Hydraulic Diagrams

SWAN AND HORTON

HYDRAULIC DIAGRAMS

FOR THE

DISCHARGE OF CONDUITS AND CANALS

Based upon the Formula of Ganguillet and Kutter

BY

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PREFACE.

The following set of diagrams, based upon the formula of Ganguillet and Kutter, is intended for use in the study of such sections of conduits and canals as are commonly employed in sewerage, water supply, water power and land drainage.

The set includes conduits of eight different types of cross-section, and canals of rectangular and trapezoidal cross-section.

In presenting this set of diagrams, it has been the aim of the authors to cover the field with as limited a number of diagrams as will readily conform to a simple and practical system for use. A short discussion of the formula and a description of the diagrams and their use appear on the following pages.

C. F.

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(Following text.)

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CHAPTER I.

The Formula of Ganguillet and Kutter.

This formula for the mean velocity of discharge of rivers, canals and conduits was obtained from a comparison of numerous experiments made in different countries upon natural and artificial water courses of many sizes and various kinds of materials.

The formula assumes that a uniform flow has been established and gives the equation of the mean velocity of flow. This equation is as follows for metric measures:

$$V = \left\{ \frac{23 + \frac{1}{n} + \frac{0.00155}{S}}{1 + \left(23 + \frac{0.00155}{S}\right) \frac{n}{\sqrt{R}}} \right\} \sqrt{R S}$$

When reduced to measures in English feet it becomes

$$V = \left\{ \frac{41.6603 + \frac{1.81132}{n} + \frac{0.00281}{S}}{1 + \left(41.6603 + \frac{0.00281}{S}\right) \frac{n}{\sqrt{R}}} \right\} \sqrt{RS}$$

It may be expressed more briefly,

$$V = c \sqrt{R S}$$

in which

$V =$ the mean velocity of flow;
$c =$ the velocity coefficient;
$R =$ the mean hydraulic radius of the stream;

S = the sine of the inclination, or fall in a unit of length;

n = a frictional factor dependent upon the nature of the surface over which the water flows.

For brevity, let us substitute letters for the numbers in the formula. We may then write

$$V = \left\{ \frac{a + \frac{l}{n} + \frac{m}{S}}{1 + \left(a + \frac{m}{S}\right) \frac{n}{\sqrt{R}}} \right\} \sqrt{RS}$$

and by substituting $x = \left(a + \frac{m}{S}\right) n$ and $z = a + \frac{l}{n} + \frac{m}{S}$ we may write

$$V = \left\{ \frac{z}{1 + \frac{x}{\sqrt{R}}} \right\} \sqrt{RS}$$

in which

$$c = \frac{z}{1 + \frac{x}{\sqrt{R}}}$$

When the quantity V is sought from general data, and the coefficient c is not needed separately, the following transformation may be made:

$$V = \left\{ \frac{z \sqrt{S}}{\sqrt{R} + x} \right\} R$$

which is a useful form from which tables may be calculated, and, as was done with many of the present diagrams, the results plotted.

Since a proper selection of the friction factor n is essential in the application of the above general equation and the use of the present diagrams based thereon, the following values for it will be here reproduced for a general guide in practice;

n = .007 to .008: Glass, new tin, lead and galvanized iron pipe.

n = .008 to .009: New seamless wrought-iron and new-coated cast-iron pipe in best of condition and alinement.

n = .009 to .010: New cast-iron pipe, new enamelled and glazed pipe of all sorts; well planed timber in perfect alinement.

n = .010 to .011: New wrought-iron riveted pipe of small diameter; new wooden stave pipe; planed timber, neat cement.

n = .011 to .012: Unplaned timber carefully joined; cement, one-third sand; new terra cotta; new well laid brickwork, carefully pointed and scraped; clean cast-iron pipe in use some time.

n = .012 to .013: Unplaned timber; cement two-thirds sand; ashlar and well-laid brickwork; ordinary brickwork plastered; earthen and stoneware pipes in good condition but not new; plaster and planed wood of inferior quality; glazed pipe poorly laid or foul from use; new wrought-iron riveted pipe with many joints and rivets.

n = .015: Rough-faced brickwork; ashlar and well-laid brickwork slightly deteriorated from use; fouled or slightly tuberculated cast-iron pipe; large wrought-iron riveted pipe, few years in use but in good condition; canvas lining.

n = .017: Brickwork and ashlar in inferior condition or badly fouled; tuberculated and fouled iron pipe; rubble in cement or plaster, in good condition; gravel-lined canals with $\frac{5}{8}$-in. grains well rammed or cement grouted.

n = .020: Rubble in cement of inferior quality; coarse rubble set dry; brickwork in bad condition; gravel-lined canals, with one inch grains, well rammed or cement grouted.

n = .0225 : Rough rubble in bad condition; canals with earthen beds in perfect order and alinement.

n = .025: Canals with earthen beds in good order and alinement and free from stones and weeds.

n = .030: Canals with earthen beds in moderately good order and alinement, with few stones and weeds.

n = .040: Canals with earthen beds in bad condition and alinement, having stones and weeds in great quantity.

For a more complete statement of the formula and its derivation the reader is referred to the following well-known books:

"The New Formula for Mean Velocity of Discharge of Rivers and Canals." By W. R. Kutter. Translated from Articles in the Cultur-Ingenieur by Louis D'A. Jackson. London, 1876.

"Flow of Water in Rivers and other Channels." By Ganguillet and Kutter. Translated, with numerous additions, by R. Hering and J. C. Trautwine. New York, 1891."

CHAPTER II.

Description of the Diagrams.

For convenience in their description, the diagrams will be considered under the following two groups: The first group, Diagrams 1 to 12, inclusive, deal with circular and similar types of conduits, more especially applicable to the conveyance of moderate volumes of water and sewage, flowing either open or under pressure. The second group, Diagrams 13 to 16, inclusive, deal with canals of rectangular and trapezoidal cross sections, more applicable to the conveyance of larger volumes of water and sewage, not flowing under pressure.

Conduits.

Diagrams 1, 2 and 3: Of the first group, Diagrams 1, 2 and 3 are discharge diagrams, very similar in construction, and, differing only in range of data, will be described together. They give velocities in feet per second, and discharges in cubic feet per second, from circular conduits, running full, for diameters ranging from 4 ins. to 20 ft.; hydraulic inclinations from 0.000025 to 0.10; with a friction factor n = .015.

The vertical scale on each diagram represents hydraulic inclinations, expressed fractionally at the right and trigonometrically (i. e. the sine of the angle of inclination) at the left. Also, at the left is given a scale of corresponding square roots of the slope. The horizontal scale represents discharges in cubic feet per second. Beginning at the left on Diagrams 2 and 3 this scale is broken at intervals, and at the same time increased in value, thus giving the diagrams a wider range of data than could be obtained by the use of a single scale. The radial lines represent diameters in feet and fractions thereof. By selecting a natural vertical scale, based upon the square root of the slope, these lines become straight between successive divisions of the horizontal scale, a feature which not only facilitated the construction of the diagrams but allows them to be readily extended beyond their present limits in any special case.

Diagram 4: As already stated, the discharge diagrams are based upon a friction factor n = .015. Diagram 4, consisting of four curves, representing different diameters, shows the relation between the discharge for n = .015 and discharges for other values of n, ranging from .008 to .018. For simplicity, this diagram may be considered a correction diagram on which the vertical scale represents friction factors and the horizontal scale correction coefficients to be applied to discharges for n = .015. The four curves intersect at a common point whose abscissa is 1.00 and ordinate .015, as might be expected. For diameters intermediate to those represented by the four curves interpolation will, of course, be necessary.

Diagrams 5-12: The remaining eight diagrams of the first group, termed for convenience ratio diagrams, give for each of the types of conduits considered the ratio of each of the three elements—area, mean velocity and discharge—of the "filled segment" to that of the "filled section" corresponding to any ratio of depth of flow to the vertical diameter. "Filled segment" refers to the cross section of the stream of the partially filled conduit, and "filled section" to the cross section of the entire conduit. The vertical scale represents the ratio of the depth of flow to the vertical diameter and the horizontal scale corresponding ratios of the hydraulic elements of the filled segment to those of the filled section.

Expressed also on each diagram are other hydraulic elements of the filled section in terms of the vertical or horizontal diameters; relations between the various geometrical elements for the purpose of outlining the section; and actual data from which the curves were constructed. These curves are strictly correct only for the data given, but they vary so slightly for different sizes, grades and friction factors that they may be considered practically independent of them.

The symbols and terms used on all ratio diagrams are those commonly employed in hydraulic work of this nature; the perimeter, P, the hydraulic radius, R, and area, A, referring, however, to the cross section of the entire conduit. Equivalent circle refers to one of equal carrying capacity.

In general these ratio diagrams represent types of sections commonly employed in practice, the different shapes of cross sections possessing either structural or hydraulic advantages. The circular section (Diag. 5) is the one most commonly employed in practice, combining strength with simplicity and economy of construction. The Gothic section (Diag. 6) combines the advantages of the circular section with increased strength of the Gothic arch. The catenary section (Diag. 8) is, theoretically, the section of greatest strength, but has the disadvantage of relatively low velocity for low flow. The egg-shaped section (Diag. 9), used somewhat extensively on combined systems of sewerage, has the hydraulic advantage of relatively high velocity for low flow. The horse shoe sections (Diagrams 11 and 12), used extensively for large-sized conduits, possess great stability with the additional advantage of economy in material and trench excavation. They have, however, the disadvantage of relatively low velocity for low flow. The basket handle section (Diag. 7) is a modification of the horse shoe section in which the Gothic arch and rounded corners were intended to give greater stability. The square section (Diag. 10) is not common, but is occasionally used for wooden sewers and in other special cases; a little study will show its applicability to any rectangular section of moderate size which does not flow full.

The Gothic, basket handle and catenary sections have been used extensively on the Metropolitan sewers in Massachusetts; the horse shoe section (Diag. 11) on the Wachusett aqueduct, and the horse shoe section (Diag. 12) on the Croton aqueduct. The other sections are used more or less extensively in these and other localities.

Canals.

The four diagrams of the second group, though referring to water courses of a different hydraulic nature, are constructed upon lines closely analagous to those of the first group and will be compared closely with them.

With conduits, which are essentially closed channels, we have, for a full section of any type, a fixed relation between the various geometrical elements of the cross section, while with canals, in order to secure this fixed geometrical relation, we must assume a definite ratio between some of the elements. The length of base and depth of flow are chosen in the present instance, and a full section will here be assumed as one whose depth of flow is equal to one-half the base. That is, if a semicircle be described upon the base of a rectangular or trapezoidal section, a line drawn tangent to this semicircle and parallel with the base, will represent the flow line of a filled section. The ratio assumed is one which combines simplicity with economy of section, it being the theoretically economical ratio for rectangular sections and is the ratio from which no great variation might be expected in actual practice.

For similar sections, then, both the geometrical and hydraulic elements of filled sections become functions of the base, and consequently discharge and ratio diagrams may be constructed in which these elements are given in terms of the length of base, and the depth of filled section.

Diagram 13: This diagram gives, for rectangular filled sections, discharges in cubic feet per second, with corresponding velocities in feet per second, for lengths of base varying from 10 to 50 ft., hydraulic inclinations from 0.000004 to 0.001, and with a friction factor $n = .025$. The construction and appearance of this diagram is so similar to the three discharge diagrams for circular conduits that further description seems unnecessary.

Diagram 14: This diagram gives the relation between discharges from actual or equivalent rectangular filled section for $n = .025$ and discharges with other values of n ranging from .015 to .040. The diagram consists of three curves, and is similar in every way to Diagram 4 for conduits.

Diagrams 15 and 16: These two diagrams, termed ratio diagrams, are analagous to the eight ratio diagrams for conduits, and give for canals the ratio of the two hydraulic elements—area and discharge—of the filled segment to that of the filled section corresponding to any ratio of depth of flow to depth of the filled section. These ratio diagrams differ from the previous ratio diagrams in that one of them, Diagram 15, refers exclusively to discharges, and the other, Diagram 16, exclusively to areas.

Since the ratio of the depth of flow to the length of base of a filled section is merely an assumed one, and, in reality, the section may flow at a relatively greater depth, the vertical scale on these two ratio diagrams is extended above the ratio 1.00 sufficiently to cover all cases which would probably arise in practice.

The table on Diagram 15 gives for trapezoidal filled sections, having various side slopes, the equivalent bases of rectangular filled sections of equal carrying capacity. A similar table on Diagram 16 gives simple equations for obtaining the area of trapezoidal filled sections directly in terms of the length of base. The mean velocity in all cases is obtained by dividing the discharge by the area.

CHAPTER III.

Use of the Diagrams.

In this chapter the following notation will be observed:

Q_f, V_f, A_f, and D_f = Discharge, mean velocity, area and vertical diameter (or depth) of the full section.

Q_s, V_s, A_s, and D_s = Discharge, mean velocity, area and depth of the filled segment.

$\frac{Q_s}{Q_f}$, $\frac{V_s}{V_f}$, $\frac{A_s}{A_f}$, $\frac{D_s}{D_f}$, = Ratios of the hydraulic elements of the filled segment to those of the filled section, expressed decimally.

H = horizontal diameter of conduit.

B = base of canal section.

Slopes = side slopes of trapezoidal canal section.

s = hydraulic slope or sine of angle of inclination.

n = friction factor dependent upon character of internal surface.

Conduits.

Conduits may flow full, partially full or under pressure. They are usually designed to carry a uniform flow under the varying conditions of Q (or V), D, s and n. Three of these conditions are usually given or assumed, and the remaining one may be obtained by the use of the diagrams. The following rules, classified under the three conditions of flow, will illustrate the proper method of using the diagrams and will serve as a special guide in practice.

Class A.—Conduits flowing full.

When the section is circular the following principal cases (1-4) may occur:

(1) Given D_f, s and n, to obtain Q_f. With D_f and s find Q_f for n = .015 from Diagram 1, 2 or 3. The product of this Q_f and the ratio on Diagram 4 corresponding to given value of n will give required Q_f.

(2) Given Q_f, s and n to obtain D: Divide Q_f by ratio on Diagram 4 corresponding to given n. With this Q_f corresponding to n = .015, and given s, find required D_f from Diagrams 1, 2 or 3. This case is slightly tentative, since D_f is required in the use of Diagram 4. It will be seen, however, that ratios on Diagram 4 corresponding to any friction factor, n, vary but slightly for a wide range in values of D, so that a value of D sufficiently accurate to use Diagram 4 may be first made by inspection.

(3) Given Q_f, D_f and n to obtain s: Divide given Q_f by ratio on Diagram 4 corresponding to given n. With this Q_f corresponding to n = .015, and given D, find required s from Diagrams 1, 2 or 3.

(4) Given Q_f (obtained from direct observation), D_f and s to obtain n: With given D_f and s find Q_f from Diagrams 1, 2 or 3 for n = .015. Divide observed Q_f by Q_f for n = .015, and with this ratio find required n from Diagram 4.

In the above four cases V_f may be substituted for Q_f, since Diagrams 1, 2 and 3 give V_f corresponding to Q_f, and since for any diameter, V_f varies directly as Q_f. A_f in these cases is obtained geometrically from D_f.

In the next four cases, in which the section is not circular, as for instance the Gothic, egg-shaped and horse shoe, a comparison is necessary between the vertical diameters of these sections, and the diameters of circular sections of equal carrying capacity.

The equations for this comparison are given on each of the ratio diagrams, as are also the geometrical relations, in terms of the vertical or horizontal diameter, necessary to outline the section. The Gothic section will be chosen as an example of these different types of sections and the rules given above when applied to this section become as follows:

(5) Given D_f, s and n of a Gothic section to obtain Q_f: From Diagram 6, Diam. of =⊂⊃= circle $= \dfrac{D_f}{1.1056}$. With this Diam. and given s find Q_f for $n = .015$ from Diagrams 1, 2 or 3. The product of this Q_f and the ratio on Diagram 4 corresponding to given n, will give required Q_f.

(6) Given Q_f, s and n of a Gothic section to obtain D_f and outline the section. With given Q_f, s and n obtain D_f of a circular section by (A-2). With this D_f obtain, from Diagram 6, required D_f of Gothic section by equation Vert. Diam. $= 1.1056 \times$ Diam. of =⊂⊃= circle. With D_f thus found outline section from relation of geometrical elements on Diag. 6.

(7) Given D_f, n and Q_f of a Gothic section to obtain s. By Diagram 6, Diam. of =⊂⊃= circle $= \dfrac{D_f}{1.1056}$. Divide given Q_f by ratio on Diagram 4, corresponding to given n. With this Q_f, corresponding to $n = .015$, and Diam. of =⊂⊃= circle, obtain required s from diagrams 1, 2 or 3.

(8) Given D_f, s and Q_f (obtained from direct observation) of a Gothic section to obtain n. From Diag. 6, Diam. of =⊂⊃= circle $= \dfrac{D_f}{1.1056}$. With this Diam. and given s find Q_f for $n = .015$ from Diagrams 1, 2 or 3. Divide observed Q_f by Q_f for $n = .015$ and with this ratio find required n from Diagram 4.

In the last four cases A_f is obtained from D_f by equations given on the ratio diagrams, and V_f by dividing Q_f by A_f. Also since the Diam. of =⊂⊃= circle refers to equal capacity and not equal area, in general V_f cannot be substituted for Q_f as in the first four cases.

Class B.—Conduits flowing partially full.

Cases arising in this class involve merely an extended use of the ratio diagrams, and the principles involved above. To avoid confusion the Gothic section will be retained as an example in the following cases of this class.

(1) Given D_f, D_s and Q_f or V_f or A_f of a Gothic section to obtain Q_s, V_s and A_s. From Diagram 6 obtain $\frac{Q_s}{Q_f}$, $\frac{V_s}{V_f}$ and $\frac{A_s}{A_f}$ corresponding to $\frac{D_s}{D_f}$. The product of Q_f and $\frac{Q_s}{Q_f}$ will give required Q_s; product of V_f and $\frac{V_s}{V_f}$ required V_s; product of A_f and $\frac{A_s}{A_f}$ required A_s.

(2) Given D_f, D_s and Q_s or V_s or A_s of a Gothic section to obtain Q_f, V_f and A_f. From Diagram 6 obtain $\frac{Q_s}{Q_f}$, $\frac{V_s}{V_f}$ and $\frac{A_s}{A_f}$ corresponding to $\frac{D_s}{D_f}$. The quotient of Q_s by $\frac{Q_s}{Q_f}$ will give required Q_f; quotient of V_s by $\frac{V_s}{V_f}$ required V_f; quotient of A_s by $\frac{A_s}{A_f}$ required A_f.

(3) Given s, n, D_s and D_f of a Gothic section to obtain Q_s. With given D_f, s and n obtain Q_f by (A-5). With this Q_f and given D_s and D_f obtain Q_s by (B-1).

(4) Given Q_s, n, D_s and D_f of a Gothic section to obtain s. With given Q_s, D_s and D_f obtain Q_f by (B-2). With Q_f, and given n and D_f obtain required s by (A-7).

(5) Given Q_s (obtained from direct observation), s, D_s and D_f of a Gothic section to obtain n. With given D_f, D_s and Q_s obtain Q_f by (B-2). With this Q_f and given D_f and s find required n from (A-8).

(6) Given Q_s, s, n and D_f of a Gothic section to obtain D_s. With given s, n and D_f obtain Q_f by (A-5). The product of D_f and $\frac{D_s}{D_f}$ corresponding to $\frac{Q_s}{Q_f}$ will give required D_s.

(7) Given Q_s, s, n and D_s of a Gothic section to obtain D_f. A tentative method is necessary as follows: Assume D_f, and, with given s and n and D_s, obtain a trial Q_s by (B-3), which should agree with given Q_s if D_f is correctly assumed; if not, assume new values of D_f until the proper one is found.

(8) Given $\frac{D_s}{D_f}$ (but knowing neither D_s nor D_f), Q_s, s and n of a Gothic section to obtain D_f. Obtain Q_f from Q_s and $\frac{D_s}{D_f}$ by (B-2), and with this Q_f and given s and n obtain D_f by (A-6).

Class C.—Conduits under Pressure.

With conduits flowing under pressure, the following losses of head are usually considered: Loss due to generating velocity, loss due to entrance, loss due to internal friction, and loss due to special causes, such as valves and sudden bends.

For uniform flow in long conduits the losses due to entrance and to generating velocity are relatively small and for entrance similar to a standard short tube, these two losses combined amount approximately to $1.5\frac{V^2}{2\,g}$. Losses due to valves and bends, also usually small, and requiring special treatment, will not be considered here.

The principal loss, then, and the only one which is considered here, is that due to internal friction, and usually represented by the hydraulic gradient—or the line joining water levels in piezometers placed at points along the conduit and which for convenience, will here be assumed as straight.

If the conduit does not at any point rise above this hydraulic gradient, and if we let s represent the inclination of this hydraulic gradient, the solution of cases in this class will be the same as for cases under Class A, to which the reader is referred.

Canals.

Under the present treatment of canals in which the "Filled Section" is an assumed one having a depth equal to one-half the base, only two conditions of flow have a practical significance: Flow in which the ratio of depth of flow to depth of filled section is 1.00 (i. e. flowing full), and flow in which this ratio is greater or less than 1.00.

The two classes corresponding to these two conditions will be considered separately.

Class A.—Sections in which the ratio of depth of flow to depth of "Filled Section" is 1.00.

If the sections are rectangular the following four principal cases occur:

(1) Given B, s and n to obtain Q_f. With given B and s obtain Q_f for n = .025 from Diagram 13. The product of this Q_f and the ratio from Diagram 14 corresponding to given n will give required Q_f.

(2) Given Q_f, s and n to obtain B. Divide Q_f by ratio on Diagram 14 corresponding to given n and with this Q_f, corresponding to n = .025, and given s, find required B from Diagram 13. This case is also slightly tentative as in the case of conduits (A-2) and an estimate of B is necessary in advance in order to use Diagram 14.

(3) Given Q_f, B, and n to obtain s. Divide given Q_f by ratio on Diagram 14 corresponding to given n. With this Q_f for n = .025 and given B find required s from Diagram 13.

(4) Given Q_f (obtained from direct observation), B and s to obtain n. With given B and s obtain Q_f for n = .025 from Diagram 13. Divide observed Q_f by Q_f for n = .025 and with this ratio find required n from Diagram 14.

In the above four cases V_f may be substituted for Q_f for reasons similar to those previously described under Class A, for conduits. A_f in all cases is obtained from equations on Diagram 16.

If the sections are trapezoidal these four cases are modified, and the section with side slopes of 2 to 1 will be considered an example, as follows:

(5) Given B, s and n of a trapezoidal section having side slopes of 2 to 1, to obtain Q_f. From Diagram 15 base of $=\!\frown\!=$ Rect. section $= \dfrac{B}{0.73}$. With this base and given s find Q_f for n = .025 by Diagram 13. The product of this Q_f and the ratio on Diagram 14 corresponding to given n will give required Q_f.

(6) Given Q_f, s and n of a trapezoidal section having side slopes of 2 to 1 to obtain B. With given Q_f, s and n obtain B of rectangular section by (A-2). From Diagram 15, required B = .73 × Base of $=\!\frown\!=$ Rect. Section.

(7) Given Q_f, B and n of a trapezoidal section with slopes of 2 to 1 to obtain s. From Diagram 15 Base of =⊂= Rect. Section $= \frac{B}{0.73}$. Also, divide given Q_f by ratio on Diagram 14 corresponding to given n. With this Q_f for n = .025 and Base =⊂= Rect. Section obtain required s from Diagram 13.

(8) Given Q_f (obtained from direct observation), B and s of a trapezoidal section with side slopes of 2 to 1 to obtain n. From Diagram 15, Base of =⊂= Rect. Section $= \frac{B}{0.73}$. With this Base and given s find Q_f for n = .025 from Diagram 13. Divide observed Q_f by Q_f for n = .025, and with this ratio find required n from Diagram 14.

In the last four cases V_f cannot, in general, be substituted for Q_f for reasons similar to those previously given under Class A for conduits. A_f in all cases is obtained from equations on Diagram 16, and V_f by dividing Q_f by A_f.

Class B.—Sections in which the ratio of depth of flow to depth of "Filled Section" is greater or less than 1.00.

(1) Given D_f (or, if B is given, $D_f = \frac{1}{2}$ B), D_s and Q_f or A_f of a trapezoidal section with side slopes of 2 to 1, to obtain Q_s and A_s. From Diagrams 15 and 16 obtain $\frac{Q_s}{Q_f}$ and $\frac{A_s}{A_f}$ corresponding to $\frac{D_s}{D_f}$. The product of Q_f and $\frac{Q_s}{Q_f}$ will give required Q_s; the product of A_f and $\frac{A_s}{A_f}$ required A_s. In all cases where V_f and V_s are sought they are obtained by dividing Q_f by A_f or Q_s by A_s, respectively.

(2) Given D_f, D_s and Q_s or A_s of a trapezoidal section with side slopes of 2 to 1 to obtain Q_f and A_f. From Diagrams 15 and 16 obtain $\frac{Q_s}{Q_f}$ and $\frac{A_s}{A_f}$ corresponding to $\frac{D_s}{D_f}$. The quotient of Q_s by $\frac{Q_s}{Q_f}$ will give required Q_f; quotient of A_s by $\frac{A_s}{A_f}$ required A_f. V_s and V_f are obtained by division as before.

(3) Given s, n, D_s and B (or D_f which equals $\frac{1}{2}$ B) of a trapezoidal section with side slopes of 2 to 1 to obtain Q_s. With given B, s and n obtain Q_f by (A-5). With this Q_f and given D_s and D_f obtain required Q_s by (B-1).

(4) Given Q_s, n, D_s and B of a trapezoidal section with side slopes of 2 to 1 to obtain s. From D_s, B and Q_s obtain Q_f by (B-2). With Q_f and given n and B obtain required s by (A-7).

(5) Given Q_s (obtained from direct observation), s, D_s and B of a trapezoidal section with side slopes of 2 to 1 to obtain n. With given Q_s, B and D_s obtain Q_f by (B-2). With this Q_f and given B and s find required n from (A-8).

(6) Given Q_s, s, n and B of trapezoidal section with side slopes of 2 to 1 to obtain D_s. With given s, n and B obtain Q_f by (A-5). With $\frac{Q_s}{Q_f}$ find $\frac{D_s}{D_f}$ from Diagram 15. The product of D_f (equal to $\frac{1}{2}$ B) and $\frac{D_s}{D_f}$ gives required D_s.

(7) Given Q_s, s, n and D_s of a trapezoidal section with side slopes of 2 to 1 to obtain B. A tentative method is necessary. Assume B, and, with given s, n and D_s, obtain a trial Q_s by (B-3), which should agree with given Q_s if B is correctly assumed; if not assume new values of B until the proper one is found.

(8) Given $\frac{D_s}{D_f}$ or $\frac{D_s}{B}$ (but knowing neither D_s, D_f nor B), Q_s, s and n of a trapezoidal section with side slopes of 2 to 1 to obtain B. With given Q_s and $\frac{D_s}{D_f}$ or $\frac{D_s}{B}$ obtain Q_f by (B-2). With Q_f and given s and n obtain B by (A-6).

The following two numerical examples will now be given which may further illustrate the use of the diagrams of the two groups.

(Ex. 1). Let it be required to find the hydraulic slope of an egg-shaped conduit 24 × 36 ins., which, when flowing 1.5 ft. deep will discharge 4 cu. ft. per sec. with n = .014. The case falls under (B-4) for conduits in which $Q_s = 4$, $n = .014$, $D_s = 18$ ins., $D_f = 36$ ins. and required to obtain s. $\frac{D_s}{D_f} = \frac{18}{36} = .500$. By Diagram 9, $\frac{Q_s}{Q_f} =$

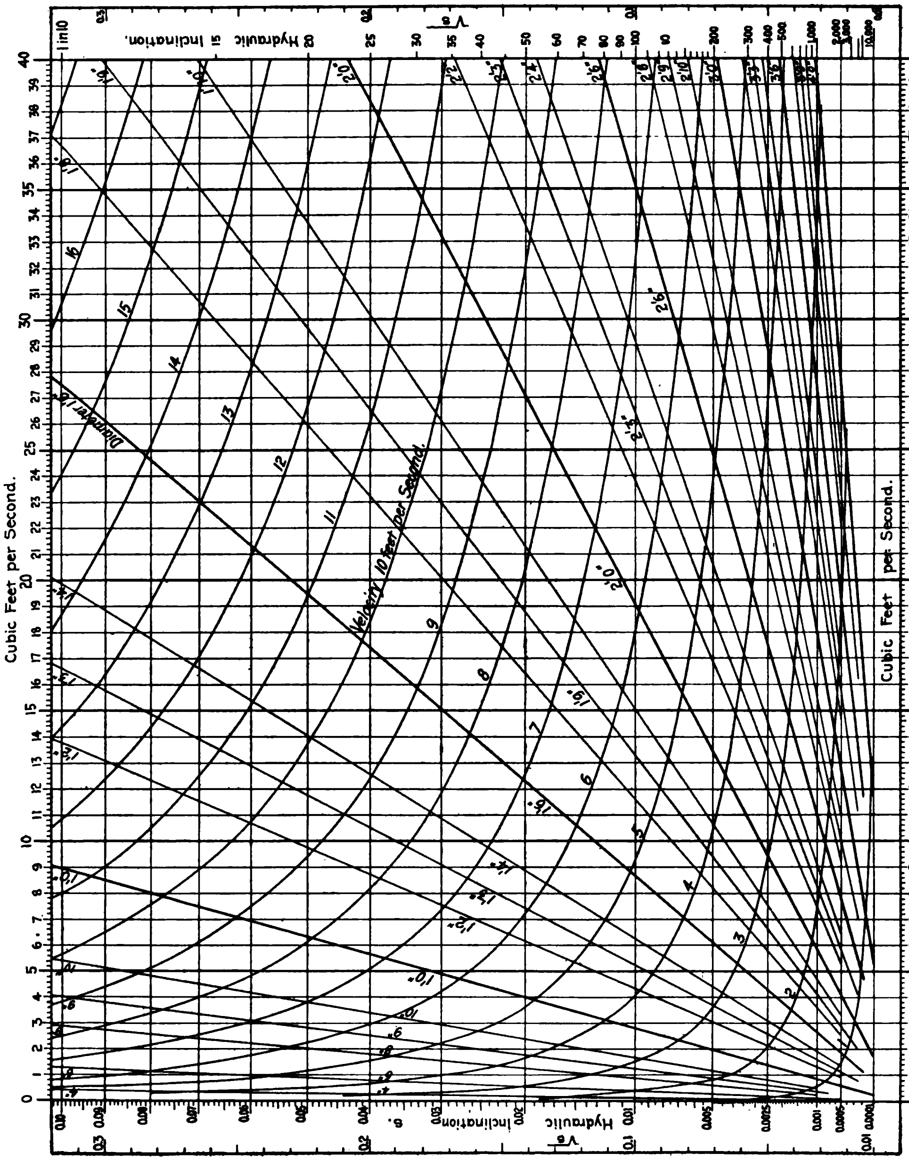
0.425. Also Diam. of $=\smile=$ circle $= \frac{36}{1.254} = 28\frac{1}{2}$ ins. $Q_f = \frac{4.0}{0.425} = 9.41$ cu. ft. per sec. Q_f (for n = .015) $= \frac{9.41}{1.09} = 8.6$ cu. ft. per sec. (by Diagram 4), which, with diameter $28\frac{1}{2}$ ins., gives required s = 0.0008 = 1 in 1250 by Diagram 2.

(Ex. 2). Let it be required to find the discharge of a trapezoidal canal with length of base 18 ft., side slopes 1 to 1, flowing 8 ft. deep, with s = 1 in 5,000, and n = .020. The case falls under (B-3) for Canals. For the filled section, then, B = 18 ft., and D = 9 ft.

By Diagram 15, Base of $=\smile=$ Rect. section $= \frac{18}{0.80} = 22.5$ ft., which, with given s = 1 in 5,000, gives $Q_f = 683$ cu. ft. per sec. for n = .025 (by Diagram 13). Q_f (for n = .020) $= 683 \times 1.235 = 843$ cu. ft. per sec. (by Diagram 14). $\frac{D_s}{D_f} = \frac{8}{9} = 0.889$, which, for side slopes 1 to 1 gives $\frac{Q_s}{Q_f} = 0.81$ (by Diagram 15). Required $Q_s = 843 \times 0.81 = 683$ cu. ft. per sec.

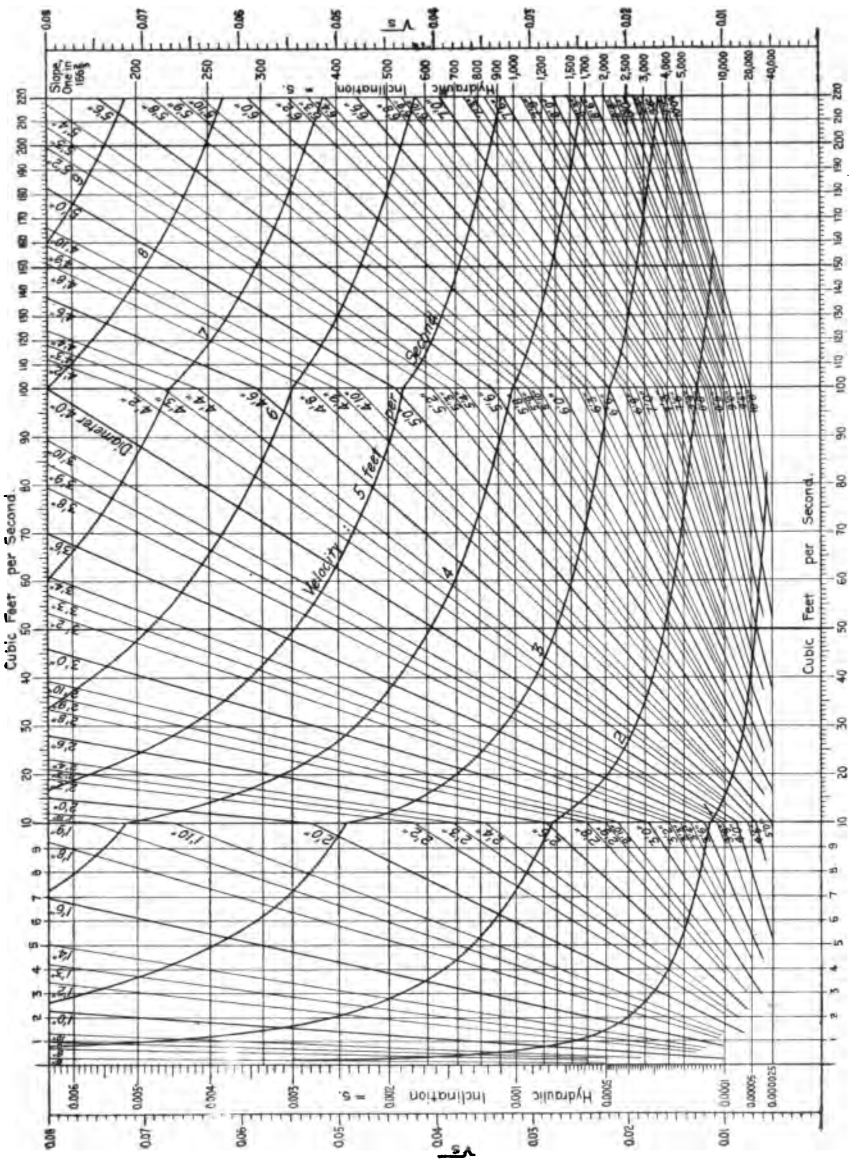
In conclusion, it may be said as to the accuracy of using these diagrams that, disregarding personal errors in reading, there will be a slight disagreement between results computed by the general formula and those given by the diagrams, due to the nature of the formula and the method of constructing the diagrams; that this disagreement will be greater for canals than for conduits, owing to the greater range of data considered under canals; and that for ordinary practice this disagreement should not be greater than one or two per cent. for conduits and two or three per cent. for canals.

Disagreements in this amount have little importance, however, when we consider that first the formula itself is empirical and, being based largely upon experiments, is subject to necessary errors in its deduction; also, that the uncertainties in selecting values for n are appreciable, and are greater for canals than for conduits, as will be seen from a study of the classified values of n in conjunction with Diagrams 4 and 14.



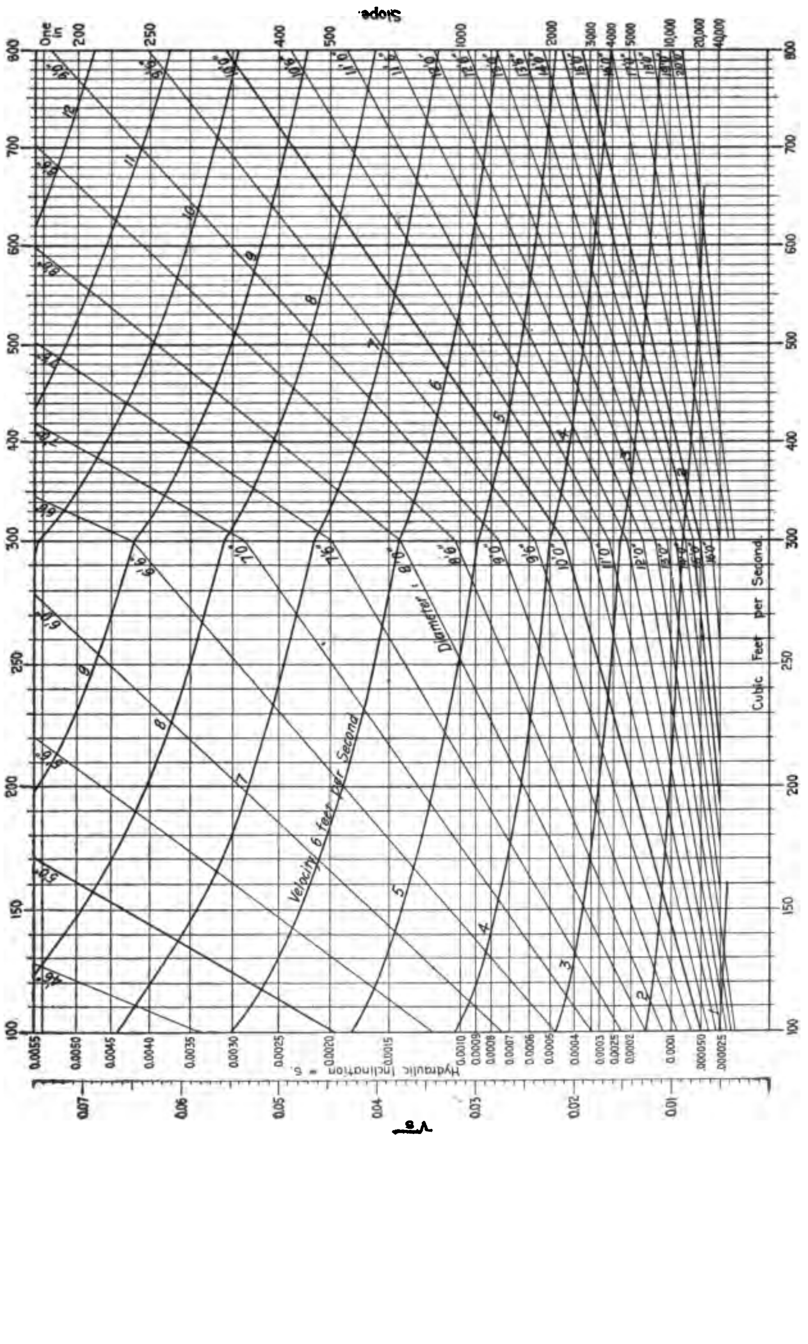
Discharge from Circular Conduits, Flowing Full, by the Formula of Ganguillet and Kutter, n = 0.015

DIAGRAM 1.



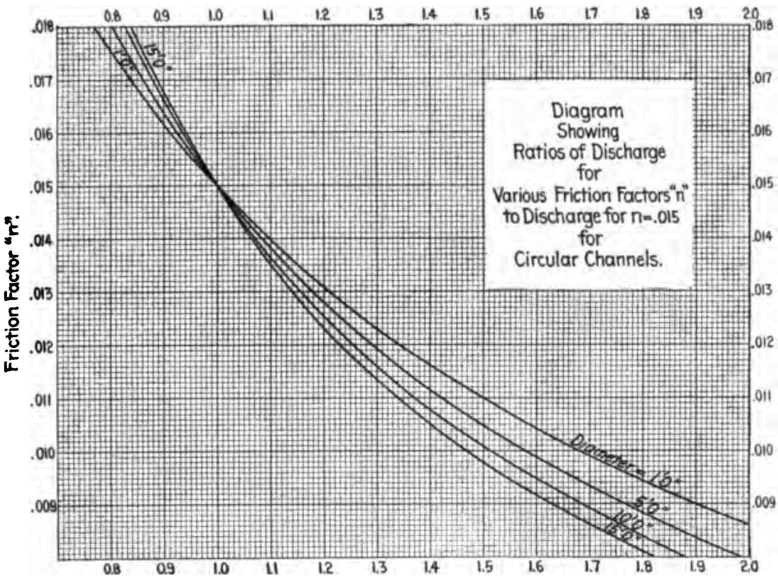
Discharge from Circular Conduits, Flowing Full, by the Formula of Ganguillet and Kutter, $n = 0.015$

DIAGRAM 2.



Discharge from Circular Conduits, Flowing Full, by the Formula of Ganguillet and Kutter, n = .015

DIAGRAM 3.



Ratio of Discharge.

DIAGRAM 4.

V = C√(RS)

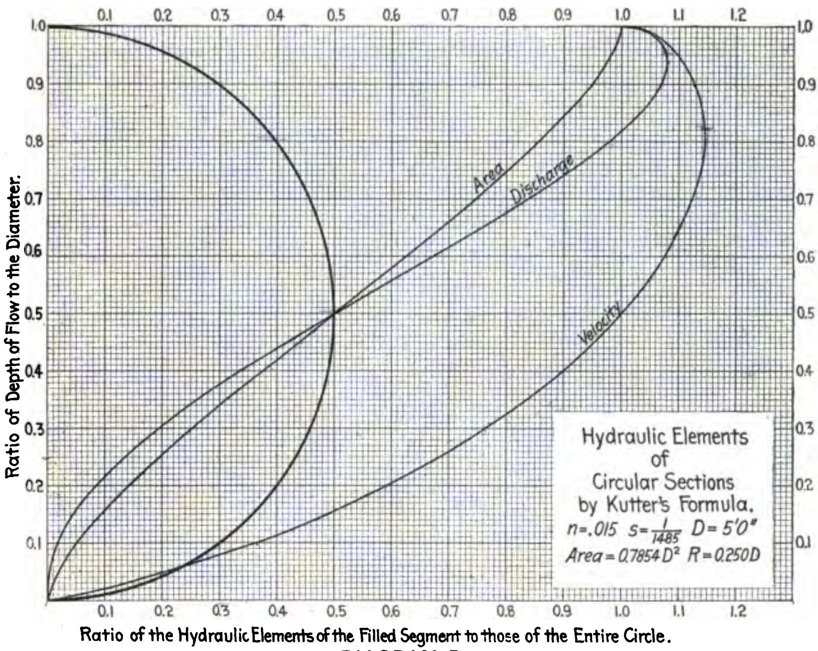


DIAGRAM 5.

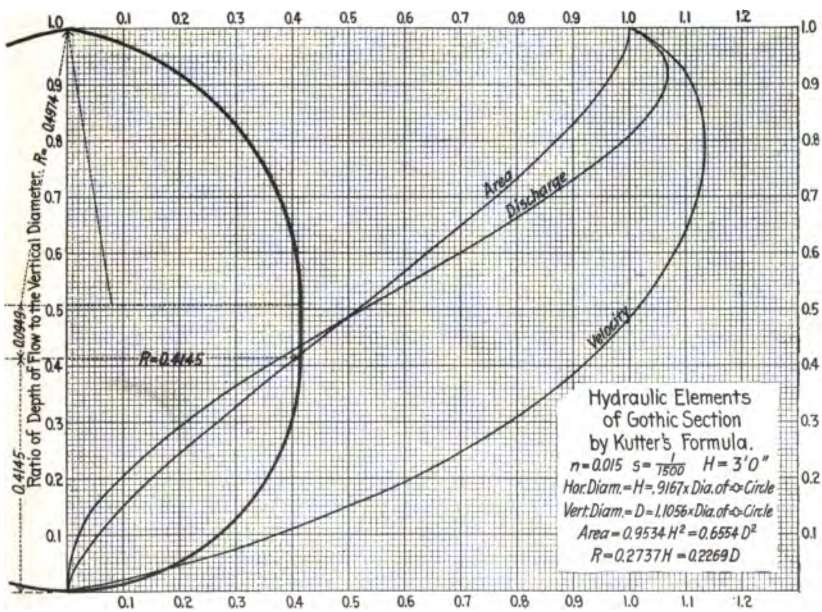
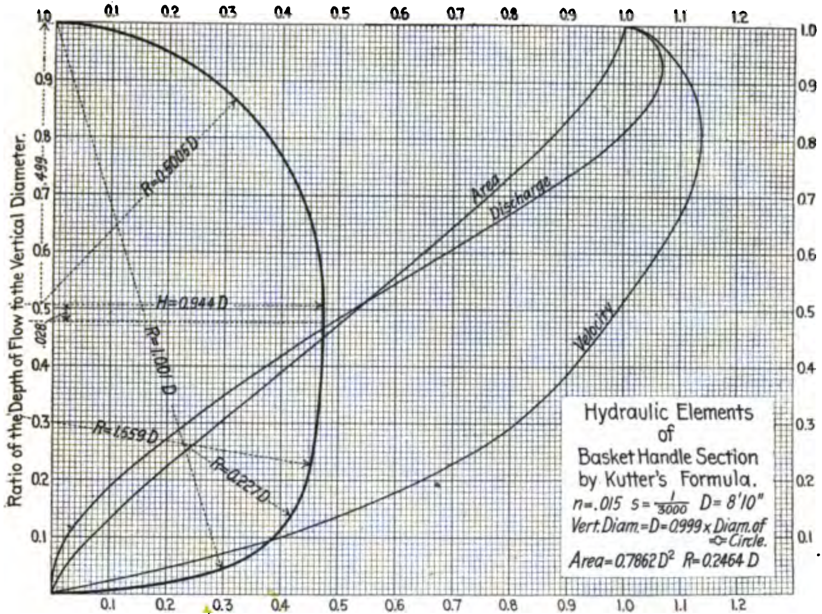
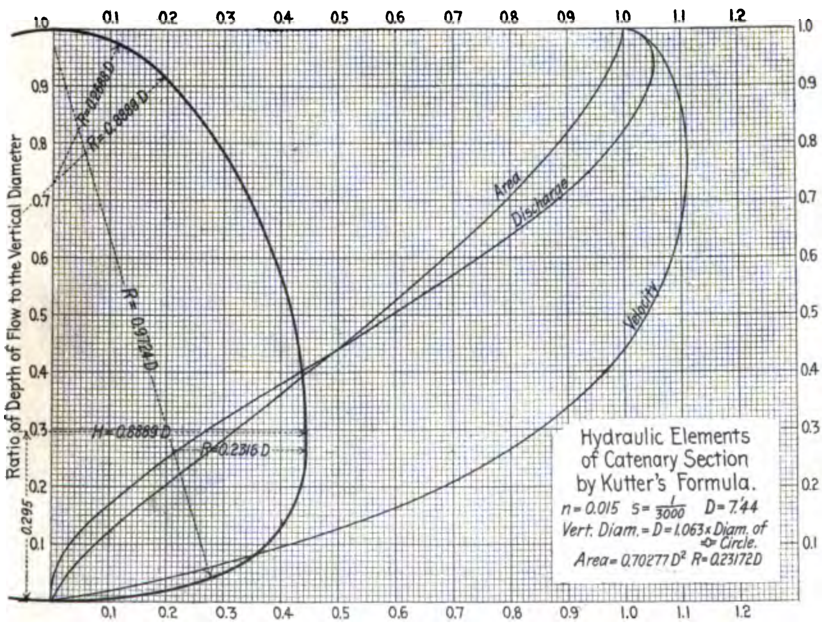


DIAGRAM 6.



Ratio of the Hydraulic Elements of the Filled Segment to those of the Entire Section.

DIAGRAM 7.



Ratio of the Hydraulic Elements of the Filled Segment to those of the Entire Section.

DIAGRAM 8.

Erratum, Diagram 9: Area (should read) = $1.1485\ H^2$.

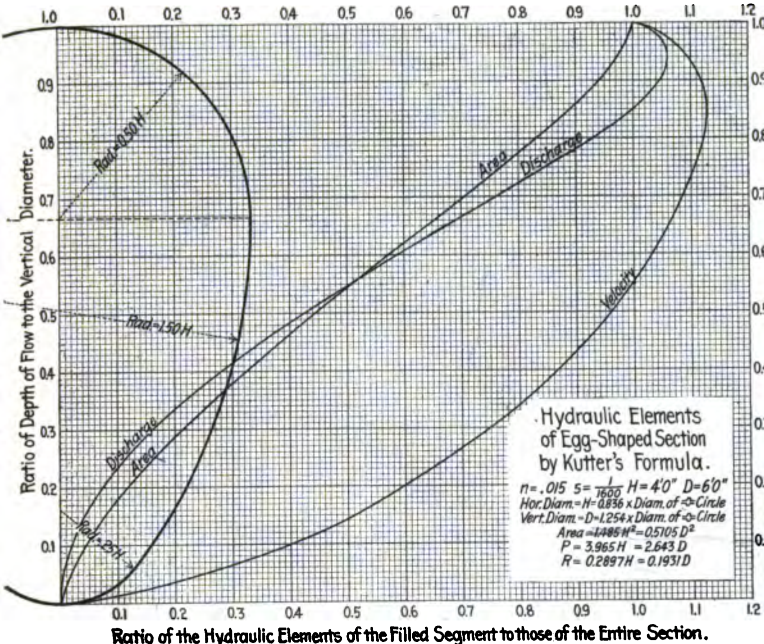


DIAGRAM 9. 10

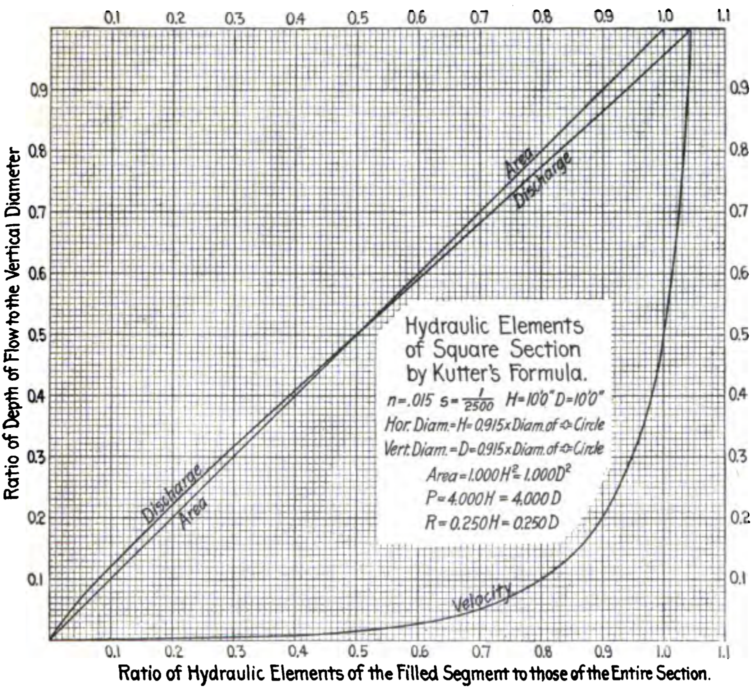


DIAGRAM 10.

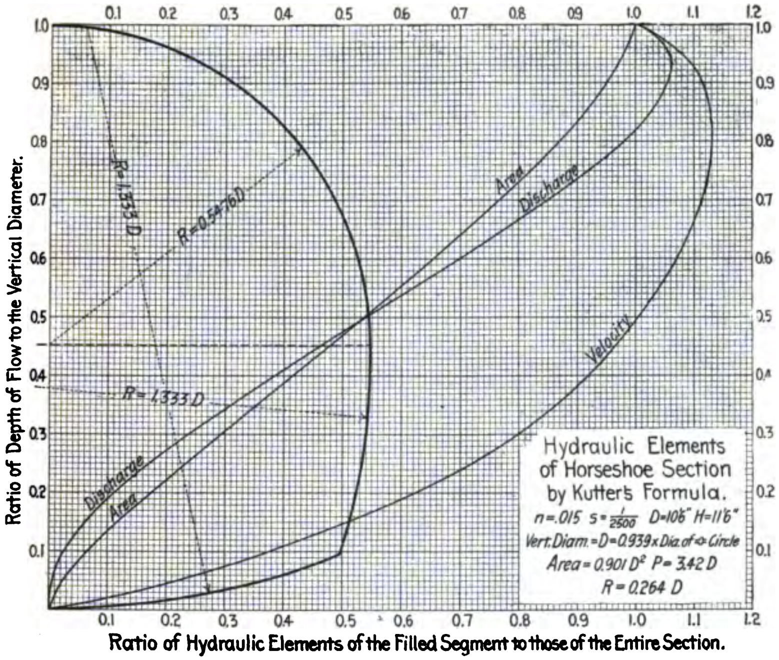


DIAGRAM 11. (WACHUSETT AQUEDUCT.)

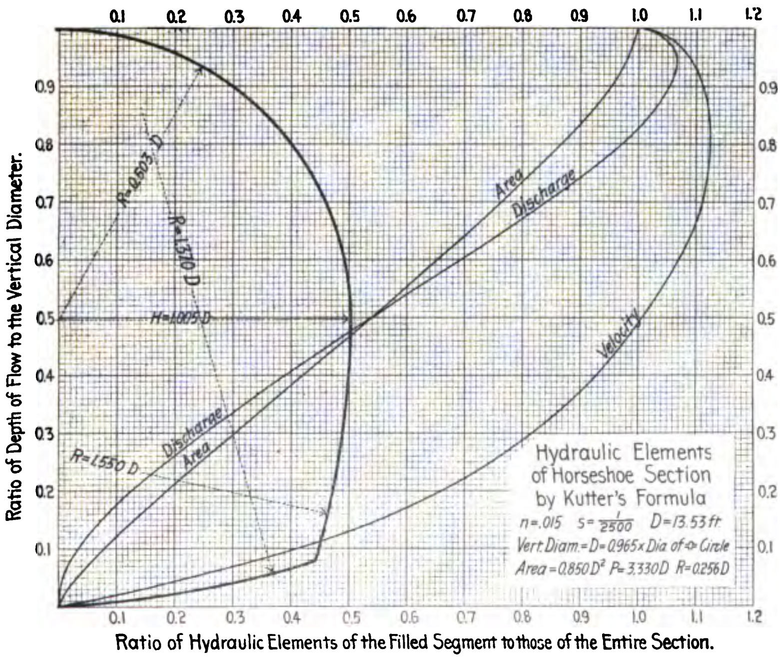
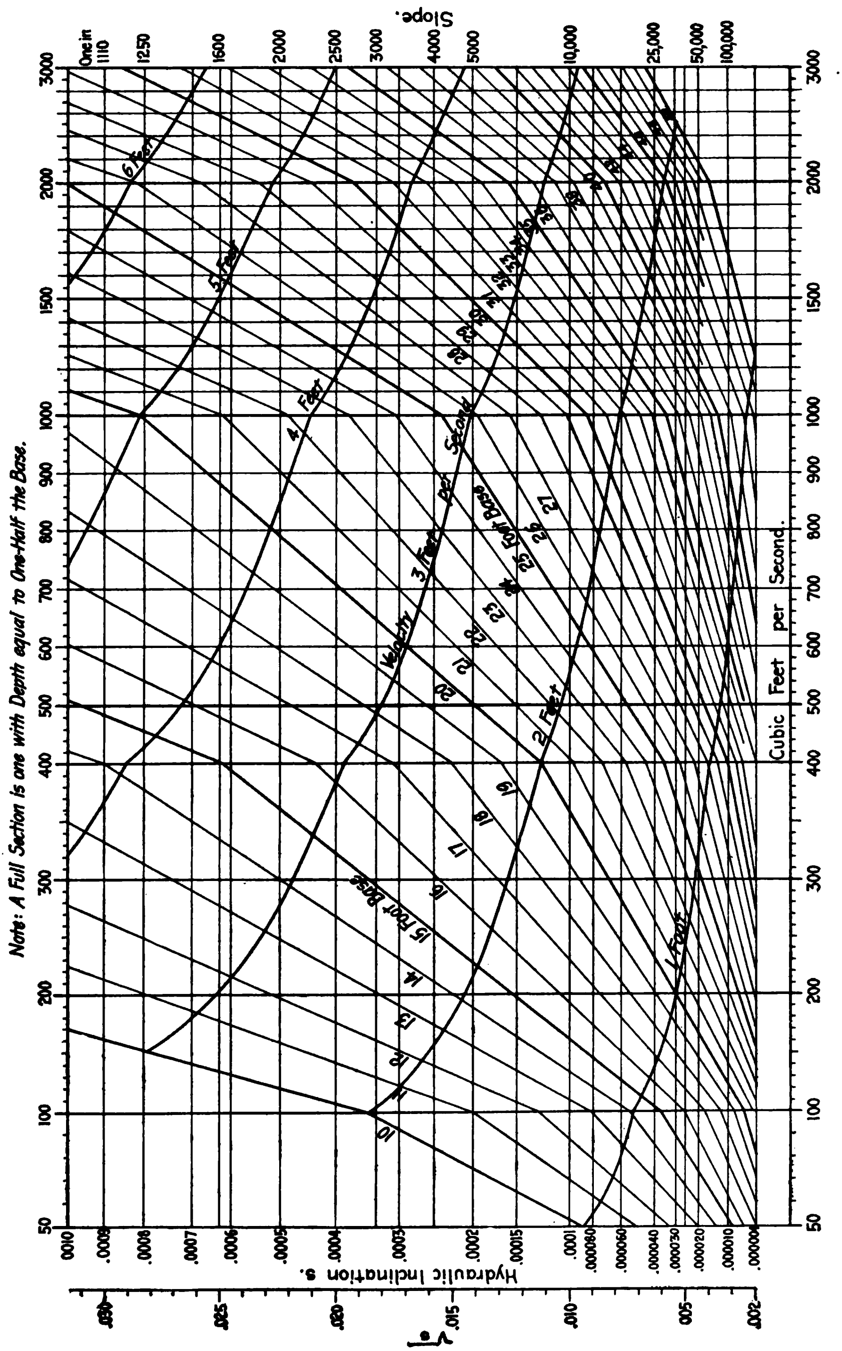


DIAGRAM 12. (CROTON AQUEDUCT.)



Discharge from Rectangular "Filled Section" by the Formula of Ganguillet and Kutter n = .025

DIAGRAM 13.

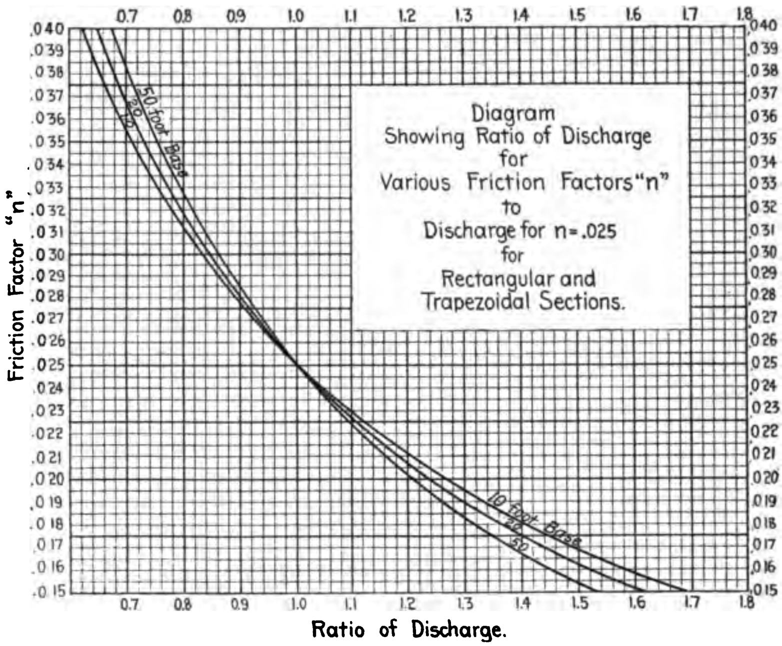


Diagram
Showing Ratio of Discharge
for
Various Friction Factors "n"
to
Discharge for n=.025
for
Rectangular and
Trapezoidal Sections.
50 foot Base
20
10
10 foot Base
20
50
Friction Factor "n"
Ratio of Discharge.
0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8
.040 .039 .038 .037 .036 .035 .034 .033 .032 .031 .030 .029 .028 .027 .026 .025 .024 .023 .022 .021 .020 .019 .018 .017 .016 .015

DIAGRAM 14.

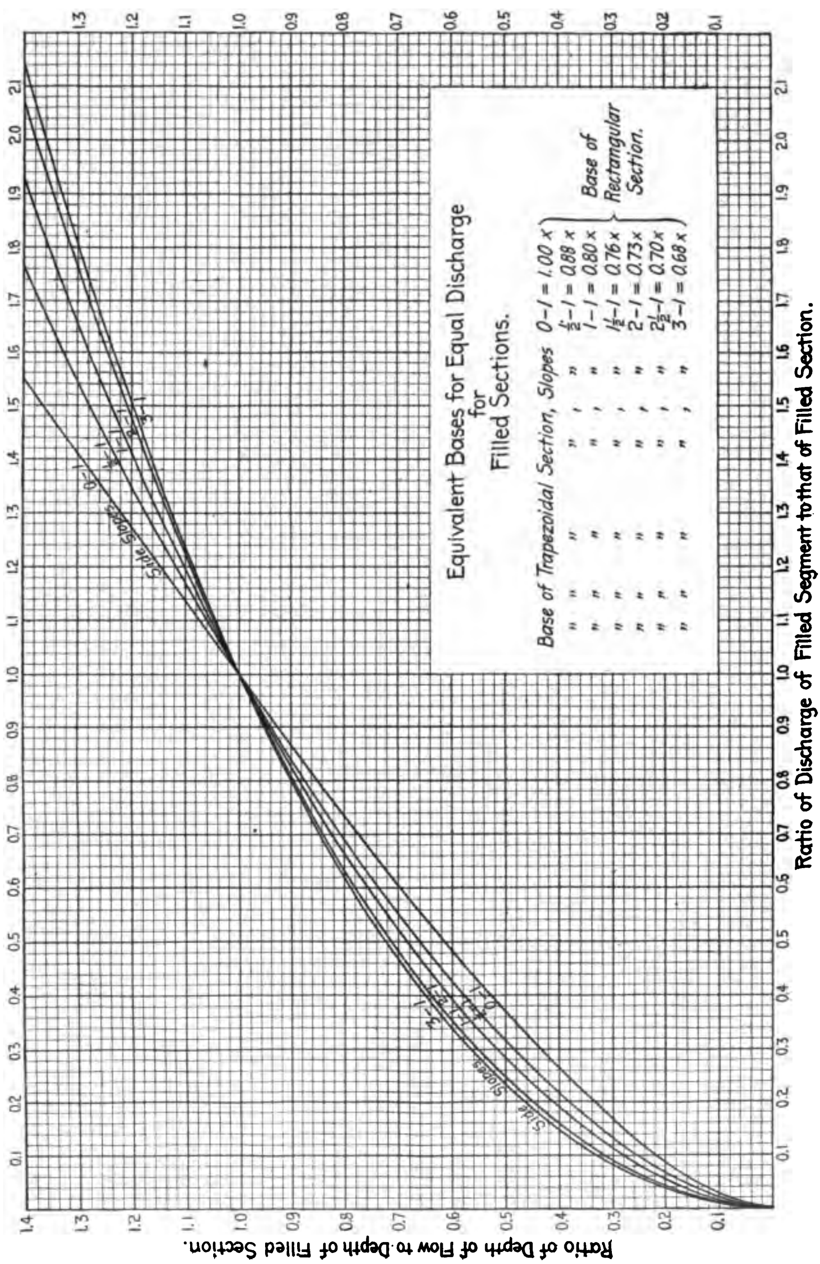

Equivalent Bases for Equal Discharge
for
Filled Sections.
Base of Trapezoidal Section, Slopes 0–1 = 1.00 x
" " " " " ½–1 = 0.88 x
" " " " " 1–1 = 0.80 x
" " " " " 1½–1 = 0.76 x
" " " " " 2–1 = 0.73 x
" " " " " 2½–1 = 0.70 x
" " " " " 3–1 = 0.68 x
Base of Rectangular Section.
Side Slopes
Ratio of Discharge of Filled Segment to that of Filled Section.
Ratio of Depth of Flow to Depth of Filled Section.

DIAGRAM 15.

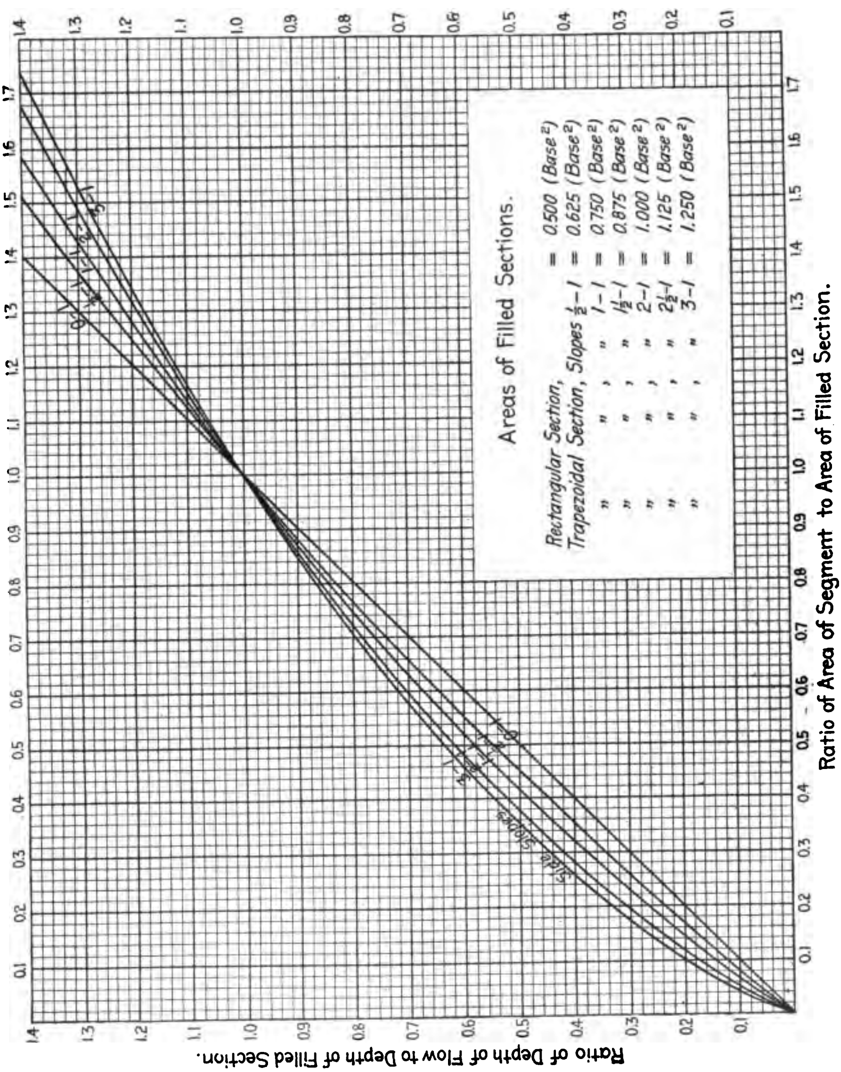

Areas of Filled Sections.
Rectangular Section, = 0.500 (Base²)
Trapezoidal Section, Slopes ½-1 = 0.625 (Base²)
" " " 1-1 = 0.750 (Base²)
" " " 1½-1 = 0.875 (Base²)
" " " 2-1 = 1.000 (Base²)
" " " 2½-1 = 1.125 (Base²)
" " " 3-1 = 1.250 (Base²)
Ratio of Area of Segment to Area of Filled Section.
Ratio of Depth of Flow to Depth of Filled Section.
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4

DIAGRAM 16.