5	7	24.484	1.396	174.6	4275.4
5	8	25.220	1.417	176.4	4448.0
5	9	25.967	1.437	178.1	4625.2
5	10	26.725	1.458	179.8	4806.1
5	11	27.494	1.479	181.4	4986.1
6	0	28.274	1.500	183.1	5176.3
6	3	30.680	1.562	187.9	5764.0
6	6	33.183	1.625	192.7	6394.9
6	9	35.785	1.687	197.2	7057.1
7	0	38.485	1.750	202.0	7774.3
7	3	41.283	1.812	206.5	8522.9
7	6	44.179	1.875	210.9	9318.3
7	9	47.173	1.937	215.4	10162.
8	0	50.266	2.000	219.7	11044.
8	3	53.456	2.062	224.0	11978.
8	6	56.745	2.125	228.3	12954.
8	9	60.132	2.187	232.4	13974.
9	0	63.617	2.250	236.6	15049.
9	3	67.201	2.312	240.7	16173.
9	6	70.882	2.375	244.6	17338.
9	9	74.662	2.437	248.6	18558.
10	0	78 540	2.500	252.5	19834.
10	3	82.516	2.562	256.5	21166.
10	6	86.590	2.625	260.2	22534.

TABLE 2.—Kutter's formula with n=.011.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
10	9	90.763	2.687	264.0	23951.
11	0	95.033	2.750	267.7	25444.
11	3	99.402	2.812	271.5	26987.
11	6	103.869	2.875	275.3	28593.
11	9	108.434	3.937	278.8	30235.
12	0	113.098	3.000	282.4	31937.
12	3	117.359	3.062	286.0	33702.
12	6	122.719	2.125	289.5	35529.
12	9	127.677	3.187	292.9	37399.
13	0	132.733	3.250	296.5	39358.
13	3	137.887	3.312	299.9	41352.
13	6	143.139	3.375	303.3	43412.
13	9	148.490	3.437	306.7	45543.
14	0	153.938	3.500	310 1	47739.
14	6	165.130	3.625	316.8	52308.
15	0	176.715	3.750	323.1	57103.
15	6	188.692	3.875	329.6	62186.
16	0	201.062	4.000	336.0	67557.
16	6	213.825	4.125	342.2	73176.
17	0	226.981	4.250	348.3	79050.
17	6	240.529	4.375	354.3	85229.
18	0	254.470	4.500	360.4	91711.
19	0	283.529	4.750	372.3	105570.
20	0	314.159	5.000	383.8	120570.

TABLE 3.—Circular Pipes, Sewers, Conduits, etc., flowing full. Kutter's formula with $n = .012$.

Table giving the values of a and r and also the values of the factors $c\sqrt{r}$ and $ac\sqrt{r}$ for use in the formulæ.

$$V = c\sqrt{r} \times \sqrt{s} \qquad Q = ac\sqrt{r} \times \sqrt{s}$$

These factors are to be used only where the value of n, that is the coefficient of roughness of lining of channel, $=.012$, as for unplaned timber when perfectly continuous on the inside and also flumes.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
0	5	0.136	0.104	23.70	3.2234
0	6	0.196	0.125	27.45	5 3800
0	7	0.267	0.146	31.05	8.2911
0	8	0 349	0.167	34.51	12.042
0	9	0.442	0.187	37.80	16 708
0	10	0.545	0.208	40.95	22.317
0	11	0.666	0.229	44.22	29.183
1	0	0.785	0.250	47.30	37.149

TABLE 3.—Kutter's formula with n=.012.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$	For discharge $ac\sqrt{r}$.
1	1	0.922	0.271	50.11	46.199
1	2	1.069	0.292	52.99	56.641
1	3	1.227	0.312	55.78	68.445
1	4	1.396	0.333	58.50	81.661
1	5	1.576	0.354	61.26	96.548
1	6	1.767	0.375	63.83	112.79
1	7	1.969	0.397	66.41	130.76
1	8	2.182	0.417	69.03	150.61
1	9	2.405	0.437	71.38	171.66
1	10	2.640	0.458	73.92	195.14
1	11	2.885	0.479	76.33	220.21
2	0	3.142	0.500	78.72	247.33
2	1	3.409	0.521	81.07	276.38
2	2	3.687	0.542	83.29	307.10
2	3	3.976	0.562	85.54	340.10
2	4	4.276	0.583	87.81	375.46
2	5	4.587	0.604	89.94	412.54
2	6	4.909	0.625	92.09	452.07
2	7	5.241	0.646	94.41	494.78
2	8	5.585	0.667	96.52	539.07
2	9	5.939	0.687	98.49	584.90
2	10	6.305	0.708	100.6	634.46
2	11	6.681	0.729	102.6	685.64
3	0	7.068	0.750	104.6	739.59
3	1	7.466	0.771	106.7	796.38
3	2	7.875	0.792	108.7	856.12
3	3	8.295	0.812	110.6	917.41

TABLE 3.—Kutter's formula with n=.012.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
3	4	8.726	0.833	112.6	982.39
3	5	9.169	0.854	114.4	1049.1
3	6	9.621	0.875	116.3	1118.6
3	7	10.084	0.896	118.1	1191.1
3	8	10.559	0.917	120.0	1267.0
3	9	11.044	0.937	121.9	1345.9
3	10	11.541	0.958	123.8	1428.3
3	11	12.048	0.979	125.7	1514.0
4	0	12.566	1.000	127.4	1600.9
4	1	13.096	1.021	129.1	1690.7
4	2	13.635	1.042	131.0	1785.8
4	3	14.186	1.062	132.7	1882.3
4	4	14.748	1.083	134.4	1982.3
4	5	15.321	1.104	136.2	2085.9
4	6	15.904	1.125	137.9	2193.0
4	7	16.499	1.146	139.5	2301.0
4	8	17.104	1.167	141.2	2415.4
4	9	17.721	1.187	142.8	2530.8
4	10	18.348	1.208	144.6	2652.8
4	11	18.986	1.229	146.3	2777.8
5	0	19.635	1.250	147.9	2903.6
5	1	20.295	1.271	149.4	3032.9
5	2	20.966	1.292	151.2	3169.8
5	3	21.648	1.313	152.8	3307.0
5	4	22.340	1.333	154.4	3448.3
5	5	23.044	1.354	155.9	3593.5
5	6	23.758	1.375	157.5	3742.7

TABLE 3.—Kutter's formula with $n=.012$.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
5	7	24.484	1.396	159.0	3892.0
5	8	25.220	1 417	160.6	4049.5
5	9	25.967	1.437	162.2	4211.2
5	10	26.729	1.458	163.8	4376.4
5	11	27.494	1.479	165.1	4540.5
6	0	28.274	1.500	166.7	4713.9
6	3	30.680	1.562	171.1	5250.1
6	6	33.183	1.625	175.6	5825.9
6	9	35.785	1.687	179.9	6436.7
7	0	38.485	1.750	184.2	7087.0
7	3	41.283	1.812	188.3	7772.7
7	6	44.179	1.879	192.4	8501.8
7	9	47.173	1.937	196.6	9275.8
8	0	50.266	2.000	200.6	10083.
8	3	53.456	2.062	204.5	10934.
8	6	56.745	2.125	208.5	11832.
8	9	60.132	2.187	212.3	12766.
9	0	63.617	2.250	216.2	13751.
9	3	67.201	2.312	219.9	14780.
9	6	70.882	2.375	223.6	158[illegible]7.
9	9	74.662	2.437	227.2	16965.
10	0	78.540	2.500	230.9	18134.
10	3	82.516	2.562	234.6	19356.
10	6	86.590	2.625	238.0	20612.
10	9	90.763	2.687	241.5	21921.
11	0	95.033	2.750	245.0	23285.
11	3	99.402	2.812	248.5	24703.

TABLE 3.—Kutter's formula with n=.012.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
11	6	103.869	2.875	252.0	26179.
11	9	108.434	2.937	255.4	27689.
12	0	113.098	3.000	258.7	29254.
12	3	117.859	3.062	262.0	30876.
12	6	122.719	3.125	265.3	32558.
12	9	127.677	3.187	268.5	34277.
13	0	132.733	3.250	271.8	36077.
13	3	137.887	3.312	274.9	37909.
13	6	143.139	3.375	278.1	39802.
13	9	148.490	3.437	281.2	41755.
14	0	153.938	3.500	284.4	43773.
14	6	165.130	3.625	290.5	47969.
15	0	176.715	3.750	296.4	52382.
15	6	188.692	3.875	302.4	57061.
16	0	201.062	4.000	308.4	62008.
16	6	213.825	4.125	314.2	67183.
17	0	226.981	5.250	319.8	72594.
17	6	240.529	4.375	325.5	78289.
18	0	254.470	4.500	331.1	84247.
19	0	282.529	4.750	342.1	96991.
20	0	314.149	5.000	352.6	110905.

TABLE 4.—Circular Pipes, Sewers, Conduits, etc., flowing full. Kutter's formula with $n=.013$.

Table giving the values of a and r and also the values of factors $c\sqrt{r}$ and $ac\sqrt{r}$ for use in the formulæ,

$$V=c\sqrt{r} \times \sqrt{s} \qquad Q=ac\sqrt{r} \times \sqrt{s}$$

These factors are to be used only where the value of n, that is the coefficient of roughness of lining of channel, $=.013$, as in ashlar and well laid brickwork, ordinary metal, earthenware and stoneware pipe, in good condition, but not new, cement and terra-cotta pipe not well jointed nor in perfect order, plaster and planed wood in imperfeet or inferior condition, and also surfaces of other material equally rough.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
0	5	0.136	0 104	21.20	2.8839
0	6	0.196	0.125	24.60	4.8216
0	7	0.267	0.146	27.87	7.4425

TABLE 4.—Kutter's formula with $n=.013$.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
0	8	0.349	0.167	31.00	10.822
0	9	0.442	0.187	34.00	15.029
0	10	0.545	0.208	36.87	20.095
0	11	0.660	0.229	39.84	26.296
1	0	0.785	0.250	42.65	33.497
1	1	0.922	0.271	45.22	41.692
1	2	1.069	0.292	47.85	51.157
1	3	1.227	0.312	50.42	61.867
1	4	1.396	0.333	52.90	73.855
1	5	1.576	0.354	55.44	87.376
1	6	1.767	0.375	57.80	102.14
1	7	1.969	0.396	60.17	118.47
1	8	2.182	0.417	62.58	136.54
1	9	2.405	0.437	64.73	155.68
1	10	2.640	0.458	67.07	177.07
1	11	2.885	0.479	69.29	199.90
2	0	3.142	0.500	71.49	224.63
2	1	3.409	0.521	73.66	251.10
2	2	3.687	0.542	75.70	279.12
2	3	3.976	0.562	77.77	309.23
2	4	4.276	0.583	79.87	341.52
2	5	4.587	0.604	81.83	375.37
2	6	4.909	0.625	83.82	411.27
2	7	5.241	0.648	85.95	450.49
2	8	5.585	0.667	87.89	490.88
2	9	5.939	0.687	89.71	532.76
2	10	6.305	0.708	91.68	578.02

TABLE 4.—Kutter's formula with n=.013.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
2	11	6.681	0.729	93.52	624.82
3	0	7.068	0.750	95.37	674.09
3	1	7.466	0.771	97.25	726.05
3	2	7.875	0.792	99.13	780.63
3	3	8.295	0.812	100.9	836.69
3	4	8.726	0.833	102.8	896.27
3	5	9.169	0.854	104.4	957.35
3	6	9.621	0.875	106.1	1021.1
3	7	10.084	0.896	107.9	1087.7
3	8	10 559	0.917	109.6	1157.2
3	9	11.044	0.937	111.3	1229.7
3	10	11.541	0.958	113.1	1305.3
3	11	12.048	0.979	114.9	1384 1
4	0	12.566	1.000	116.5	1463.9
4	1	13.096	1.021	118.1	1546.9
4	2	13.635	1.042	119.8	1633.5
4	3	14.186	1.062	121.4	1722.0
4	4	14.748	1.083	123.0	1813.8
4	5	15 321	1.104	124.6	1908.0
4	6	15.904	1.125	126.2	2007.0
4	7	16.499	1.146	127.7	2206.1
4	8	17.104	1.167	129.3	2211.1
4	9	17.721	1.187	130.7	2316.9
4	10	18.348	1.208	132.4	2429.1
4	11	18 986	1.229	134.0	2543.9
5	0	19.635	1.250	135.4	2659.0
5	1	20.205	1.271	136.9	2778.7

TABLE 4.—Kutter's formula with n=.013.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
5	2	20.966	1.292	138.5	2903.5
5	3	21.648	1.312	139.9	3029.4
5	4	22.340	1.333	141.4	3159.0
5	5	23.044	1.354	142.9	3292.3
5	6	23.758	1.375	144.3	3429.2
5	7	24.484	1.396	145.6	3566.2
5	8	25.220	1.417	147.1	3710.9
5	9	25.967	1.437	148.6	3859.7
5	10	26.729	1.458	150.1	4012.2
5	11	27.494	1.479	151.4	4162.7
6	0	28.274	1.500	152.9	4322.9
6	3	30.680	1.562	157.0	4816.8
6	6	33.183	1.625	161.2	5339.7
6	9	35.785	1.687	165.2	5911.5
7	0	38.485	1.750	169.2	6510.6
7	3	41.283	1.812	173.0	7142.0
7	6	44.179	1.879	176.9	7814.2
7	9	47.173	1.937	180.8	8527.9
8	0	50.266	2.000	184.5	9272.6
8	3	53.456	2.062	188.2	10059.
8	6	56.745	2.125	191.9	10889.
8	9	60.132	2.187	195.4	11753.
9	0	63.617	2.250	199.1	12663.
9	3	67.201	2.312	202.6	13613.
9	6	70.882	2.375	205.9	14597.
9	9	74.662	2.437	209.3	15629.
10	0	78.540	2.500	212.8	16709.0

TABLE 4.—Kutter's formula with n=.013.

d=diameter in ft.	ins.	a=area in square feet.	r=hydraulic mean depth in feet.	For velocity $c\sqrt{r}$.	For discharge $ac\sqrt{r}$.
10	3	82.516	2.562	216.2	17837.
10	6	86.590	2.625	219.4	18996.
10	9	90.763	2.687	222.6	20205.
11	0	95.033	2.750	225.9	21464.
11	3	99.402	2.812	229.1	22774.
11	6	103.869	2.875	232.4	24139.
11	9	108.434	2.937	235.4	25533.
12	0	113.098	3.000	238.6	26981.
12	3	117.859	3.062	241.7	28484.
12	6	122.719	3.125	244.8	30041.
12	9	127.677	3.187	247.8	31633.
13	0	132.733	3.250	250.9	33301.
13	3	137.887	3.312	253.8	34998.
13	6	143.139	3.375	256.8	36752.
13	9	148.490	3.437	259.7	38561.
14	0	153.938	3.500	262.6	40432.
14	6	165.130	3.625	268.4	44322.
15	0	176.715	3.750	274.0	48413.
15	6	188.692	3.875	279.6	52753.
16	0	201.062	4.000	285.2	57343.
16	6	213.825	4.125	290.6	62132.
17	0	226.981	4.250	295.8	67140.
17	6	240.529	4.375	301.0	72409.
18	0	254.470	4.500	306.3	77932.
19	0	282.529	4.75.	316.6	89759.
20	0	314.159	5.000	326.5	102559.

TABLE 5.—Value of $c\sqrt{r}$ to be used *only* in the use of the second type of the use of Bazin's formula for *open channels* with an even lining of cut stone, brick-work, or other material with surfaces of equal roughness exposed to the flow of water. This formula is

$$V = c\sqrt{r} \times \sqrt{s}$$

where $$c = \sqrt{1 \div .000013\left(4.354 + \frac{1}{r}\right)}$$

Hydraulic mean depth in feet, r.	$c\sqrt{r}$	Hydraulic mean depth in feet, r.	$c\sqrt{r}$
0.104	23.710	0.312	55.783
0.125	27.617	0.333	58.346
0.146	31.284	0.354	60.898
0.167	34.569	0.375	63.336
0.187	38.147	0.396	65.756
0.208	41.327	0.417	68.159
0.229	44.484	0.437	70.337
0.250	47.430	0.458	72.615
0.271	50.267	0.479	74.764
0.292	53.077	0.500	76.907

TABLE 5.—Value of $c\sqrt{r}$ in Bazin's Formula, Second Category.

Hydraulic mean depth in feet, r.	$c\sqrt{r}$	Hydraulic mean depth in feet, r.	$c\sqrt{r}$
0.562	83.048	1.750	163.46
0.625	88.772	1.875	169.80
0.687	94.315	2.000	175.99
0.750	99.573	2.125	182.02
0.812	104.53	2.250	187.77
0.875	109.35	2.375	193.36
0.937	114.00	2.500	198.83
1.000	118.50	2.750	209.31
1.062	122.82	3.000	219.36
1.125	127.05	3.250	228.98
1.187	131.00	3.500	238.18
1.250	135.03	3.750	246.96
1.312	138.93	4.000	255.58
1.375	142.79	4.250	263.81
1.437	146.42	4.500	271.87
1.500	149.90	4.750	279.78
1.625	156.83	5.000	287.30

TABLE 6.—Values of $\sqrt{r}$ for diameters given in Tables.

Diameter. Ft.	Ins.	$\sqrt{r}$ in Feet.	Diameter. Ft.	Ins.	$\sqrt{r}$ in Feet.
0	5	0.323	2	9	0.829
0	6	0.354	2	10	0.842
0	7	0.382	2	11	0.854
0	8	0 408	3	0	0.866
0	9	0.433	3	1	0.878
0	10	0.456	3	2	0.890
0	11	0.479	3	3	0.901
1	0	0.500	3	4	0.913
1	1	0.520	3	5	0.924
1	2	0.540	3	6	0.935
1	6	0.559	3	7	0.946
1	4	0.577	3	8	0.957
1	5	0.595	3	9	0.968
1	6	0.612	3	10	0.979
1	7	0.629	3	11	0.990
1	8	0.646	4	0	1.000
1	9	0.661	4	1	1.010
1	10	0.677	4	2	1.021
1	11	0.692	4	3	1.031
2	0	0.707	4	4	1.041
2	1	0.722	4	5	1.051
2	2	0.736	4	6	1.061
2	3	0.750	4	7	1.070
2	4	0 764	4	8	1.080
2	5	0.777	4	9	1.089
2	6	0.790	4	10	1.099
2	7	0.804	4	11	1.109
2	8	0.817	5	0	1 118

Table 6.—Values of $\sqrt{r}$ for diameters given in Tables.

Diameter. Ft.	Ins.	$\sqrt{r}$ in Feet.	Diameter. Ft.	Ins.	$\sqrt{s}$ in Feet.
5	1	1.127	10	0	1.581
5	2	1.137	10	3	1.601
5	3	1.146	10	6	1.620
5	4	1.155	10	9	1.639
5	5	1.164	11	0	1.658
5	6	1 173	11	3	1.677
5	7	1.181	11	6	1.696
5	8	1.190	11	9	1.714
5	9	1.199	12	0	1.732
5	10	1.208	12	3	1.750
5	11	1.216	12	6	1.768
6	0	1.225	12	9	1.785
6	3	1.250	13	0	1.803
6	6	1.275	13	3	1.820
6	9	1.299	13	6	1.837
7	0	1.323	13	9	1.854
7	3	1.346	14	0	1.871
7	6	1.369	14	6	1 904
7	9	1.392	15	0	1.936
8	0	1.414	15	6	1.968
8	3	1.436	16	0	2 000
8	6	1.458	16	6	2.031
8	9	1.479	17	0	2.061
9	0	1.500	17	6	2.091
9	3	1.521	18	0	2.121
9	6	1.541	19	0	2.180
9	9	1.561	20	0	2.236

TABLE 7.—Giving fall in feet per mile; the distance corresponding to a fall of one foot, and also the values of s and $\sqrt{s}$.

$s = \frac{h}{l} =$ sine of slope = fall of water surface (h) in any distance (l) divided by that distance.

Fall in feet per mile.	Slope, one in	s.	$\sqrt{s}$.
1	5280.	.000189393	.013762
2	2640.	.000378787	.019463
3	1760.	.000568182	.023836
4	1320.	.000757576	.027524
5	1056.	.000946969	.030773
6	880.0	.001136364	.033710
7	754.3	.001325797	.036411
8	660.0	.001515151	.038925
9	586.6	.001704445	.041286
10	528.0	.001893939	.043519
11	443.6	.002083333	.045643
12	440.0	.002272727	.047673
13	406.1	.002462121	.049620
14	377.1	.002651515	.051493
15	352.0	.002840909	.053300
16	330.0	.003030303	.055048
17	310.6	.003219696	.056742
18	293.3	.003409090	.058388
19	277.9	.003598484	.059988
20	2:4.0	.003787878	.061546
21	251.4	.003977272	.063066

TABLE 7.—Slopes.

Fall in feet per mile.	Slope, one in	s.	$\sqrt{s}$.
22	240.0	.004166667	.064549
23	229.6	.004356060	.066000
24	220.0	.004545454	.067419
25	211.2	.004734848	.068810
26	203.1	.004924242	.070173
27	195.2	.005113636	.071510
28	188.6	.005303030	.072822
29	182.1	.005492424	.074111
30	176.0	.005681818	.075378
31	170.3	.005871219	.076624
32	165.0	.006060606	.077850
33	160.0	.006250000	.079057
34	155.3	.006439393	.080246
35	150.9	.006628788	.081417
36	146.6	.006818181	.082572
37	142.7	.007007575	.083711
38	139.0	.007196969	.084836
39	135.4	.007386363	.085944
40	132.0	.007575757	.087039
41	128.8	.007765151	.088120
42	125.7	.007954545	.089188
43	122.8	.008143939	.090244
44	120.0	.008333333	.091287
45	117.3	.008522727	.092319
46	114.8	.008712121	.093339
47	112.3	.008901515	.094348
48	110.0	.009090909	.095346
49	107.7	.009280303	.096334
50	105.6	.009469696	.097312
51	103.5	.009659090	.098281
52	101.5	.009848484	.099241
53	99.60	.010037871	.100189

TABLE 7.—Slopes.

Fall in feet per mile.	Slope, one in	s.	$\sqrt{s}$.
54	97.77	.010227273	.101130
55	96.00	.010416667	.102060
56	94.28	.010606060	.102983
57	92 63	.010795454	.103901
58	91.03	.010984848	.104809
59	89.49	.011174242	.105708
60	88.00	.011363636	.106600
65	81.23	012310606	.110953
70	75.43	.013257575	.115141
80	66.00	.015151515	.123091
90	58.66	.017045454	.130559
100	52.80	.018939393	.137620
120	44.00	.022727272	.150756
140	37.71	.026515151	.162835
160	33.00	.030303030	.174077
180	29.33	.034090909	.184637
200	26.40	.037878787	.194625
240	22.00	.041666667	.213200
280	18.86	.053030303	.230283
320	16.50	.060606060	.246183
360	14.66	.068181818	.261116
400	13.20	.075757575	.275241
450	11.73	.085227272	.291937
500	10.56	.094696969	.307729
600	8.800	.113636363	.337100
700	7.543	.132575757	.364109
800	6.660	.151515151	.389249
900	5.866	.170454545	.412861
1000	5.280	.189393939	.435194
1500	3.520	.284090909	.532925

TABLE 7.—Slopes continued.

(This table is a continuation of the Table of Slopes given in No. 67, Science Series, entitled "Hydraulic Tables Based on Kutter's Formula.")

Slope, one in	Feet, per mile.	s.	$\sqrt{s}$.
100	52.80	.010000000	.100000
200	26.40	.005000000	.070710
300	17.60	.003333333	.057735
1001	5.274	.000999000	.031067
1002	5.269	.000998004	.061591
1003	5.264	.000997008	.031576
1004	5.259	.000996016	.031560
1005	5.253	.000995025	.031544
1006	5.248	.000994036	.031528
1007	5.243	.000993048	.031513
1008	5.238	.000992064	.031497
1009	5.233	.000991080	.031481
1010	5.228	.000990099	.031466
1011	5.222	.000989120	.031450
1012	5.217	.000988142	.031435
1013	5.212	.000987167	.031419
1014	5.207	.000986193	.031404
1015	5.202	.000985222	.031388
1016	5.197	.000984252	.031373
1017	5.192	.000983284	.031357
1018	5.187	.000982318	.031342
1019	5.181	.000981354	.031327
1020	5.176	.000980392	.031311
1021	5.171	.000979432	.031296
1022	5.166	.000978571	.031282
1023	5.161	.000977517	.031255

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	s.	$\sqrt{s}$.
1024	5.156	.000976562	.031250
1025	5.151	.000975610	.031235
1026	5.146	.000974659	.031219
1027	5.141	.000973710	.031204
1028	5.136	.000972763	.031189
1029	5.131	.000971817	.031174
1030	5.126	.000970873	.031159
1031	5.121	.000969932	.031144
1032	5.116	.000968992	.031129
1033	5.111	.000968054	.031114
1034	5.106	.000967118	.031099
1035	5.101	.000966184	.031083
1040	5.077	.000961538	.031009
1041	5.072	.000960615	.030994
1042	5.067	.000959693	.030975
1043	5.062	.000958773	.030964
1044	5.058	.000957855	.030949
1045	5.053	.000956938	.030934
1046	5.048	.000956023	.030919
1047	5.043	.000955110	.030905
1048	5.038	.000954198	.030890
1049	5.033	.000953289	.030875
1050	5.029	.000952381	.030861
1051	5.025	.000951475	.030846
1052	5.019	.000950570	.030831
1053	5.014	.000949668	.030817
1054	5.010	.000948767	.030802
1055	5.005	.000947867	.030787
1056	5.000	.000946970	.030773
1057	4.995	.000946074	.030758
1058	4.990	.000945180	.030744

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	$s.$	$\sqrt{s.}$
1059	4.986	.000944287	.030729
1060	4.981	.000943396	.030715
1061	4.976	.000942507	.030700
1062	4.972	.000941620	.030686
1063	4.967	.000940734	.030671
1064	4.962	.000939850	.030657
1065	4.958	.000938967	.030643
1066	4.953	.000938086	.030628
1067	4.948	.000937207	.030614
1068	4.944	.000936330	.030599
1069	4.939	.000935454	.030585
1070	4.935	.000934579	.030571
1071	4.930	.000933707	.030557
1072	4.925	.000932836	.030542
1073	4.921	.000931967	.030528
1074	4.916	.000931099	.030514
1075	4.912	.000930233	.030499
1076	4.907	.000929368	.030485
1077	4.902	.000928505	.030471
1078	4.898	.000927644	.030457
1079	4.893	.000926784	.030443
1080	4.889	.000925926	.030429
1081	4.884	.000925069	.030415
1082	4.880	.000924214	.030401
1083	4.875	.000923361	.030387
1084	4.871	.000922509	.030373
1085	4.866	.000921659	.030359
1086	4.862	.000920819	.030345
1087	4.857	.000919954	.030331
1088	4.853	.000919118	.030317
1089	4.848	.000918274	.030303

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	s.	$\sqrt{s}$.
1090	4.844	.000917431	.030289
1091	4.839	.000916590	.030275
1092	4.835	.000915751	.039261
1093	4.831	.000914914	.030247
1094	4.826	.000914077	.030234
1095	4.822	.000913242	.030220
1096	4.817	.000912409	.030206
1097	4.813	.000911576	.030192
1098	4.809	.000910747	.030178
1099	4.804	.000909918	.030165
1100	4.800	.000909090	.030151
1101	4.796	.000908265	.030137
1102	4.792	.000907441	.030124
1103	4.787	.000906618	.030110
1104	4.783	.000905797	.030096
1105	4.778	.000904977	.030083
1106	4.774	.000904159	.030069
1107	4.769	.000903342	.030055
1108	4.765	.000902527	.030042
1109	4.761	.000901713	.030028
1110	4.757	.000900900	.030015
1111	4.752	.000900090	.030001
1112	4.748	.000899279	.029988
1113	4.744	.000898473	.029975
1114	4.739	.000897666	.029961
1115	4.735	.000896861	.029948
1116	4.731	.000896057	.029934
1117	4.727	.000893655	.029921
1118	4.723	.000894508	.029908
1119	4.719	.000893655	.029894
1120	4.714	.000892857	.029881

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	*s.*	$\sqrt{s}$.
1121	4 710	.000892061	.029868
1122	4.706	.000891266	.029854
1223	4.702	.000890472	.029841
1124	4.698	.000889680	.029828
1125	4.693	.000888888	.029814
1126	4.689	.000888099	.029801
1127	4.685	.000887311	.029788
1128	4.681	.000886525	.029775
1129	4.677	.000885740	.029761
1130	4.673	.000884956	.029748
1131	4.668	.000884173	.029735
1132	4.664	.000883392	.029722
1133	4.660	.000882623	.029709
1134	4.656	.000881834	.029696
1135	4.652	.000881057	.029683
1136	4.648	.000880282	.029669
1137	4.644	.000879507	.029656
1138	4.640	.000878734	.029643
1139	4.636	.000877963	.029630
1140	4.632	.000877193	.029617
1141	4.628	.000876424	.029604
1142	4.623	.000875744	.029591
1143	4.619	.000874890	.029578
1144	4.615	.000874126	.029566
1145	4.611	.000873365	.029553
1146	4.607	.000872600	.029540
1147	4.603	.000871840	.029527
1148	4.599	.000871080	.029514
1149	4.595	.000871192	.029501
1150	4.591	.000869566	.029488
1151	4.587	.000868810	.029476

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	$s.$	$\sqrt{s.}$
1152	4.583	.000868055	.029463
1153	4.579	.000867303	.029450
1154	4.575	.000866577	.029438
1155	4.571	.000865801	.029425
1156	4.567	.000865052	.029412
1157	4.563	.000864304	.029399
1158	4.559	.000863558	.029386
1159	4.556	.000862813	.029374
1160	4.552	.000862069	.029363
1161	4.548	.000861326	.029348
1162	4.544	.000860585	.029336
1163	4.540	.000859845	.029323
1164	4.536	.000859106	.029311
1165	4.532	.000858370	.029298
1166	4.528	.000857623	.029285
1167	4.524	.000856898	.029273
1168	4.521	.000856164	.029264
1169	4.517	.000855432	.029248
1170	4.513	.000854701	.029235
1171	4.509	.000853971	.029223
1172	4.505	.000853242	.029210
1173	4.501	.000852515	.029198
1174	4.497	.000851789	.029185
1175	4.494	.000851064	.029173
1176	4.490	.000850340	.029161
1177	4.486	.000849626	.029148
1178	4.482	.000848896	.029136
1179	4.478	.000848176	.029123
1180	4.475	.000847458	.029111
1181	4.471	.000846740	.029099
1182	4.467	.000846024	.029086

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	*s.*	$\sqrt{s.}$
1183	4.463	.000845309	.029074
1184	4.459	.000844595	.029062
1185	4.456	.000843882	.029049
1186	4.452	.000843170	.020037
1187	4.448	.000842460	.029025
1188	4.444	.000841751	.029013
1189	4.441	.000841043	.029001
1190	4.437	.000840336	.028988
1191	4.433	.000839631	.028976
1192	4.430	.000838926	.028964
1193	4.426	.000838223	.028952
1194	4.422	.000837521	.028940
1195	4.418	.000836820	.028928
1196	4.415	.000836120	.028916
1197	4.411	.000835422	.028904
1198	4.407	.000834725	.028892
1199	4.404	.000834028	.028880
1200	4.400	.000833333	.028868
1201	4.396	.000832639	.028855
1202	4.393	.000831946	.028843
1203	4.389	.000831255	.028831
1204	4.385	.000830565	.028819
1205	4.382	.000829875	.028808
1206	4.378	.000829187	.028786
1207	4.374	.000828500	.028784
1208	4.371	.000827815	.028772
1209	4.367	.000827129	.028760
1210	4.364	.000826446	.028748
1211	4.360	.000825764	.028736
1212	4.356	.000825083	.028724
1213	4.353	.000824402	.028713

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	s.	$\sqrt{s}$.
1214	4.349	.000823723	.028701
1215	4.346	.000823045	.028689
1216	4.342	.000822368	028677
1217	4.339	.000821693	.028665
1218	4.335	.000821018	.028653
1219	4.331	.000820344	.028641
1220	4.328	.000819672	.028630
1221	4.324	.000819001	.028617
1222	4.321	.000818355	.028506
1223	4.317	.000817661	.028595
1224	4.314	.000816993	.028583
1225	4.310	.000816326	.028571
1226	4.307	.000815661	.028559
1227	4.303	.000814996	.028548
1228	4.300	.000814332	.028536
1229	4.296	.000813670	.028525
1230	4.293	.000813008	.028513
1231	4.289	.000812348	.028501
1232	4.286	.000811688	.028490
1233	4.282	.000811030	.028478
1234	4.279	.000810373	.028467
1235	4.275	.000809717	.028455
1236	4.272	.000809061	.028444
1237	4.269	.000808407	.028433
1238	4.265	.000807795	.028421
1239	4.261	.000807102	.028409
1240	4.258	.000806452	.028398
1241	4.255	.000805802	.028387
1242	4.251	.000805153	.028375
1243	4.248	.000804505	.028364
1244	4.244	.000808858	.028352

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	*s*.	$\sqrt{s}$.
1245	4.241	.000803213	.028341
1246	4.238	.000802568	.028329
1247	4.234	.000801925	.028318
1248	4.231	.000801282	.028307
1249	4.228	.000800640	.028295
1250	4.224	.000800000	.028284
1251	4.221	.000799396	.028273
1252	4.217	.000798722	.028262
1253	4.214	.000798095	.028250
1254	4.211	.000797448	.028239
1255	4.207	.000796813	.028228
1256	4.204	.000796178	.028217
1257	4.200	.000795545	.028205
1258	4.197	.000794913	.028194
1259	4.194	.000794281	.028183
1260	4.190	.000793651	.028172
1261	4.187	.000793021	.028161
1262	4.184	.000792393	.028149
1263	4.181	.000791765	.028138
1264	4.177	.000791139	.028127
1265	4.174	.000790514	.028116
1266	4.171	.000789889	.028105
1267	4.167	.000789266	.028094
1268	4.164	.000788644	.028083
1269	4.161	.000788030	.028072
1270	4.157	.000787402	.028061
1271	4.154	.000786782	.028050
1272	4.151	.000786321	.028038
1273	4.148	.000785546	.028027
1274	4.144	.000784929	.028016
1275	4.141	.000784314	.028006

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	$s.$	$\sqrt{s.}$
1276	4 138	.000783699	.027995
1277	4.135	.000783085	.027984
1278	4.131	.000782473	.027973
1279	4.128	.000781861	.027962
1280	4.125	.000781250	.027951
1281	4.122	.000780640	.027940
1282	4.118	.000780031	.027929
1283	4.115	.000779423	.027918
1284	4.112	.000778816	.027907
1285	4.109	.000778210	.027896
1286	4.106	.000777605	.027886
1287	4.103	.000777001	.027875
1288	4.099	.000776398	.027864
1289	4.096	.000775795	.027853
1290	4.093	.000775116	.027841
1291	4.090	.000774593	.027831
1292	4.087	.000773994	.027821
1293	4.084	.000773395	.027810
1294	4.080	.000772798	.027799
1295	4.077	.000772201	.027789
1296	4.074	.000771605	.027778
1297	4.071	.000771010	.027767
1298	4.068	.000770416	.027756
1299	4.065	.000769823	.027746
1300	4.062	.000769231	.027735
1301	4.058	000768624	.027724
1302	4.055	.000768049	.027714
1303	4.052	.000767460	.027703
1304	4.049	.000766871	.027692
1305	4.046	.000766283	.027682
1 06	4.043	.000765697	.027671

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	*s.*	$\sqrt{s.}$
1307	4.040	.000765111	.027661
1308	4.037	.000764526	.027650
1309	4.034	.000763942	.027639
1310	4.031	.000763359	.027629
1311	4.037	.000762776	.027618
1312	4.024	.000762195	.027608
1313	4.021	.000761615	.027597
1314	4.018	.000761035	.027587
1315	4.015	.000760456	.027576
1316	4.012	.000759878	.027566
1317	4.009	.000759301	.027555
1318	4.006	.000758725	.027545
1319	4.003	.000758150	.027534
1320	4.000	.000757576	.027524
1321	3.997	.000757002	.027514
1322	3.994	.000756430	.027503
1323	3.991	.000755858	.027493
1324	3.988	.000755217	.027481
1325	3.985	.000754717	.027472
1326	3.982	.000754148	.027462
1327	3.979	.000753579	.027451
1328	3.976	.000753012	.027441
1329	3.973	.000752445	.027431
1330	3.970	.000751880	.027420
1331	3.967	.000751315	.027410
1332	3.964	.000750751	.027400
1333	3.961	.000750187	.027389
1334	3.958	.000749625	.027379
1335	3.955	.000749064	.037369
1336	3.952	.000748503	.027359
1337	3.949	.000747943	.027349

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	$s.$	$\sqrt{s.}$
1338	3.946	.000747384	.027338
1339	3.943	.000746826	.027328
1340	3 940	.000746268	.027318
1341	3.937	.000745712	.027308
1342	3.934	.000745156	.027298
1343	3.932	.000744601	.027287
1344	3.929	.000744048	.027277
1345	3.926	.000743420	.027267
1346	3.923	.000742942	.027257
1347	3.920	.000742390	.027247
1348	3.917	.000741840	.027237
1349	3.914	.000741289	.027227
1350	3.911	.000740741	.027217
1351	3.908	.000740192	.027207
1352	3.905	.000739659	.027197
1353	3.902	.000739098	.027186
1354	3.899	.000738552	.027176
1355	3.897	.000738007	.027166
1356	3.894	.000737463	.027156
1357	3.891	.000736920	.027146
1358	3.888	.000736377	.027136
1359	3.885	.000735879	.027126
1360	3.882	.000735294	.027116
1361	3.879	.000734754	.027106
1362	3.877	.000734214	.027096
1363	3.874	.000733676	.027086
1364	3.871	.000733138	.027077
1365	3.868	.000732601	.027067
1366	3.865	.000732064	.027057
1367	3.862	.000731529	.027047
1368	3.860	.000730994	.027037

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	s.	$\sqrt{s}$.
1369	3.857	.000730460	.027027
1370	3.854	.000729927	.027017
1371	3.851	.000729395	.027007
1372	3.848	.000728863	.026997
1373	3.846	.000728332	.026988
1374	3.843	.000727802	.026978
1375	3.840	.000727273	.026968
1376	3.837	.000726744	.026958
1377	3.834	.000726216	026948
1378	3.832	.000725689	.026939
1379	3.829	.000725163	.026929
1380	3.826	.000724638	.026919
1381	3.823	.000724113	.026909
1382	3.821	.000723589	.026899
1383	3.818	.000723066	.026890
1384	3.815	.000722543	.026880
1385	3.812	.000722022	.026870
1386	3.809	.000721501	.026861
1387	3.807	.000720981	.026851
1388	3.804	.000729461	.026841
1389	3.801	.000729942	.026832
1390	3.799	.000719424	.026822
1391	3.796	.000718907	.026812
1392	3.793	.000718391	.026803
1393	3.790	.000717875	.026793
1394	3.788	.000717360	.026784
1395	3.785	.000716846	.026774
1396	3.782	.000716332	.026764
1397	3.779	.000715819	.026755
1398	3.777	.000715308	.026745
1399	3.774	.000714796	.026736

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	$s.$	$\sqrt{s.}$
1400	3.771	.000714286	.026726
1401	3.769	.000713776	.026717
1402	3.766	.000713267	.026707
1403	3.763	.000712758	.026698
1404	3.761	.000712251	.026688
1405	3.758	.000711744	.026679
1406	3.755	.000711238	.025669
1407	3.753	.000710732	.026659
1408	3.750	.000710227	.026650
1409	3.747	.000709723	.026641
1410	3.745	.000709220	.026631
1411	3.742	.000708717	.026622
1412	3.739	.000708215	.026612
1413	3.737	.000707714	.026603
1414	3.734	.000707213	.026593
1415	3.731	.000706714	.026584
1416	3.729	.000706215	.026575
1417	3.726	.000705716	.026565
1418	3.724	.000705218	.026556
1419	3.721	.000704722	.026547
1420	3.718	.000704225	.026537
1421	3.716	.000703730	.026528
1422	3.713	.000703235	.026519
1423	3.710	.000702741	.026509
1424	3.708	.000702247	.026500
1425	3.705	.000701754	.026491
1426	3.703	.000701262	.026481
1427	3.700	.000700708	.026472
1428	3.697	.000700280	.026463
1429	3.695	.000699790	.026454
1430	3.692	.000699300	.026444

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	s.	$\sqrt{s}$.
1431	3.690	.000698812	.026535
1432	3.687	.000698324	.026426
1433	3.685	.000698837	.026417
1434	3.682	.000697350	.026407
1435	3.680	.000696864	.026398
1436	3.677	.000696379	.026389
1437	3.674	.000695894	.026380
1438	3.672	.000695410	.026371
1439	3.669	.000694927	.026361
1440	3.667	.000694444	.026352
1441	3.664	.000693963	.026343
1442	3.662	.000693481	.026334
1443	3.659	.000693001	.026325
1444	3.657	.000692521	.026316
1445	3.654	.000692042	.026307
1446	3.651	.000691563	.026298
1447	3.649	.000691085	.026288
1448	3.646	.000690608	.026279
1449	3.644	.000690131	.026270
1450	3.641	.000689655	.026261
1451	3.639	.000689180	.026252
1452	3.636	.000688705	.026243
1453	3.634	.000688231	.026234
1454	3.631	.000687758	.026225
1455	3.629	.000687285	.026216
1456	3.626	.000686813	.026207
1457	3.624	.000686342	.029198
1458	3.621	.000685871	.026189
1459	3.619	.000685401	.026180
1460	3.617	.000684931	.026171
1461	3.614	.000684463	.026162

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	*s*.	$\sqrt{s}$.
1462	3.612	.000683994	.026153
1463	3.609	.000683527	.026144
1464	3.607	.000683060	.026135
1465	3.604	.000682594	.026126
1466	3.602	.000682128	.026118
1467	3.599	.000681663	.026109
1468	3.597	.000681199	.026100
1469	3.594	.000680735	.026091
1470	3.592	.000680272	.026082
1471	3.589	.000679810	.026073
1472	3.587	.000679348	.026064
1473	3.585	.000678887	.026055
1474	3.582	.000678426	.026047
1475	3.580	.000677966	.026038
1476	3.577	.000677507	.026029
1477	3.575	.000677048	.026020
1478	3.572	.000676590	.026011
1479	3.570	.000676132	.026003
1480	3.568	.000675676	.025994
1481	3.565	.000675220	.025985
1482	3.563	.000674764	.025976
1483	3.560	.000674309	.025967
1484	3.558	.000673854	.025959
1485	3.556	.000673401	.025950
1486	3.553	.000672948	.025941
1487	3.551	.000672495	.025933
1488	3.548	.000672043	.025924
1489	3.546	000671592	.025915
1490	3.544	.000671141	.025907
1491	3.541	.000670020	.025898
1492	3.539	.000670241	.025889

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	s.	$\sqrt{s}$.
1493	3.537	.000669792	.025880
1494	3.534	.000669344	.025872
1495	3 532	.000668896	.025863
1496	3.529	.000668449	.025854
1497	3.527	.000668003	.025846
1498	3.525	.000667557	.025837
1499	3.522	.000667111	.025828
1500	3.520	.000666666	.025820
1501	3.518	.000666222	.025811
1502	3.515	.000665779	.025803
1503	3.513	.000665336	.025794
1504	3.511	.000664894	.025783
1505	3.508	.000664452	.025777
1506	3.506	.000664106	.025768
1507	3.504	.000663570	.025760
1508	3.501	.000663130	.025751
1509	3.499	.000662691	.025743
1510	3.497	.000662252	.025734
1511	3.494	.000661813	.025726
1512	3.492	.000661376	.025717
1513	3.490	.000660938	.025709
1514	3.487	.000660502	.025700
1515	3.485	.000660066	.025691
1516	3.483	.000659631	.025683
1517	3.481	.000659196	.025675
1518	3.478	.000658761	.025666
1519	3.476	.000658328	.025658
1520	3.474	.000657895	.025649
1521	3.471	.000657462	.025641
1522	3.469	.000657030	.025633
1523	3.467	.000656599	.025624

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	*s.*	$\sqrt{s.}$
1524	3.465	.000656168	.025616
1525	3.462	.000655737	.025607
1526	3.460	.000655308	.025599
1527	3.458	.000654879	.025591
1528	3.456	.000654450	.025582
1529	3.453	.000654022	.025579
1530	3.451	.000653595	.025566
1531	3.449	.000653168	.025557
1532	3.447	.000652741	.025549
1533	3.444	.000652316	.025540
1534	3.442	.000651890	.025532
1535	3.440	.000652117	.025524
1536	3.438	.000651042	.025516
1537	3.435	.000650618	.025507
1538	3.433	.000650195	.025499
1539	3.431	.000649773	.025491
1540	3.429	.000649351	.025482
1541	3.426	.000648930	.025474
1542	3.424	.000648502	.025466
1543	3.422	.000648988	.025457
1544	3.420	.000647668	.025449
1545	3.417	.000647275	.025441
1546	3.415	.000646831	.025433
1547	3.413	.000646412	.025425
1548	3.411	.000645995	.025416
1549	3.409	000645578	.025408
1550	3.407	.000645161	.025400
1551	3.404	.000644745	.025392
1552	3.402	.000644330	.025384
1553	3.400	.000643915	.025375
1554	3.398	.000643501	.025367

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	*s.*	$\sqrt{s}$.
1555	3.396	.000643087	.025359
1556	3.394	.000642674	.025351
1557	3.392	.000642261	.025343
1558	3.389	.000641848	.025335
1559	3.387	.000641437	.025327
1560	3.385	.000641025	.025318
1561	3.382	000640615	.025310
1562	3.380	.000640205	.025302
1563	3.378	.000633397	.025294
1564	3.376	.000639386	.025286
1565	3.374	.000638978	.025278
1566	3.372	.000638570	.025270
1567	3.370	.000638162	.025262
1568	3.367	.000637755	.025254
1569	3.365	.000637349	.025246
1570	3.363	.000636943	.025238
1571	3.361	.000636537	.025230
1572	3.359	.000636132	.025222
1573	3.357	.000635728	.025214
1574	3.355	.000635324	.025206
1575	3.352	.000634921	.025198
1576	3.350	.000634518	.025190
1577	3.348	.000634115	.025182
1578	3.346	.000633714	.025174
1579	3.344	.000633312	.025166
1580	3.342	.000632911	.025158
1581	3.340	.000632511	.025150
1582	3.338	.000632112	.025142
1583	3.335	.000631712	.025134
1584	3.333	.000631313	.025126
1585	3.331	.000630915	.025118

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	s.	$\sqrt{s}$.
1586	3.329	.000630517	.025110
1587	3.327	.000630120	.025102
1588	3.325	.000629323	.025094
1589	3.323	.000629327	.025086
1590	3.321	000628931	.025078
1591	3 319	.000628535	.025071
1592	3.317	.000628141	.025063
1593	3.315	.000627746	.025055
1594	3.312	.000627353	.025047
1595	3.310	.000626959	.025039
1596	3.308	.000626566	.025031
1597	3.306	.000626174	.025023
1598	3.304	.000625782	.025016
1599	3.302	.000625391	.025008
1600	3.300	.000625000	.025000
1601	3.298	.000624609	.024992
1602	3.296	.000624220	.024984
1603	3.294	.000623805	.024976
1604	3.292	.000623441	.024969
1605	3.290	.000623053	.024961
1606	3.288	.000622655	.024953
1607	3.286	.000622277	.024946
1608	3.284	.000621891	.024938
1609	3.282	.000621504	.024930
1610	3.280	.000621118	.024922
1611	3.277	.000620732	.024915
1612	3.275	.000620347	.024907
1613	3.273	000619963	.024899
1614	3.271	.000619579	.024891
1615	3.269	.000619195	.024884
1616	3.267	.000618812	.024876

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	s.	$\sqrt{s}$.
1617	3.265	.000618429	.024868
1618	3.263	.000618047	.024861
1619	3.261	.000617665	.024853
1620	3.259	.000617284	.024845
1621	3.257	.000616903	.024838
1622	3.255	.000616523	.024830
1623	3.253	.000616143	.024822
1624	3.251	.000615764	.024815
1625	3.249	.000615384	.024807
1626	3.247	.000615006	.024799
1627	3.245	.000614628	.024792
1628	3.243	.000614251	.024784
1629	3.241	.000613874	.024776
1630	3 239	.000613497	.024769
1631	3 237	.000613121	.024761
1632	3.235	.000612746	024754
1633	3.233	.000612370	.024746
1634	3.231	.000611995	.024739
1935	3.229	.000611621	.024731
1636	3.227	.000611247	.024723
1637	3.225	.000610874	.024716
1638	3.223	.000610501	.024708
1639	3.222	.000610128	.024701
1640	3.220	.000609756	.024693
1641	3.218	.000609385	.024686
1642	3.216	.000609013	.024678
1543	3.214	.000608643	.024671
1644	3.212	.000608273	.024664
1645	3.210	.000607900	.024656
1646	3.208	.000607527	.024648
1647	3.206	.000607164	.024641

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	s.	$\sqrt{s}$.
1648	3.204	.000606801	.024633
1649	3.202	.000606428	.024626
1650	3.200	.000606060	.024618
1651	3.198	.000605694	.024612
1652	3.196	.000605327	.024603
1653	3.194	.000604961	.024596
1654	3.192	.000604595	.024589
1655	3.190	.000604230	.024581
1656	3.188	.000603865	.024574
1657	3.186	.000603500	.024566
1658	3.185	.000603133	.024559
1659	3.183	.000602773	.024551
1660	3.181	.000602409	.024544
1661	3.179	.000602047	.024537
1662	3.177	.000601685	.024529
1663	3.175	.000601323	.024522
1664	3.173	.000600962	.024515
1665	3.171	.000600601	.024507
1666	3.169	.000 00240	.024500
1667	3 167	.000599880	.024492
1668	3.165	.000599520	.024485
1669	3.164	.000599161	.024478
1670	3.162	.000598802	.024470
1671	3.160	.000598444	.024463
1672	3.158	.000598086	.024456
1673	3.156	.000597729	.024448
1674	3.154	.000597371	.024441
1675	3.152	.000597015	.024434
1676	3.150	.000596659	.024427
1677	3.148	.000596303	.024420
1678	3.147	.000595948	.024413

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	s.	$\sqrt{s}$.
1679	3.145	.000595593	.024405
1680	3.143	.000595238	.024398
1681	3.141	.000594884	.024390
1682	3.139	.000594530	.024383
1683	3.137	.000594177	.024376
1684	3.135	.000593824	.024369
1685	3.134	.000593472	.024361
1686	3.132	.000593102	.024354
1687	3.130	.000592768	.024347
1688	3.128	.000592417	.024340
1689	3.126	.000592066	.024332
1690	3.124	.000591717	.024325
1691	3.122	.000591366	.024318
1692	3.121	.000501017	.024311
1693	3.119	.000590667	.024304
1694	3.117	.000590319	.024297
1695	3.115	.000589471	.024290
1696	3.113	.000589622	.024282
1697	3.111	.000589275	.024275
1698	3.110	.000588928	.024268
1699	3.108	.000588582	.024261
1700	3.106	.000588235	.024254
1701	3.104	.000587889	.024246
1702	3.102	.000587545	.024239
1703	3.100	.000587199	.024232
1704	3.099	.000586854	.024225
1705	3.097	.000586510	.024218
1706	3.095	.000586166	.024211
1707	3.093	.000585823	.034204
1708	3.091	.000585480	.024197
1709	3.090	.000585138	.024190

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	s.	$\sqrt{s}$.
1710	3.088	.000584795	.024183
1711	3.086	.000584453	.024175
1712	3.084	.000548112	.024168
1713	3.083	.000583771	.024161
1714	3.081	.000583431	.024154
1715	3.079	.000583090	.024147
1716	3.077	.000582751	.024140
1717	3.075	.000582411	.024133
1718	3.073	.000582072	.024126
1719	8.072	.000581734	.024119
1720	3.070	.000581395	.024112
1721	3.068	.000581058	.024105
1722	3.066	.000580720	.024098
1723	3.064	.000580384	.024091
1724	3.063	.000580046	.024084
1725	3.061	.000579710	.024077
1726	3.060	.000579374	.024070
1727	3.058	.000579039	.024063
1728	3.056	.000578704	.024056
1729	3.054	.000578369	.024049
1730	3.052	.000578035	.024042
1731	3.050	.000577701	.024035
1732	3.048	.000577367	.024028
1733	3.047	.000577034	.024021
1734	3.045	.000576701	.024015
1735	3.043	.000576369	.024008
1736	3.041	.009576037	.024001
1737	3.040	.000575705	.023994
1738	3.038	.000275374	.028987
1739	3.036	.000575043	023980
1740	3.035	.000574712	.023973

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	*s*.	$\sqrt{s}$.
1741	3.033	.000574382	.023966
1742	3.031	.000574053	.023959
1743	3.029	.000572723	.023953
1744	3.028	.000573394	.023946
1745	3.026	.000573066	.023939
1746	3.024	.000572738	.023932
1747	3.022	.000572410	.023925
1748	3.021	.000572082	.023918
1749	3.019	.000571755	.023911
1750	3.017	.000571429	.023905
1751	3.015	.000571102	.023898
1752	3.014	.000570776	.023891
1753	3.012	.000570451	.023884
1754	3.010	.000570160	.023878
1755	3.009	.000569801	.023871
1756	3.007	.000569476	.023864
1757	3.005	.000569152	.023857
1758	3.003	.000568828	.023850
1759	3.002	.000568584	.023843
1760	3.000	.000568182	.023837
1761	2.998	.000567859	.023830
1762	2.997	.000567537	.023823
1763	2.995	.000567215	.023816
1764	2.993	.000566893	.023809
1765	2.992	.000566572	.023803
1766	2.990	.000566251	.023796
1767	2.988	.000565931	.023789
1768	2.986	.000565612	.023783
1769	2.985	.000565291	.023776
1770	2.983	.000564972	.023769
1771	2.981	.000564653	.023762

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	s.	$\sqrt{s}$.
1772	2.980	.000564334	.023756
1773	2.978	.000564016	.023749
1774	2.976	.000563692	.023742
1775	2.975	.000563380	.023736
1776	2.973	.000563063	.023729
1777	2.971	.000562746	.023722
1778	2.969	.000562430	.023716
1779	2.968	.000562114	.023709
1780	2.966	.000561798	.023702
1781	2.965	.000561482	.023696
1782	2.963	.000561168	.023689
1783	2.961	.000560852	.023682
1784	2.960	.000560538	.023676
1785	2.958	.000560224	.023662
1786	2.956	.000559910	.023663
1787	2.955	.000559597	.023656
1788	2.953	.000559284	.023649
1789	2.951	.000558972	.023643
1790	2.950	.000558659	.023636
1791	2.948	.000558347	.023629
1792	2.946	.000558036	.023623
1793	2.945	.000557724	.023616
1794	2 943	.000557414	.023610
1795	2.942	.000557103	.023603
1796	2.940	.000556793	.023596
1797	2.938	.000556483	.023589
1798	2.937	.000556173	.023583
1799	2.935	.000555864	.023577
1800	2.933	.000555555	.023570
1801	2.932	.000555247	.023564
1802	2.930	.000554939	.023557

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	*s.*	$\sqrt{s.}$
1803	2.928	.000554631	.023551
1804	2.927	.000554324	.023544
1805	2.925	.000554017	.023538
1806	2.924	.000553798	.023531
1807	2.922	.000553403	.023525
1808	2.920	.000553097	.023518
1809	2.919	.000552792	.023512
1810	2.917	.000552486	.023505
1811	2.915	.000552181	.023499
1812	2.914	.000551876	.023492
1813	2.912	.000551572	.023486
1814	2.911	.000551268	.023479
1815	2.909	.000550964	.023473
1816	2.908	.000550661	.023466
1817	2.906	.000550358	.023460
1818	2.904	.000550055	.023453
1819	2.903	.000549742	.023447
1820	2.901	.000549451	.023440
1821	2.900	.000549149	.023434
1822	2.898	.000548847	.023427
1823	2.896	.000548546	.023421
1824	2.895	.000548246	.023415
1825	2.893	.000547945	.023408
1826	2.892	.000547695	.023402
1827	2.890	.000547344	.023395
1828	2.888	.000547046	.023389
1829	2.887	.000546747	.023383
1830	2.885	.000546448	.023376
1831	2.884	.000546150	.023370
1832	2.882	.000545852	.023363
1833	2.881	.000545554	.023357

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	$s.$	$\sqrt{s}.$
1834	2.879	.000545256	.023351
1835	2.877	.000544949	.023344
1836	2.876	.000544662	.023338
1837	2.874	.000544437	.023331
1838	2.873	.000544096	023325
1839	2.871	.000543774	.023319
1840	2.870	000543478	.023313
1841	2.868	.000543183	.023306
1842	2.866	.000542888	.023300
1843	2.865	.000542594	.023294
1844	2.863	.000542299	.023287
1845	2.862	.000542005	.023281
1846	2.860	.000541712	.023275
1847	2 859	.000541419	.023268
1848	2 858	.000541126	.023262
1849	2.856	.000540833	023256
1850	2.854	.000540541	.023250
1851	2.853	.000540249	.023243
1852	2.851	.000539957	.023237
1853	2.849	.000539611	023230
1854	2.848	.000539374	.023224
1855	2.847	.000539084	.023218
1856	2.845	.000538793	.023212
1857	2.843	.000538503	.023206
1858	2.842	.000538213	.023199
1859	2.840	.000537924	.023193
1860	2.839	.000537633	.023187
1861	2.837	.000537346	.023181
1862	2.836	.000537057	.023174
1863	2.834	.000536769	.023168
1864	2.833	.000536481	.023162

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	s.	$\sqrt{s}$.
1865	2.831	.000536193	.023156
1866	2.830	.000535906	.023150
1867	2.828	.000535613	.023143
1868	2.827	.000535332	.023137
1869	2.825	.000535046	.023131
1870	2.822	.000534759	.023125
1871	2.822	.000534474	.023119
1872	2.821	.000534188	.023112
1873	2.819	.000533903	.023106
1874	2.818	.000533618	.023100
1875	2.816	.000533333	.023094
1876	2.815	.000533049	.023088
1877	2.813	.000532765	.023082
1878	2.812	.000532481	.023076
1879	2.810	.000532198	.023069
1880	2.809	.000531915	.023063
1881	2.807	.000531632	.023057
1882	2.806	.000531344	.023051
1883	2.804	.000531067	.023045
1884	2.803	.000530785	.023039
1885	2.801	.000530504	.023033
1886	2.800	.000530223	.023027
1887	2.798	.000529940	.023020
1888	2.797	.000529661	.023014
1889	2.795	.000529381	.023008
1890	2.794	.000529101	.023002
1891	2.792	.000528821	.022996
1892	2.791	.000528541	.022990
1893	2.789	.000528262	.022984
1894	2.788	.000527983	.022978
1895	2.786	.000527705	.022972

TABLE 7.—Slopes.

Slope, one in	Feet, per mile.	s.	$\sqrt{s}$.
1896	2.785	.000527426	.022966
1897	2.783	.000527148	.022960
1898	2.782	.000526870	.022954
1899	2.780	.000526593	.022948
1900	2.779	.000526316	.022942

TABLE 8.—Comparison of coefficients (c) in the formula.

$$V=c\sqrt{rs}.$$

D'Arcy's coefficient for clean pipes under pressure.—Kutter's coefficients for pipes flowing full with $n=.011$ and $s=.001$.

Diameter. Ft.	Ins.	D'Arcy's Coefficients for clean pipes.	Kutter's Coefficient, $n=.011$. $s=.001$.
0	5	103.8	82.9
0	6	105.3	87.4
0	7	106.4	91.5
0	8	107.2	95.0
0	9	107.9	97.9
0	10	108.5	100.5
0	11	108.9	103.3
1	0	109.3	105.7
1	2	109.9	109.5
1	4	110.4	113.0
1	6	110.7	116.2
1	8	111.0	118.8
1	10	111.3	121.3

TABLE 8.

Diameter. Ft.	Ins.	D'Arcy's Coefficients for clean pipes.	Kutter's Coefficient, $n = .011$. $s = .001$.
2	0	111.5	123.6
2	3	111.7	126.5
2	6	111.9	129.1
2	9	112.1	131.5
3	0	112.2	133.6
3	3	112.3	135.6
3	6	112.4	137.2
3	9	112.5	138.8
4	0	112.6	140.4
4	3	11[illegible].7	141.7
4	6	112.7	143.0
5	0	112.8	145.4
5	6	112.9	147.6
6	0	113.0	149.5
6	6	113.0	151.2
7	0	113.1	152.7
8	0	113.2	155.4
9	0	113.2	157.7
10	0	113.3	159.7

TABLE 9.—Of coefficients (c) from the formulæ of D'Arcy, Kutter and Fanning for small pipes below 5 inches in diameter.

$$V=c\sqrt{rs.}$$

Diameter in inches	(c) D'Arcy's Co-efficient for clean pipes.	(c) Kutter's Co-efficient from formula $n=.011$ $s=.001$	(c) Kutter's Co-efficient recommended by L. D. A. Jackson.	(c) Fanning's Co-efficient for clean iron pipes.
0 ⅜	59.4	32.0	82.9	
½	65.7	36.1	82.9	
¾	74.5	42.6	82.9	
1	80.4	47.4	82.9	80.4
1¼	84.8	51.9	82.9	
1½	88.1	55.4	82.9	88.0
1¾	90.7	58.8	82.9	92.5
2	92.9	61.5	82.9	94.8
2½	96.1	66.0	82.9	
3	98 5	70.1	82.9	96.6
4	101.7	77.4	82.9	103.4
5	103.8	82.9	82.9	

TABLE 10.—Showing the velocity in feet per second in pipes, by Kutter's formula (6) and also by the tables, the value of n being .011.

Diameter, Feet.	Inches.	Slope, one in	Velocity, by Kutter's formula.	Velocity, by Flynn's tables.
1	0	66	6.62	6.51
1	0	2640	1.02	1.03
2	0	66	10.89	10.75
2	0	2640	1.67	1.70
4	0	66	17.52	17.28
4	0	2640	2.70	2.73
6	0	66	22.63	22.54
6	0	2640	3.54	3.56

Table 11.—Showing the velocity in feet per second in pipes, by Kutter's formula (6) and also by the tables, the value of n being .013.

Diameter, Feet.	Diameter, Inches.	Slope, one in	Velocity, by Kutter's formula.	Velocity, by Flynn's tables.
1	0	66	5.34	5.25
1	0	2640	0.81	0.83
2	0	66	8.91	8.80
2	0	2640	1.36	1.39
4	0	66	14.44	14.34
4	0	2640	2.24	2.27
6	0	66	18.91	18.82
6	0	2640	2.94	2.98